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American Association of Equine Practitioners

Bureau of Land Management (BLM)

Wild Horse and Burro Program

BLM Task Force Report

August 2011



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AAEP BLM Task Force Report
August 2011

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EXECUTIVE SUMMARY

The AAEP BLM Task Force evaluated horses in the Bureau of Land Management (BLM) Wild Horse and Burro Program through several visits to wild horse gathers, and short- and long-term holding facilities. The task force concluded that the care, handling and management practices utilized by the agency are appropriate for this population of horses and generally support the safety, health status and welfare of the animals.

The task force noted many areas of quality care and management in the program, which are documented throughout the report. The AAEP's core recommendations for the improvement of care, handling and management of the nation's wild horse and burro population are as follows:

- While the task force thought the use of helicopters as observed during the gathers of horses from the range was humane, all contract helicopter pilots should adopt conservative flying patterns that allow a safe buffer distance between the helicopter and the horses, and between the helicopter and the ground.

- All capture pens for the temporary holding of animals that have just been captured should be constructed so that chute configurations include wider corral pen sections instead of narrow rectangular pens. This configuration gives passive animals a circular escape from the aggressive animals. In addition, the traps should be constructed with solid side panels in the final capture pen to prevent horses from getting their heads or legs outside of the pen and to discourage horses from attempting to climb out of the enclosure.

- Areas of solid footing should always be provided in short-term holding facilities to allow the horses a place to lie down. This issue was particularly a concern at the Salt Lake Regional Wild Horse and Burro Center in Herriman, Utah.

- A uniform surgical anesthesia protocol should be in place and reviewed with all contract veterinarians concerning surgical procedures performed at all BLM horse management sites.

- Resident horse numbers should be adjusted as needed seasonally within short-term holding facilities to avoid overcrowding when extreme weather is expected or present. The welfare of the horses should be the determining factor for population density.

- Biosecurity standards and protocols should be adopted at short-term holding facilities in order to reduce the spread of the bacteria Streptococcus equi subspecies equi, commonly known as strangles, and minimize outbreaks of this and other infectious diseases.

- The task force encourages current efforts by the BLM to produce a centralized database to track the history of all horses in the BLM program. The records should include positive or negative trends in adoption programs and outcomes of socially productive programs like those in place at certain prisons.

The task force also reflected upon the evolution of the Wild Horse and Burro Program from an adoption program into a welfare program for these animals. While a significant number of wild horses have found homes through the BLM's innovative adoption and placement programs, statistics show that the number of wild horse adoptions has declined significantly over the past five years. Many wild horses now live out their lives at government-supported long-term holding facilities.

Clearly the mission of the BLM Program – Healthy Ranges, Healthy Horses – is not a simple one. A central issue for all discussions involving the care and management of the wild horse population is controlling the reproductive rate of the wild horses on the range. The AAEP encourages the BLM to prioritize research and application of effective fertility control methods in order to reduce the foaling rate in wild herds.

Introduction

The American Association of Equine Practitioners (AAEP) was founded in 1954. The mission of the AAEP is to improve the health and welfare of the horse, to further the professional development of its members, and to provide resources and leadership for the benefit of the equine industry. As the world's largest professional organization dedicated to equine veterinary medicine, with a membership of nearly 10,000 veterinarians and veterinary students who dedicate their life's work to caring for the horse, the AAEP is a world leader in equine veterinary medical education and very active in horse welfare and equine industry programs.

In June 2010, the AAEP received a letter from Don Glenn, Division Chief of the Wild Horse and Burro Program of the Bureau of Land Management (BLM). Mr. Glenn's letter invited a small team of veterinarians from the AAEP to visit the BLM operations and facilities, spend time on wild horse and burro gathers and evaluate the management of the wild equids. Specifically the letter from the BLM requested the AAEP "review animal care and handling within the Wild Horse and Burro Program, and make whatever recommendations, if any, the Association feels may be indicated, and if possible, issue a public statement regarding the care and welfare of animals under BLM management."

In July 2010 the AAEP Board of Directors created the AAEP BLM Task Force and approved the following charge for the project:

Charge of the AAEP task force:

The Bureau of Land Management (BLM) has requested that the American Association of Equine Practitioners (AAEP) evaluate the handling, health care, and welfare of the horses and burros (equids) at their wild equid gathers and holding facilities. The AAEP BLM Task Force will visit multiple BLM sites to observe gathers and evaluate conditions at short-term holding and long term pasture facilities. The task force data collection will be limited to the safety, health status, health management, care, handling and welfare of equids in the BLM program.

The Task Force will provide a report to the AAEP Board of Directors (BOD) before the summer 2011 BOD meeting. Once reviewed by the BOD, a written report of the BLM Task Force findings and any related recommendations will be supplied to the BLM. It is not the charge of the Task Force to evaluate the BLM program with regard to moral, ethical or economic issues.

Methodology

Methodology of investigation:
A task force of 10 AAEP member veterinarians was selected. The task force included veterinarians from private practice, universities and industry and their veterinary work was in various parts of the country. Task force members represented a range of experience in different facets of equine medicine and surgery. Most of the veterinarians had no prior experience with the BLM program. One had visited a BLM facility previously and one veterinarian is a member of a group practice that does contract work for a BLM short-term facility.

Site visits:
Teams of three to four members from the task force visited multiple BLM facilities and operations during a 6- month period between October 2010 and March 2011. Trips to observe gathers and short-term holding sites occurred in October, November and February. Timing of these visits was based on the BLM gather schedule and team member availability. The long-term pasture sites were visited in March near the close of winter. The task force members that participated at the first gather site served as experienced anchors for the subsequent visits, which incorporated other task force members for a fresh perspective.

The BLM provided each site visit team with a BLM employee as a guide and source of information. Task force members were introduced to all the BLM, APHIS (US Animal and Plant Health Inspection Service) and contract employees at each site. These employees included BLM executive and administrative staff, BLM horse specialists, BLM employees who worked at short-term holding facilities, veterinarians who worked under BLM contracts, APHIS veterinarians and others. The team also met many of the gather contract employees including pilots, wranglers and owners of the contract businesses. The task force team had unrestricted opportunity to discuss the BLM program and procedures with any person at any site.

Evaluation of the BLM Wild Horse and Burro program included observations of three gathers in southwest Wyoming, west/central Nevada, and northeast Nevada. The trips to observe the gathers also included visits to four short-term holding facilities in Wyoming, Nevada and Utah. Two long-term holding pastures were visited in Oklahoma.

Teams of three task force members attended each gather day; a total of seven different task force members participated in gather observations. Each observer independently completed an evaluation form for each day, generating 15 independent evaluation forms.

Task force team members observed horses being gathered off the range by herding via helicopter into temporary collection corrals. They observed many of these horses being transported by stock trailer from the capture corral to temporary holding pens near the gather. They also visited several short-term holding facilities where recently gathered horses are housed for several months to a year after being gathered. At all these sites they observed the condition and management of the horses. They assessed the fencing, footing, management and animal density within the pens and corrals, and inspected feed and water arrangements for the horses. At some of these sites they observed

movement of small groups of horses through the chutes designed to restrain the horses for brief periods while receiving basic medical treatment. Observed procedures included identification, age estimation, freeze branding, deworming, vaccination and blood sample collection. One team observed castration of a group of mature stallions at a short-term holding facility. Information gathered by interviews with individuals involved with the collection, handling and care of the horses and burros supplemented the direct observations of the team members on the trips.

At the two long-term holding sites, observers were escorted over the ranches by truck and/or ATV. Between 40-70% of the total population of horses at the sites were observed. Fencing, gates, water (streams and ponds) and hay were evaluated directly. Handling facilities at the long-term sites were observed but were not in use during the visits.

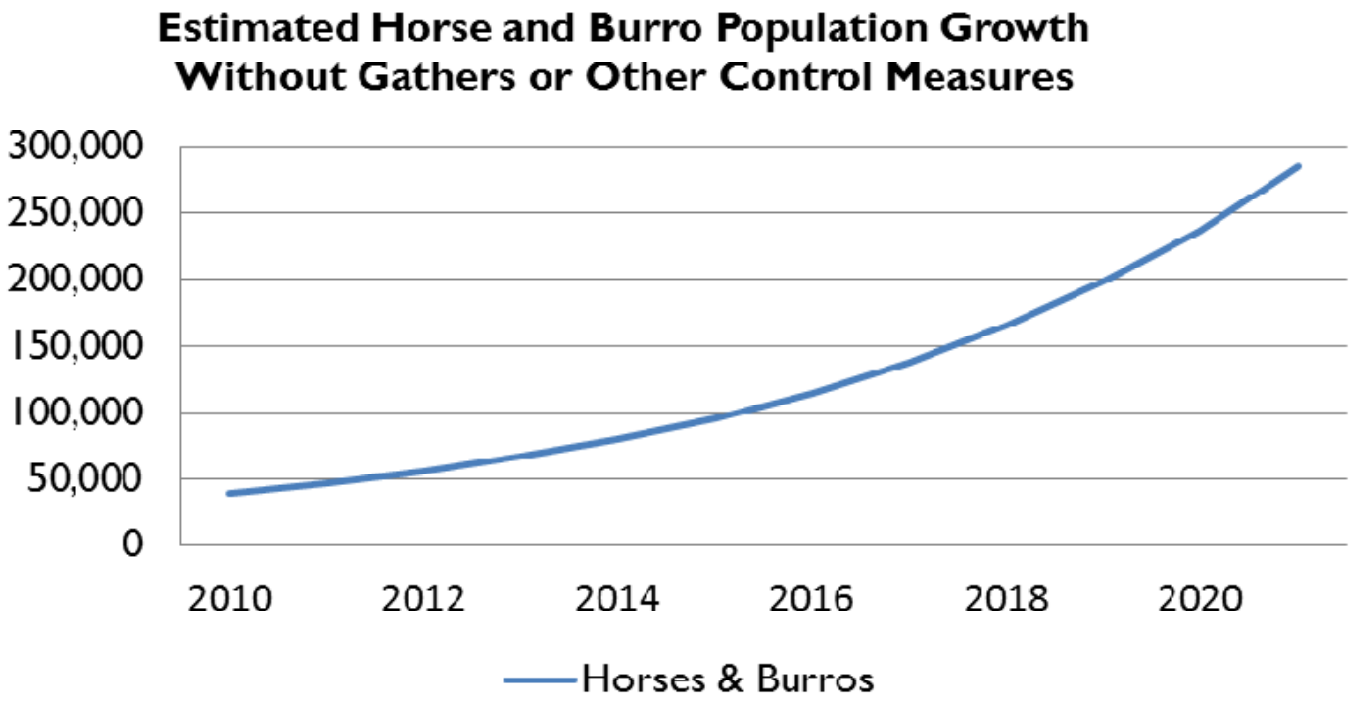
Evaluation forms:
The task force created forms to record observations and data collected during the visits to the horse gathers, short-term holding facilities and long-term holding pastures. Separate evaluation forms were designed for each of the three types of sites. Body condition scores as determined by the Henneke Body Score Scale, based on a nine-point scoring system, were noted for horses at each site. The safety of all handling procedures was assessed. Horses at the gathers and holding facilities were observed for signs of stress or clinical disease, which were assessed by evaluating their alertness and demeanor, skin and hoof condition, respiratory rate and depth, quality of manure, and presence or absence of nasal and/or ocular discharge.

Tabulation of the data:
Following each site visit, task force members filled out report forms independently. Reports were tabulated by a task force member who did not participate in the data collection. Data from each evaluation form was collated and recorded on a spreadsheet for each evaluation form item: 1) gathers, 2) short-term holding facilities and 3) long-term holding pastures. Numerical data was summed where appropriate and averaged if a single data point was recorded slightly differently by each observer. Ranges of values were also recorded in the spreadsheet. Comments provided by each observer were combined if similar. All comments by each observer were given equal weight in the results and discussion section.

The AAEP task force members were not paid as they donated their time and expertise for their work on this project. The BLM reimbursed the task force teams for travel expenses.

Observations and Results

Background information on the horses on the range: "Given the protection afforded by the Wild Free-Roaming Horses and Burros Act of 1971 and a general lack of natural predators, wild horse populations increase at an average rate of 20 percent a year and can quickly exceed the carrying capacity of their ranges." Source: 6-30-2011
http://www.blm.gov/wo/st/en/info/newsroom/2011/april/NR_04_26_2011.html



Source : 6-30-2011
http://www.doioig.gov/images/stories/reports/pdf/BLM%20Wild%20Horse%20and%20Burro%20Program%20Public.pdf

The task force team members were told by the BLM horse specialists that the amount of range forage material is often limited and weather dependent. Water is limited in some range areas and also weather dependent. Some herds travel many miles a day from forage areas and back to obtain water.

Current estimated numbers of horses on the range as reported on the BLM web site:

Wild Horse and Burro Populations by State

State Totals 2011 Population Statistics

State	Horses	Burros	Total
AZ	434	2,761	3,195
CA	2,872	1,171	4,043
CO	984	0	984
ID	500	0	500
MT	165	0	165
NV	17,710	1,347	19,057
NM	63	0	63
OR	2,456	15	2,471
UT	2,497	189	2,686
WY	5,333	0	5,333
TOTAL	33,014	5,483	38,497

Source: 6-30-2011

http://www.blm.gov/wo/st/en/prog/wild_horse_and_burro/wh_b_information_center/statistics_and_maps/Populations_by_State.html

Sequence of capture and holding facilities observed by the task force:
Horses brought in off the range were herded towards a gather trap by helicopter as described below. Horses were herded into the wings of the trap (a funnel shaped structure usually a few hundred yards long made of jute fabric hung on t-posts), then captured in temporary capture pens which were small gated pens that had been built at the narrow end of the wings of the trap. These pens provided short-term confinement for groups of horses that had just come in off the range. Shortly after capture, these small bands were moved from the trap to temporary holding corrals by stock trailer. The temporary holding corrals were larger corrals that had been constructed a few miles away from the capture site for the purpose of housing newly gathered horses for several days. The temporary holding corrals had a single file alleyway and manual squeeze chute for close examination of the horses and for sorting into various pens by age and gender. The alleyway included a loading ramp with solid sides for loading horses into semi tractor trailers. Traps and temporary holding corrals were dismantled by the contractors once a gather was complete, and panels, gates, chutes and other elements were transported to the next gather area and reassembled.

When suitable transport was available, gathered horses were transported from the temporary holding corrals to permanent facilities known as short-term holding facilities. These sites all had large permanent corrals with automatic waters that were designed to house horses. The short-term holding sites all had padded hydraulic chutes suitable for restraining horses for medical procedures, and multiple pens to segregate horses by age and gender.

Gathered horses that had received basic identification and medical procedures in the short-term holding facilities moved on to a variety of different destinations after two to twelve months. Some of the facilities had adoption programs on site; others shipped young horses to BLM-sponsored adoption events. Selected groups of horses were transported to special training programs sponsored by prisons or by the Mustang Heritage Foundation. The majority of older horses were eventually shipped to long-term holding pastures in the Midwest. These pastures serve as permanent homes for many horses brought in off the range.

The AAEP task force observed traps and temporary holding corrals at each of the three gathers they attended. They visited four short-term holding facilities and two long-term holding pastures.

Gather sites:
Gather sites included the Adobe Town/Salt Wells Creek Complex Herd Management Area (HMA) in southern Wyoming, the Pine Nuts HMA south of Reno, Nevada and the Antelope Complex HMA near Wendover, in northeast Nevada. Five gather days were observed: one day at Adobe Town/Salt Wells Creek, two days at Pine Nuts, and two days at Antelope Complex.

Weather conditions experienced during gathers were mild (40-60 degrees F) to cold (2-30 degrees F). Light snow fell during one gather, while a ground cover of 4 inches of snow was present at another. Wind speed was variable, from no wind to wind that escalated to an excess of 40 mph. High winds on two days resulted in early cessation of the gather.

The Adobe Town/Salt Wells trap site used a natural rock formation consisting of a series of tall buttes to form one wall of the trap. Horses approaching the gather site from the west could not see the trap until they turned the corner around the butte. The Pine Nuts trap site was placed in a flat valley at the base of a series of low mountains. An existing barbed wire fence that ran up one mountainside was used as a stage for part of the jute (burlap) wings. The Antelope Complex trap was also placed in a flat valley adjacent to surrounding mountains. An existing post and wire corral was used to support part of the jute fence that framed the trap.

Gather personnel at all gathers included an APHIS veterinarian, one or more BLM horse specialists, and a private contract team of supervisors, wranglers and pilots who were responsible for finding and capturing the horses in the area. The task force teams witnessed gather operations performed by two different independent contractors, Cattoor Livestock Roundup Inc. of Nephi, Utah and Sun J Livestock Inc. of Vernal, Utah.

The role of the APHIS veterinarian was to tend to the safety and welfare of the wild horses. The BLM horse specialists oversaw the gathered herds and made decisions on issues such as gender ratio adjustment and selecting horses slated for release back to the range. The AAEP task force members who attended gathers interviewed the on-site APHIS veterinarians and horse specialists, and observed their activities during gather operations. They observed the work of the contract company wranglers as horses were brought into the traps and transported to the temporary holding corrals. At the Adobe Town/Salt Wells complex, they observed the wranglers load horses into tractor trailers for transport to short-term holding.

Gather process:
The search for bands of horses in the selected range area was done by helicopter, and selected groups were herded to the trap site by helicopter. As the horses were brought in from the range, the helicopter was usually about 100 to 300 yards distance behind the group, flying at an altitude well above the herd. The helicopter made loop-like passes to encourage herd movement in the desired direction. The horses appeared to be easily driven in the intended direction with the helicopter in this flying pattern.

As the horses approached the wings of the trap (the funnel shaped are that led to the capture pens), the helicopter flew closer to the horses to encourage steady movement into the trap. The wings of the trap were fenced by a visual barrier made of jute or plastic mesh fabric strung along existing fencing or between metal T posts that served as fence posts. The fabric was about 4 feet high and was stretched so that it touched the ground. Actual capture of the horses was achieved when the selected group (generally 4-12 horses) was herded through the wings into the capture pens of the trap. These pens were made out of heavy gauge corral panels tethered to posts in the ground.

The horses usually entered the wings at a canter. Some horses trotted down the entry to the trap. No horses came in at a fast gallop. Groups of incoming horses were encouraged to enter the trap by the release of a “decoy horse”—a domestic horse that was held near the mouth of the wings until the herd approached, then released. The horse had been trained to canter into the trap, and the wild horses tended to follow it.

Horses that entered the capture pens were captured as the wranglers closed entry gates behind them. A total of 167 horses were gathered during the task force observations from a total number of 23 "drives." The number of "drives" per day observed by the task force members ranged from two to twelve. The average number of horses gathered per drive was seven.

On the Pine Nuts gather, a barbed wire fence that ran up the side of a mountain was used as a support for some of the jute fencing in the wings. The jute had been strung part way up the mountain but there was exposed barbed wire fence that ran up the mountain slope above the wings. Several horses being herded escaped by jumping the barbed wire fence that had no jute strung on it. *(See gather recommendation section.)* These individuals were herded and captured later the same day after the wire fence had been more completely covered by jute. All horses that jumped the fence were observed in the trap and no serious injuries were noted.

At the Adobe Town/Salt Wells Complex gather, a few straggler horses did not enter the trap, or turned when they entered the wings of the trap and escaped. These individuals were roped close to the trap by wranglers mounted on saddle horses and brought into the corral to join the horses there. The roping process was done in a calm, efficient, and humane manner and was effective in gathering the odd horse that did not enter the wings with its herd mates.

At the Antelope Complex gather site a group of horses refused to enter the wings several times and were allowed to return to the range when high wind forced suspension of the gather operation for the day. One elderly gray mare was released at the capture site at the direction of the BLM horse specialist. Two other horses on the second day at Antelope were deemed too hard to drive with the helicopter and they were left on the range a long distance from the trap.

On one of the gather days at the Pine Nuts HMA and one day at the Antelope Complex HMA, high winds forced the operation to be suspended mid way through the day, but successful drives occurred at each of these sites before the gathers were suspended.

Temporary holding corrals:
Temporary holding corrals, made of commercial pipe corral panels, had been built at each gather site to serve as the initial sorting and holding area. Various pen configurations were observed at the three temporary holding corrals. Some corrals were a series of small round pens which were about twenty feet wide at the broadest diameter. These pens were linked bracelet fashion by connecting gates. Others were a series of narrow alleys eight to ten feet wide, with parallel sides divided by gates. All corrals and chutes at the gather sites were effective; those that were built with wider diameters allowed submissive horses to position themselves away from dominant individuals. These corrals with round pen configurations were large enough to allow horses to organize into circular groups rather than line up head to tail *(see gather recommendation section)*.

The horses were grouped with the herd mates they were gathered with in the corrals. All groups stood relatively quietly, but in the groups where they were held in a narrow alleyway, one or two aggressive stallions kicked at other horses in the group frequently. At the Antelope Complex, several horses attempted to climb the panels and several tried to push through the panels with their heads between the rails *(see gather recommendation section)*.

Trailer transport from the traps:
Recently captured horses stayed in the capture pens of the traps for 30 to 90 minutes before they were loaded into stock trailers and moved to the temporary holding corrals. The loading process occurred after the wranglers opened a gate that separated the final capture pen and the rear entrance of a stock trailer that had been backed up to the trap. Horses then stepped up into the trailer. Horses that did not follow the horse in front of them were urged to step into the trailer by contract company wranglers who waved a "wild rag" (a plastic grocery bag tied to a long stick) in the vicinity of the hindquarters of the horse. The rattling noise that the bag made encouraged the horses to step up into the trailer.

Minimal sorting observed at the trap site at the Adobe Town/Salt Wells complex assured that foals were loaded on the same trailer as their dams for the short trip to the temporary holding area. Adult horses were loaded before foals. To reduce the chance of injury, the foals were positioned behind a partition that separated them from the mature horses. The trailer drove off as soon as it was loaded, transporting the horses a few miles to the temporary holding/sorting corrals. The loading and trailering processes observed were safe and efficient.

Condition of the horses after gather:
Horses entering the trap were in good condition and did not display signs of distress or exhaustion. On entry into the capture pens, all horses exhibited increased respiratory rates consistent with the exercise of the roundup. Most horses showed mild to moderate hair coat sweat that was weather and travel-distance dependent. None of the horses observed was judged to be in any worse condition from the exercise than domestic horses after a workout or a competition. They appeared to physically recover quickly from being brought in off the range, as evidenced by a reduction in their respiratory rate and coat sweat. Horse behavior during loading and transport did not suggest fatigue, medical compromise or excessive apprehension.

Observed injuries at the three gathers were minor. Approximately 5% of horses experienced superficial abrasions or small nonsuturable lacerations during the gather process. All the injuries observed by the task force team and the APHIS veterinarian would be expected to heal without treatment.

One horse on one gather day at Adobe Town/Salt Wells Creek Complex collapsed just before entering the jute wings during the drive towards the trap. The owner of the contract company was closest to the horse and attempted resuscitation. The horse did not respond to the resuscitation efforts and died very soon after he collapsed with no struggle. The collapse occurred in full view of the AAEP Task Force observers and the APHIS veterinarian. A full necropsy was performed by the APHIS veterinarian at the site within 90 minutes. The necropsy was observed by the three AAEP Task Force members in attendance. The cause of death of this young male, approximately 18 months of age, was not determined during necropsy. The process for investigating the death was thorough and transparent.

Temporary holding/sorting corrals near the gather site:
The contractor team erected temporary holding/sorting corrals near the gather site on well drained land that was accessible to large tractor trailers and other vehicles. These vehicles hauled panels, gates, chutes, water tanks, hay and other items needed to create and manage the complex of holding pens and chutes erected just for the gather. The corrals were configured to allow the sorting of gathered horses into individual groups.

The corrals were constructed of commercial panels secured to posts. Many panel sections were covered with rolls of plastic snow fence that created a visual barrier. Gates were used as partitions at various intervals. The architecture included alleys and a manual squeeze chute or stocks that allowed brief assessment of individual horses prior to sorting, as well as an alleyway that led to a loading chute designed to load horses onto semi tractor trailers. The corral configuration was such that the horses could be sorted into several different groups by gender and age; all gathered horses that were unloaded after the gather were sent through an inner chute that had several exit routes that led to separate pens designated for stallions, young horses, and mares with and without foals. Wranglers opened up the desired exit gate once the horse's gender and approximate age were confirmed, and the horse was directed into a pen with horses of similar gender and age.

The sorting process was performed soon after the horses arrived in the stock trailers from the trap site. The sorting observed was safe and efficient and done with respect for the horses' welfare. Personnel were skilled, experienced and efficient.

The temporary holding corrals were well constructed and safe. The pens were of a sufficient size for temporary confinement of the sorted groups of horses. One stallion jumped out of the corral at the Pine Nuts gather, even though the fence was 6 feet high. The horse did not appear to suffer any injury when he jumped out, and was allowed to return to the range. Access to food and water in all pens was within the acceptable standards for horse health, and horses were observed eating hay and drinking water soon after they were introduced to the corrals.

Record keeping by both the contractor representative and the BLM personnel appeared adequate. Skilled oversight was in place with the presence of BLM and APHIS personnel, including BLM horse specialists and an APHIS veterinarian at every gather. At the Antelope Complex, a Nevada state brand inspector was present to certify that no privately owned horses were collected and shipped with the BLM horses. The interaction between the contractor team, the on-site APHIS veterinarian and the on-site BLM team was positive, respectful and productive.

The BLM personnel informed the task force teams that horses stayed in the temporary corrals for a short interval, usually from several hours to several days. If weather conditions did not allow safe travel, horses occasionally stayed for a few weeks. The horses were kept at the temporary corrals until appropriate loads of sorted horses were accumulated and travel arrangements finalized. At that point, they were loaded into large semi-tractor trailers and transported to a permanent short-term holding facility. After all horses from a gather had vacated the sorting corrals, the pens were dissembled by the contract team.

Condition of horses in temporary holding/sorting corrals:
The health status of horses brought in off the range could be assessed in more detail in the temporary holding corrals. The observed horses appeared healthy without evidence of chronic injuries, disease or congenital defects other than a small number with a unilateral club foot (about 1% noted at Adobe Town/Salt Wells Complex). Overall hoof condition of the captured horses was judged good. No horses were judged to show signs of systemic disease as determined by the criteria listed in the methodology section of this report. Horses averaged a body condition score of 4/9, with 3-15% at each gather scoring 3/9. Wet mares (those nursing foals) tended to be thinner than their herd mates. The average body condition of the Nevada horses was thinner than those in Wyoming.

At the Antelope Complex HMA gather, 2-5% horses had minor skin abrasions, which appeared to be related to the gather process. In the opinion of the APHIS veterinarian and the task force, these minor injuries did not require veterinary attention. One horse at the Pine Nuts HMA gather was observed to have suffered a small wire laceration during one of the drives on the second day. Chronic or pre-existing injuries were limited to two horses: one mare at Adobe Town/Salt Wells Complex appeared to have a healed carpal fracture which resulted in leg deviation but she was not lame. Another horse was noted with a cheek laceration at the Pine Nuts gather. At the Antelope Complex gather, one branded horse was captured.

The task force was told that the contractors refer any animals with serious injuries to the on-site APHIS veterinarian for assessment. That veterinarian may choose to administer simple treatment at the temporary holding corrals if the facility affords safe restraint. If the injury is extensive, the APHIS veterinarian may direct the horse to be examined at the short-term holding facility by the veterinarian on contract with the BLM. If the APHIS veterinarian judges the injury to be life threatening, that veterinarian may advise euthanasia either on site or at the nearest holding site. The AAEP task force did not observe any serious injuries that required veterinary intervention during their visits.

At the Adobe Town/Salt Wells Creek Complex HMA in southern Wyoming, the BLM horse specialist sorted out a small percentage of the mature stallions. These individuals were kept in a separate pen to be released back onto the range after the gather in that area was completed. One uniquely colored mare and foal were also retained at the sorting pen site for release. The strategy, as reported by the BLM staff, was to adjust gender ratio of the wild horses in that Complex by selecting 60% male horses and 40% female horses for release. At the Antelope Complex gather, the BLM horse specialist released an older gray mare that he felt was too old for the sorting and shipping process. The decisions of the BLM horse specialist pertaining to the selection of individual horses for release were honored by the contractor without any controversy.

Trailer loading for transport to short-term holding:
Trailer loading for transport from the temporary holding/sorting corrals, where the recently gathered horses are kept for 2-14 days, to a short-term holding facility where they will stay for a longer period, was observed at the Adobe Town (Wyoming) and Antelope (Nevada) gather sites. The loading was done safely and efficiently by herding the horses up a ramp into the large semi tractor trailer one at a time. All horses had been sorted by sex and age prior to loading. They were loaded by gender in up to four partitioned areas in the tractor trailer. Foals were loaded in a separate partitioned area on the same trailer as their mothers.

Less than 10% of the horses on the large trailers had minor superficial abrasions. These were an accumulation of the gather process, transport to the holding area, the sorting process and time with other wild horses in the sorting pens. These injuries appeared superficial and would be expected to heal without treatment.

Short-Term Holding Facilities

The number of horses in BLM-controlled holding facilities reported as of June 2011:

PREPARATION FACILITIES	**2,440**
MAINTENANCE FACILITIES	**8,167**
CONTRACT HOLDING FACILITIES	29,341
Grand Total	39,948

Source: 6-30-2011
http://www.blm.gov/pgdata/etc/medialib/blm/wo/Planning_and_Renewable_Resources/wild_horses_and_burros/statistics_and_maps/transparency_page.Par.57230.File.dat/FacRpt0611.pdf

The horses listed in **Preparation Facilities and Maintenance Facilities (10,607)** are the population that includes the horses discussed under short-term holding in this report.

The task force visited four short-term holding facilities: Rock Springs (Wyoming) in October, Broken Arrow-Fallon (Nevada) in November, Palomino Valley (Nevada) in November and Salt Lake Regional Wild Horse & Burro Center (Utah) in February.

Three teams of three AAEP task force members visited these four sites. Twelve separate evaluation forms were completed by the teams. A total of seven different task force members participated in short-term holding evaluation, with each observer independently filling out an evaluation form for each holding facility.

Three holding facilities were government owned/operated (Rock Springs, Palomino Valley and Salt Lake Regional Wild Horse & Burro Center) and one was a privately owned facility (Broken Arrow) operated under contract with BLM. Palomino Valley was the oldest holding site and Broken Arrow was the newest. All four sites were well constructed. The layout was different at each site, reflecting the evolution of design concepts.

The newest facility (Broken Arrow) was the most efficient as it required the fewest personnel for caretaking, and the logistics of moving, feeding and working on large groups of horses was streamlined by the feedlot style design of the site.

Facilities at Rock Springs, Broken Arrow and Palomino Valley were all on level areas with excellent soil drainage. The Salt Lake facility was built on a steep hillside and the layout, although functional, was compromised by the constant grade. When the horses came out of the restraining chute at Salt

Lake they had to immediately climb a fairly steep grade in the alley before they entered the first pens or traveled either way along the hillside to the other holding pens. The task force members toured the handling chutes at the Salt Lake facility but no horses were worked through the handling facilities that day.

Facility capacity at the four sites was variable with the largest facility (Broken Arrow) constructed to hold over 2,000 horses. Existing horse populations at the time of the visits varied from small (150-175) to large numbers (1,600-1,800).

Horse pen construction and management:
The fences at the newer facilities were made of metal pipe; the oldest facility was fenced with wire mesh fence framed with a top board. All fences were strong, effective, designed for low maintenance and well maintained. The feeding areas were clean and safe. Footing was level and well drained at the three facilities that had sandy footing (Rock Springs, Broken Arrow and Palomino Valley). The Salt Lake Regional Wild Horse & Burro Center in Utah was located in a very hilly area that was not well drained as the pens were constructed on the sides of the hills. At the time of the site visit, the ground was very muddy due to recent snowfall. All pens were very muddy with no covered shelter, no firm ground for the horses to stand or lie on, and the horses were standing in 4 to 8 inches of a mud/manure mixture *(see short-term holding facility recommendation section)*.

Manure management was adequate at Rock Springs, Broken Arrow and Palomino Valley. Manure at the Salt Lake facility mixed with mud and standing water, creating unacceptable footing for the horses in pens. Any form of manure management would have been impossible in the muddy conditions. The Salt Lake facility had overcrowding of the pens, especially for the muddy footing *(see short-term holding facility recommendation section)*.

Hay feeder design varied from long trough bunks to round feeders or V-shaped mangers positioned in the center of pens to hay fed on the ground. The feedlot style pens (Broken Arrow) had long trough bunks that extended along the entire fence line adjacent to the access road. A concrete apron existed at ground level along the horse side of the trough, allowing the horses secure, dry footing in all weather. The trough had vertical metal struts that flanked a broad concrete bunk that held hay. Horses could stick their heads through the struts to access the hay. This was an efficient design, as only a few staff were needed to feed up to 2,500 horses, and each horse had good access to hay at a site along the long trough. Pens that were designed with manger type central feeders required more personnel to do the feeding (Palomino Valley and Salt Lake Regional Wild Horse & Burro Center). Pens that used ground feeding (Rock Springs) had a truck drive through each pen once a day. Large sections of hay were rolled off the truck and spread on the ground every few feet. Automatic watering troughs were present at all sites. Water supply appeared clean and adequate at all facilities visited. Horses were observed eating the hay offered at all sites, and drinking from the available watering units.

Condition of horses at the short-term holding facilities:
The majority of the horses observed at the various facilities visited were in good body condition with Henneke scores ranging from 4/9 to 6/9. Horses were fed well, sometimes to excess, with many of the longer term residents exhibiting body condition scores that would be termed fat (7/9).

Horse herd behavior among the groups at each facility was similar to herd behavior normally observed in similar sized groups of domestic horses.

At Broken Arrow, the newest facility, an allowance of 700 square feet of space per horse was used in determining the holding capacity of the pens. None of the pens at Broken Arrow, Palomino Valley or Rock Springs appeared crowded. The Salt Lake City facility pens, however, contained too many horses for the winter weather conditions *(see short-term holding facility recommendation section)*.

The feedlot trough design at Broken Arrow was associated with a few medical issues. Approximately 10% of the horses displayed minor shoulder abrasions that were secondary to pushing against the trough partitions to reach hay. Other horses displayed chronic ocular discharge that appeared related to sticking their heads in loose hay in the troughs. Many young horses showed a focal patchy alopecia (hair loss) of the facial region—this condition may reflect a communicable disease caused by a skin pathogen that is spread in the close quarters of the feed troughs, though a diagnosis of the condition was not made or reported. These conditions would be expected to resolve when animals were moved to an adopted home, training program or long-term pasture and members of the task force did not consider these to be a risk to the horses' health.

Observed injuries were uncommon other than a few minor abrasions. The abrasions that were noted were similar to those commonly seen in domestic horses that are confined together in a pasture.

A small number of horses at the holding sites appeared thin. At the Broken Arrow site in Nevada, some of the thin animals appeared to be aged. About 10 geldings who were recent castrates appeared to be experiencing castration complications as evidenced by swollen prepuces. At the Palomino Valley facility in Nevada there were a small number (about 10) of thin horses who either showed outward signs of strangles, a bacterial respiratory infection, or were reported to be recovering from strangles *(see short-term holding facility recommendation section)*. Most horses that had conditions of medical concern (primarily strangles or castration complications) were housed in corrals designated for observation. These corrals had close access to chutes where treatment could be performed if deemed necessary.

The task force teams were told that the average length of stay at the short-term holding facilities often exceeds 200 days, with a range of 90 to 300 days. Over this confinement period horses do not move enough to wear their feet to a healthy condition as they do on the range. Most horses undergo foot trimming during their stay in short-term holding. The AAEP teams did not observe any hoof trimming but made close inspection of several padded hydraulic squeeze chutes that were used for this purpose. When a trim is scheduled, the horse is herded through an alleyway or chute into the squeeze chute. The entry door, sides, floor and exit door of the squeeze chute are hydraulically controlled. Once the horse is enclosed in and restrained with the padded squeeze panels, the chute is rotated 90 degrees onto its side with a separate hydraulic system. The foot trimmer accesses the feet through the floor which opens once the horse is in lateral recumbency. Foot trimming is reported to be a quick procedure, accomplished either with hand tools or a special hoof trimming disc on a hand grinder. The squeeze chutes the task force examined were well designed and appeared safe for restraint.

The foot condition of most horses was good. Less than 5% of the horses at Broken Arrow had long feet in need of trimming. The staff at the sites acknowledged this, saying these individuals were slated for the trimming process soon *(see short-term holding facility recommendation section)*. The feet were not deemed to be an immediate health risk to the horses.

Chutes and tubs:
All four facilities had well designed, sturdy alleyways, chutes, tubs and squeeze chutes for a variety of procedures that are done once horses arrive at the facility including identification, branding, vaccination, Coggins testing, neck strap placement, castration, occasional veterinary treatment of individual conditions, and foot trimming. The AAEP team that visited the site in Rock Springs, Wyoming observed a number of horses moved through the chute for identification, freeze branding, vaccination, collection of blood for Coggins testing and neck rope placement. Another AAEP team observed 12 stallions moved through the chute for castration at Palomino Valley in Nevada. At other facilities, where identification and medical procedures were not done during the team visit, observers walked over all the catwalks and inspected the chutes and hydraulics closely.

Medical procedures observed:
The AAEP team at Rock Springs observed several horses undergoing identification and medical procedures for the first time. The handling team was composed of several BLM employees and a veterinarian who did contract work for the BLM. The handling team was skilled and efficient. No horse was in the chute for more than a few minutes. The horses accepted restraint from the hydraulic squeeze panels which were adjusted to each horse as needed by an operator who was skilled and quick. There was minimal resistance to the procedures that involved needles or freeze branding.

During the health and identification procedures the horses were identified with neck ropes and a freeze brand. The neck ropes were necessary for initial visual identification and are removed when animals are adopted or prepared for shipment to long-term holding pastures. The horses were freeze branded with an assigned number on the upper left side of the neck using the international horse Alpha Angle Freeze Mark Identification system developed by Kryo Kinetics. The horses were then immunized with several vaccines as outlined by the BLM program protocols and dewormed with an oral ivermectin drench. A blood sample was taken for testing from each horse for screening for Equine Infectious Anemia (Coggins test). No injuries were observed during the medical procedures. Dental age estimation, gender and color with markings were recorded for each horse along with their neck rope number and freeze brand number. Medical procedures were also recorded with each horse's record.

The side panels of the entry chute were designed with visual barriers leading up to a lighter area. The animals were motivated to move towards the light and thus advance towards the squeeze chute. Horses awaiting entrance to the chute appeared relatively calm and often voluntarily moved to the next section when a gate was released. A flag made of a plastic grocery bag secured to a long stick ("wild rag") was occasionally used to encourage forward movement. When the flag was used it was shaken at the rear of the animal to encourage forward movement in a manner similar to encouragement that is commonly used for moving domesticated horses.

The designs of all chutes and alleys were circular so that horses looped back to the destination pen. Once the medical and identification procedures were completed on a given horse, it was released into

the exit alley, and all animals trotted away without exhibiting stress or ill effects. The Salt Lake facility was located on a hillside and the chute and paddock system was mildly compromised by the unlevel terrain. The chutes were examined but no animals were observed in the chute system. The prevailing muddy conditions that were present during the team visit would have made footing and movement unacceptable.

At Palomino Valley in Nevada, the AAEP team observed the castration of 12 mature stallions. The operations were performed by a veterinarian who contracts with the BLM, assisted by several BLM staffers. Each stallion slated for castration was moved into the squeeze chute and induced to lateral recumbency with an intravenous short-term paralytic agent (succinyl choline). After the horse was recumbent, an intravenous combination of a sedative (xylazine hydrochloride) and a dissociative general anesthetic (ketamine hydrochloride) was administered. The horse was then rolled on its back and all four legs were secured to overhead beams to assure that the horse stayed in dorsal recumbency. The scrotum was incised over each testicle and both testicles were then removed by standard surgical technique. Once castration was complete each gelding was transported to a recovery pen on a hydraulic lift platform. Recovery from the general anesthetic occurred in about 15 minutes for all horses. After recovery each gelding rose to his feet and joined the herd of newly gelded horses.

One horse did not resume strong spontaneous breaths right after becoming recumbent. The upper airway was stimulated by the surgical team and the horse then resumed an adequate breathing cycle and the operation proceeded uneventfully. A few horses did not appear to be in a full plane of surgical anesthesia when the scrotum was incised for the castration. This was evidenced by leg movement against the ropes that tied the hind legs to the overhead beams *(see short-term holding facility recommendation section)*.

All horses stood up without incident after they regained consciousness. Behavior after the operation was as expected after administration of a dissociative anesthetic: horses were a little wobbly and unsteady for a few minutes, then regained normal body control. Observed hemorrhage was minimal and considered normal for this surgery.

The AAEP team did not observe any cryptorchid castrations (castration of horses with a retained testis) during their visit. Interviews with the BLM contract veterinarian revealed that the incidence of cryptorchidism is about 3% in wild horses.

Feed and water protocols:
Hay and water were plentiful and of excellent quality. Water sources were clean and full. All horses had hay in front of them at all times during the AAEP team visits and were observed to be eating and drinking.

The teams did not observe any thin or emaciated horses being introduced from the range to short-term holding, but interviews with BLM staff indicate that this situation sometimes occurs. It was reported that caution is used on “refeeding” thin horses new to a holding facility: grass hay and oat hay are fed to these animals until it is safe to introduce the richer alfalfa mix that is the normal diet.

Vaccination and anthelmintic protocols:
Interviews with BLM personnel and contract veterinarians indicated that the vaccination protocol that is in place is administered consistently and records are kept to assure that each horse is covered with the same antigens delivered on the same schedule. A single rabies vaccine dose is administered to all horses on the first day of medical inspection and management. A series of two doses of vaccine given a month apart is administered to induce immunity against West Nile virus, Eastern and Western Equine Encephalitis viruses, tetanus, equine herpes virus, strangles and equine influenza virus. Horses that stay in short-term holding longer than 6 months are given an additional dose of strangles, equine herpes virus and influenza virus vaccines. Anthelmintic treatment involves an oral drench with ivermectin that is given every four months as long as the horse remains in short-term holding.

The care of horses that are adopted through the BLM is in the hands of the new owners, but all horses are assured to have received an initial vaccine series as described above. The regimen we observed is practical, cost effective and humane. It is within an acceptable standard of medical care and presents no risk to horses' health.

The BLM Wild Horse and Burro Program does not administer additional vaccinations or anthelmintics to wild horses once they are moved to long-term holding pastures.

Biosecurity:
The task force did observe a small number (approximately 15 horses, or about 0.5%) of horses at Broken Arrow and Palomino Valley that were underweight with body scores of 2/9 and 3/9. These horses were housed in separate observation pens and it was reported by BLM employees that these were horses under observation or treatment for disease. There was little or no isolation of these horses from the other horses in the short-term holding facility *(see short-term holding facility recommendation section)*. It was reported that adoption returns were readmitted to the facility at Rock Springs. This activity was considered by the task force as a potential biosecurity risk *(see short-term holding facility recommendation section)*.

Long-Term Holding Pastures

The number of horses reported in BLM controlled long term holding facilities as of June 2011:

PREPARATION FACILITIES	2,440
MAINTENANCE FACILITIES	8,167
CONTRACT HOLDING FACILITIES	**29,341**
Grand Total	39,948

Source: 6-30-2011
http://www.blm.gov/pgdata/etc/medialib/blm/wo/Planning_and_Renewable_Resources/wild_horses_and_burros/statistics_and_maps/transparency_page.Par.57230.File.dat/FacRpt0611.pdf

The number of horses listed in **Contract Holding Facilities (29,341)** are the population of horses that includes the horses discussed under long-term holding in this report.

Horses that are older or for which there is no immediate adoption demand are sent to long-term holding facilities to live out their lives in natural conditions. The ranches that provide the long-term pastures are privately owned. Ranch owners contract with the BLM and are paid a daily sum for each horse housed at those facilities.

Four task force members visited long-term holding pastures at two different ranches in Oklahoma. The two facilities were the Two Mounds Ranch and the Hughes Ranch near Bartlesville, Oklahoma. Each observer independently filled out an evaluation form for each site, thus eight evaluation forms were obtained for long-term holding facilities.

Transport, arrival and release:
Horses are shipped to these two facilities from short-term holding facilities in California, Nevada, Wyoming, Colorado and Oregon. While the task force members did not observe transport, both ranch owners reported satisfaction with the job the truckers and hauling companies perform transporting the horses. The ranch owners commented that horses are not crowded in the trailers and arrive in good condition. Injuries during transportation were reported to be very rare, with only one injury observed for both ranches during the last year. Records of arriving horses and their condition are kept in duplicate, with one copy kept at the ranch and the other sent to the BLM on a monthly basis.

Horse pens/pastures:
Both ranches utilized 5- or 6-strand wire fencing with flags and pipe gates for the pasture boundary. Natural terrain provides windbreaks and shade. Horses graze on native grasses or improved pasture from April 15 until October 15. During late fall, winter and early spring horses are fed 6.5 pounds of alfalfa hay per horse per day. This hay is distributed three times per week so that each horse receives 45.5 pounds of hay per week. Water sources consist of streams and ponds, which are plentiful and clean.

Horses are observed and counted three times per week when fed during the winter and once a week in the summer by the ranch staff. BLM personnel observe and count horses once a year. Horses are not vaccinated or dewormed after they are turned out in these pastures. They live out their natural life span without medical intervention. Many horses live on BLM contract holding facilities for 10-25 years.

APHIS veterinarians have educated the ranch owners in evaluation of horses to determine when advanced age, serious injury or debilitation indicates euthanasia. Euthanasia is by gunshot and carcass disposal is in approved pits. Most deaths (either natural or by euthanasia) occur in the winter and early spring.

Condition of horses:
Two Mounds Ranch, in Bartlesville, Oklahoma, is a mare-only facility that began to care for BLM horses in January 2010. The ranch supports 1,011 horses at a stocking density of 7 acres per horse. No breeding occurs on the ranches, but mares that are pregnant on arrival are segregated and kept in smaller enclosures close to the residence of the owners. When visited, Two Mounds Ranch had 120 foals, weaned and newborn, on site. The weaned foals are sent back to short-term holding facilities for medical treatment and entry into the adoption programs.

After arrival mares are kept in a large pipe fence corral to let them settle and adapt to the hay diet. They are then acclimated to wire fenced pastures of about 10 acres before they are moved to the large wire fenced pastures. Facilities for moving and observing individual horses are available if needed and were determined to be safe, efficient and in excellent condition.

The AAEP task force members traveled over 30% of the pasture land and observed approximately 40% of the horse population at the Two Mounds Ranch. The grassland was evaluated as excellent as was the hay being fed. Body condition score of observed horses averaged 5/9, and ranged from 4/9 to 6/9. No disease or injuries were observed and hoof condition was good. The ranch owners reported strangles in some of the weaned foals, but had observed no recurrence of infection in any individuals who had recovered from the initial episode. Twenty deaths (approximately 2% of the population) had occurred in the mature horse population in the previous year from old age and debilitation. Seventeen horses died naturally and three were euthanized.

Hughes Ranch, in Bartlesville, OK, only houses geldings and has been caring for BLM horses for approximately twenty years. This ranch consists of 2 facilities: the home ranch, which includes 12,000 acres with 1,500 horses, and Candy Creek, which includes 7,000 acres and 750 horses. Stocking density is 8-11 acres per horse on native grass and 2 acres per horse in improved pastures. Smaller improved pastures have constructed shade and house newly arrived horses. The natural attrition rate of horses lost to old age and debilitation varies between 7-11% per year. Of the horses lost to old age or debilitation, 25% die naturally, and 75% are euthanized. The larger percentage of loss of horses at the Hughes Ranch is attributed to the fact that horses have been in residence for many years at this ranch and the population includes many aged individuals. Horses have only been housed for 14 months at Two Mounds ranch so the accumulated attrition rate is much lower.

There were many roads throughout the property, so approximately 70% of the pasture land and 65% of the horses were observed. Body condition scores ranged from 4/9 to 6/9, with an average of 4/9. Injuries were reported to be very rare. The owners could name all of the injuries over the years the ranch has contracted with the BLM. No disease or injuries among any resident horses were observed by the AAEP task force members. The media are allowed periodic access to the long-term holding facilities by appointment with BLM, and the public can visit the facilities during an annual tour that began in 2011.

Discussion and Conclusions

Horses on the range:
Projections based on the population growth suggest long-term or permanent damage will occur to the range when the wild horse populations are allowed to exceed the estimated carrying capacity of Herd Management Areas (HMA). Herd numbers over the HMA carrying capacity also expose the horses to suffering and death from insufficient natural water and forage. These conditions are magnified when natural weather extremes occur. It is the opinion of the BLM Task Force that limiting the number of horses on the HMAs is in the best interest of the health and welfare of the horses *(see range recommendation section)*.

Gather sites:
Gather sites were well chosen by experienced contractors who knew the topography of the specific HMA range. Natural features were used to create effective trap boundaries whenever possible. The footing at all the trap sites was good. In some sites horses negotiated small natural obstacles like gullies without incident.

The construction of the jute wings and trap was simple and effective at the three sites observed. The jute at the Antelope Complex gather was worn and was not well secured for a windy day on the first gather day. The jute had been replaced for the second day with new jute and it performed well in no-wind conditions. At the Pine Nuts gather some horses jumped uncovered barbed wire fences and additional jute had to be used to cover the fences for successful capture. To protect the welfare of the horses, the use of existing barbed wire fences as a boundary for gather drives should be avoided. If it becomes necessary to use an existing barbed wire fence it should be adequately covered for an appropriate distance for the geography of each gather site to prevent injury *(see gather recommendation section)*.

Gather process:
Based on observations of five gather days in the high desert country in Wyoming and Nevada, the use of helicopters to herd horses to a trap was judged humane, efficient and effective.

On some drives during the Adobe Town/Salt Wells Creek Complex gather, the helicopter flew in a close horizontal plane to the trailing horses as the group approached the trap. The helicopter was also close to the ground in a vertical plane on some of these final trap drives. Flying patterns observed during the Pine Nuts HMA and Antelope Complex gathers were more conservative: the helicopter maintained a longer distance away from the trailing horses and flew higher above the ground as the horses were herded into the trap. Effectiveness of the herding drives was similar at all the observed gathers.

Close proximity of the helicopter skids, rotors, body or tail to the horses and/or ground poses a safety risk for the horses. Conservative flying patterns that allow a reasonable buffer distance between the helicopter and the horses, and the helicopter and the ground are recommended at all times *(see gather recommendation section)*.

The gather process was well organized, implemented in a quiet and efficient manner, and the equipment appeared to be in good condition and effective. The two gather contractors operated in a similar manner and had similar equipment. The horses were handled in a respectful and humane manner.

The AAEP task force teams met three different APHIS veterinarians and several horse specialists who worked for the BLM at the gathers. All these individuals were highly qualified, well trained and articulate. All were motivated to act in the best interest of the horses and the best interest of the rangeland. Many of the horse specialists had advanced degrees in range management, wildlife ecology or other related scientific fields. The APHIS veterinarians had advanced training in procedures like field necropsy. Cooperation between individuals representing the two government agencies was smooth. The various jobs they carried out were done efficiently and skillfully. The AAEP

recommends maintaining the qualified individuals in the current areas of expertise to provide careful horse management during gathers.

Traps, capture pens, chutes at gather sites:
The traps served their purpose and the capture pens were of sturdy construction. The corrals that were built with wider rounded pens linked together appeared safer for the horses than the capture pens that were built as narrow rectangular alleys. The horses were only in these pens and alleys for a very brief period, but a few young animals at one gather in Nevada were traumatized by an aggressive stud that kicked repeatedly. The young horses in the alley next to the stud had no room to get away and suffered several kicks. They would have been able to take defensive action by getting inside a ring of other horses in a wider corral *(see gather recommendation section)*.

Wild equids who are confined appear to exhibit calmer behavior when fenced with a visual barrier that reduces stimulation from outside the corral. Some of the capture pen panels were lined with a visual barrier (plastic snow fencing) while others had no barrier. The addition of solid panels or consistent use of visual barriers might be helpful in capture pen construction *(see gather recommendation section)*.

The AAEP recommends solid side panels in the final capture pen panels to minimize the pushing of heads between the rails and to keep legs from going between the rails if horses attempt to climb the panels. Solid panels may lessen the chance for injuries that could occur in this area.

Trailer transport from the traps:
Trailer transport of horses from the traps to the temporary holding corrals was humane, efficient and effective. The AAEP teams watched the horses as they were driven off in the slatted stock trailers. They were impressed by the calm behavior that the horses displayed when loaded in a vehicle and transported in a trailer for the first time.

Condition of the horses after the gather:
The condition of the horses immediately after capture was judged to be good, with the exception of the one horse that collapsed and died right before entering the trap. There was no sign of exhaustion or medical compromise in the other horses that were observed being gathered. The gathered horses had elevated respiratory rates as expected for any exercised horse, and some had mild to moderate body coat sweat which was dependent on the weather and distance traveled. All horses recovered quickly from the exercise of the gather once in the capture pens and were observed eating hay soon after transport to the temporary holding corrals.

Temporary holding/sorting corrals near the gather sites:
The temporary holding corrals and chutes were solidly constructed and well designed for the purpose of sorting newly gathered horses and housing them for several days. Each corral design observed was different, reflecting the topography of the region and the elements and materials that the individual contractor used to construct the site. All were effective and safe.

It was remarkable that one stallion was able to leap over a corral fence that was about six feet tall at the holding site in Nevada. The corral panels were not deemed low; the individual horse was exceptionally athletic. The fences contained the rest of the horses well.

Hay and water were plentiful for all horses. Hay was distributed along the fences so that it did not get trampled underfoot. All horses were able to access the hay without difficulty. The AAEP recommends continuing this system of feeding and watering, as it is a basic necessity for maintaining the health and welfare of the horses.

Condition of the horses in temporary holding and sorting corrals:
The horses observed were considered to be healthy. Close inspection of horses that had recently been brought in off the range revealed most of them to be in a good nutritional plane though some wet mares were a little leaner than their herd mates. Nursing domestic mares often become lean as their foals mature due to the demands of lactation so this was judged normal and not a risk to horse health or welfare. Horses gathered in the winter in Nevada were thinner than horses gathered in the fall in Wyoming—this was also considered a normal variation as the winter season would reduce the amount of forage available and increase weather related stresses on herd activity. As half the wild horses in the U.S. reside in the state of Nevada, competition for available forage may also have been more intense for horses in the Nevada HMAs.

Gather-related injuries were judged to be minimal and all those observed would have been expected to heal without treatment. Horses adapted to the conditions of the temporary corrals quickly. Feed and water were plentiful and accessible to all horses.

Trailer loading for transport to short-term holding facilities:
Observed loading procedures were judged to be humane and effective. Some horses sustained minor skin scrapes or small nonsuturable lacerations during loading or within the transport trailer. This was not surprising given the close proximity of horses on the trailer. Observed injuries were judged to be minor and would have been expected to heal without treatment. Ventilation on the trailer was judged to be adequate.

The practice of hauling foals at the rear of the trailer separated by a partition caused minor distress due to the separation of the foals from their mothers. This temporary distress was outweighed by the safety benefits of avoiding injury to the foals by keeping them away from the larger mature animals in the trailer.

The large semi-tractor trailers appeared safe and well ventilated. All semi-tractor trailer transport observed was in single level trailers. Personnel participating in the gather process were professional, knowledgeable, quiet and efficient. Horses were moved primarily by quiet hand and arm gestures, much as domesticated horses are moved. If necessary, flags were used to encourage forward movement. Transport by large single level semi-tractor trailers does not pose a health or welfare risk for horses.

Short-term holding facilities

The short-term holding facilities varied significantly by site. The Salt Lake Regional facility had significant challenges relating to footing, drainage and manure management because of the hillside construction. The AAEP was of the opinion that, at the time of our task force visit, the wet muddy conditions at this site posed a risk to horse health *(see short-term holding facility recommendation*

section). The other three short-term holding facilities that were inspected had excellent footing and good drainage and manure management.

Horse pen construction and management at the short-term holding facilities:
The facilities were all in good repair. The newer facilities appeared most efficient in operation but all were deemed functional. The design of the Salt Lake Regional facility on a hillside was less than ideal but the handling facilities for medical inspection and procedures were adequate. The pens at the Salt Lake facility had serious challenges with the wet weather, creating adverse conditions for confined herds *(see short-term holding facility recommendation section)*.

The task force site visit at the Salt Lake Regional facility was the day following a snow storm and there was still some snow on the ground. For the weather conditions observed, there was overpopulation of the horses in the pens. It was too muddy for any equipment to get into the pens to scrape or move the mud/manure mixture. There were no areas of solid footing observed for horses to have a place to lie down. The visiting task force team was of the opinion that the housing of the horses in the muddy pens and the overcrowding was unacceptable for the weather conditions observed and posed a health risk for horses at the site *(see short-term holding facility recommendation section)*.

Condition of horses at the short-term holding facilities:
Most of the horses at the short-term holding facilities were in good body condition. Their behavior was calm and relaxed. Horses behaved much as a group of domestic horses would when confined to pens of similar size, they congregated in groups and spent much of the day resting or eating. Foals and young horses displayed the most curiosity about humans.

No serious injuries were observed among the horses at the short-term holding facilities.

Horses were observed with active cases of strangles at the Palomino Facility. A small number of other horses at this site appeared unthrifty and were withdrawn from the rest of their pen herd—these individuals were reportedly recovering from strangles infection. Strangles appears to be the most serious health risk for wild horses that have been gathered. Strangles is a very difficult disease to control as normal appearing horses may be asymptomatic carriers. The disease may be endemic in certain wild herds out on the range, but the housing conditions of the holding facilities aid in concentration of fomites, and thus outbreaks of infection occur with regularity at some holding sites.

The task force recommends that the BLM consult with experts on biosecurity and adopt best practices for controlling the outbreaks and spread of strangles and other infectious diseases. Written biosecurity guidelines should be enforced at all holding facilities *(see short-term holding facility recommendation section)*.

A few horses had long feet in need of trimming. The BLM staff explained that trimming is done on a rotation and that all horses that have long feet are on a waiting list for the trimmer. The AAEP recommends scheduling of hoof trimming on a rotation that avoids excessive hoof length *(see short-term holding facility recommendation section)*.

A few other horses in the medical observation pens showed signs of castration complications (preputial edema and stiffness). Castration complications are common in domestic horses and the

incidence of complications in the wild horses appeared similar. Some of these horses were in an unthrifty physical state, suggesting serious complications. Given the fact that 3% of the castrations involved cryptorchid colts, complications are to be expected. The AAEP advises devising a protocol to manage these complications, but recognizes that practical considerations involved when handling wild equids limits therapy options.

Chutes and tubs:
Construction of the chutes and tubs and foot trimming squeeze chutes were well planned and well built with minimal hazards. The design of the alleys and chutes reflected modern principles of animal handling that have been popularized by Dr. Temple Grandin.

The task force could not make any suggestions on improving or changing the chute design at any of these facilities. They have been designed and constructed with the safety and welfare of the horse as a high priority during essential handling functions. Like the pens, the chute design has evolved over time, and is most advanced at the newer facilities, but all of the chute setups were judged exceptional.

Medical procedures observed:
The initial management for identification, freeze branding, immunization, deworming and Coggins testing of horses through the chute was handled with efficiency and skill. The travel process through the alley appeared to induce minimal stress. Horses that lagged in the chutes were coaxed to move forward in a humane fashion. The squeeze chute operators were skilled and worked quickly to safely restrain each horse in the chute. The veterinarian and BLM staff who handled the brand and needle procedures worked quickly and efficiently. Each horse observed was in the chute for less than 2-3 minutes. All horses exited the chute calmly and trotted off in the alley leading to the sorting pens. Their behavior after the procedures was reflective of the humane handling methods.

Stallions that were restrained in the squeeze chute in preparation for castration were handled in a similar efficient and safe manner. Intravenous injection of the short-term paralytic agent, succinylcholine, was accomplished with quick accuracy in all observed cases. Subsequent assumption of recumbency occurred quickly for all stallions; none of the horses were harmed when they were released from the chute panels just prior to dropping to the ground in lateral recumbency. One horse was observed to have minor apnea after assuming recumbency but he resumed deep breathing after some stimulation.

Some of the stallions did not appear to be in a full plane of surgical anesthesia when the scrotum was incised for the castration. This was evidenced by leg movement against the ropes that tied the hind legs to the overhead beams.

The AAEP recommends establishing a written anesthetic protocol for contract veterinarians to make sure all horses have reached a surgical plane of anesthesia before castrations begin *(see short-term holding facility recommendation section)*. This is especially important when the paralytic drug succinylcholine is used for initial restraint as it has no analgesic or anesthetic effect.

Feed and water protocols:
Horses were allowed access to large amounts of hay, which appeared to be of excellent quality, on a daily basis. During all inspections all groups had fresh clean water to drink. The AAEP task force was of the opinion that some horses were fed to excess as evidenced by body condition scores that reflected a substantial amount of body fat.

Vaccination and anthelmintic protocols:
The vaccination protocol that the BLM uses for wild equids is not as complete as that described in the official published AAEP guidelines for vaccination. The AAEP guidelines advise that a series of three injections be given to induce maximum protection for most initial immunizations. A series of two injections is recommended for rabies immunization. The BLM horses are given two injections for most vaccines and one injection for rabies protection.

Even though the vaccination schedule that is used by the BLM does not mirror the published AAEP guidelines, the BLM schedule is acceptable and similar to protocols commonly practiced in domestic horses before the AAEP guidelines were released.

The anthelmintic protocol that is in use is adequate and would be expected to control of intestinal parasites in a group housing environment.

Biosecurity:
The AAEP recommends that the BLM develop biosecurity guidelines for each facility in an attempt to avoid adding diseased horses to the short-term holding facilities and to prevent spread of disease. The guidelines should address practices to avoid new cases of strangles and the proper handling of known cases. The AAEP recommends inclusion of biosecurity guidelines regarding return of previously adopted horses to the facility, travel of local working horses on and off the property, and possible infection from wildlife *(see short-term holding facility recommendation section)*.

Long-term pasture facilities:
There are no stallions at either facility and the only foals born are from mares shipped pregnant to the facility. Weanlings from these mares are returned to short-term holding facilities for medical treatment and to enter the adoption programs. Thus the number of horses is consistent. The two long-term facilities evaluated are well maintained as excellent range/ranch type environments for unadopted horses to live out their lives.

Transport, arrival and release at long-term pasture facilities:
The task force team did not observe the arrival or release of any horses at the long-term pasture facilities. All reports from interviews indicated the transport system is working well.

Horse pens/pastures:
The fences and the horse handling facilities at both ranches visited were in good condition and safe for the horses. The pasture, food supplies, and water were sufficient to maintain the health and welfare of the horses. Horses had plenty of space to simulate conditions on the range with much better food and water than found on the range.

Condition of horses at long-term pasture facilities:
The lack of disease and injury as well as the long life span indicates the horses are well cared for. Minimal to no intervention (handling and medical procedures) reflects life as it would be in the wild, with the exception that the horses will never suffer from lack of food or water, natural conditions that periodically stress wild herds that live on the rangeland managed by the BLM.

Supplemental Information on BLM Wild Horse and Burro Adoption Programs

Burros: BLM staffers reported that presently there is a ready adoption market for burros as pets. This is due to the fact that burros have a wide popular appeal and are cheaper to keep and house than horses. The task force only viewed a few wild burros (less than 15) at one short-term holding facility, and all these animals were expected to find adoption homes.

Horses: In contrast to wild burros, the current adoption market for wild horses gathered from the range is very limited.

Some of the wild horses that were seen by the task force at short-term holding facilities were slated for later transport to a variety of government sponsored programs linked to adoption promotion. Current programs include regional **BLM supported adoption events**, **Extreme Mustang Makeover training programs/competitions** sponsored by the Mustang Heritage Foundation, and **state prison projects**.

Horses that enter BLM-supported adoption events are offered for adoption to the public untrained. Horses judged to be older than 11 years are occasionally offered for sale in groups, untrained. Horses that go through the Mustang Makeovers or the prison projects are offered for sale or adoption after a period of training.

While a significant number of wild horses have found homes through these programs since they were created, statistics show that the number of wild horse adoptions has declined significantly over the past several years.

WILD FREE-ROAMING HORSE AND BURRO REMOVAL AND ADOPTION, FISCAL YEAR 2010

Total Adopted, Fiscal Years 1971 through 2009/a/:	**224,309**
Total Adopted, Fiscal Year 2010:	**3,074**
Total Removed, Fiscal Year 2010/c/:	**10,255**

Source : 6-30-2011
http://www.blm.gov/pgdata/etc/medialib/blm/wo/Planning_and_Renewable_Resources/wild_horses_and_burros/statistics_and_maps/transparency_page.Par.5661.File.dat/10pls5-13Template.pdf

Wild horse population and adoption numbers: Contrast between 2004 and 2010:

	FY 2004	FY 2010
Adoption numbers (decrease of 3,864)	6,644	2,960

	FY 2010	FY 2020
Projected Population (Increase of 199,635)	38,365	238,000

	FY 2004	FY 2010
Horses and Burros in Holding Facilities (Increase of 15,800)	22,000	37,800

	FY 2004	FY 2010
Program Funding (Increase of 29.4 Million)	$36.7 Million	$66.1 Million

Source: 6-30-2011
http://www.doioig.gov/images/stories/reports/pdf/BLM%20Wild%20Horse%20and%20Burro%20Program%20Public.pdf

Comments on adoption of wild horses, the Unwanted Horse, and the AAEP

Changes in popular culture, a shift away from agrarian interests and recent strains in the global and national economy have led to a declining interest in horse ownership in general among the American public. There are more horses in this country, both domestic and wild, than there are homes to care for them. The challenges related to this reality, termed "**the unwanted horse,**" are significant. The welfare issues relating to this growing equine population is the focus of a broad coalition of equine organizations known as the Unwanted Horse Coalition. http://www.unwantedhorsecoalition.org/

As a founding organization of this coalition, the AAEP has broad familiarity with the economic, social and welfare issues associated with unwanted horses. The task force does not predict that the adoption market for wild horses will expand in years to come, and may actually continue to decline. Government expense on adoption or training projects may not increase the number of horses that are placed in homes, simply because the demand for horses in general has decreased in the past several years.

The Wild Horse and Burro program started out as an adoption program and has evolved into a welfare program. The work of the AAEP BLM Task Force in observing wild horse gathers and holding facilities has heightened our organization's awareness of the complex issues relating to management of the growing population of wild equids that populate the open range in the western United States. Clearly the mission of the BLM program - **Healthy Ranges, Healthy Horses –** is not a simple one.

Education of the AAEP membership on the Wild Horse and Burro Program will evolve from the work of the Task Force. Publication of the Task Force findings and recommendations will enhance overall awareness in the veterinary profession of issues relating to wild horses.

The purpose of the AAEP is concisely stated in the organization's mission statement: "To improve the health and welfare of the horse, to further the professional development of its members, and to provide resources and leadership for the benefit of the equine industry." As such, the AAEP is a resource for equine medical expertise to the BLM Wild Horse and Burro program at a variety of levels.

AAEP RECOMMENDATIONS

Overall, the AAEP is of the opinion that the care, handling and management of the horses in the BLM Wild Horse and Burro program are appropriate. The management practices observed by the task force at gathers and at various holding facilities generally supported the safety, health status and welfare of the wild horses.

The AAEP task force offers the following recommendations to strengthen the practices currently in place and assist in supporting the handling, health care, and welfare of the horses and burros (equids) at BLM gathers and holding facilities.

HORSES ON THE RANGE

- The BLM should utilize the best science available to obtain accurate herd management area census information in order to determine the healthy sustainable equid numbers for each area.

- The BLM should prioritize research and application of effective methods to reduce the foaling rate in wild herds.

WILD HORSE GATHERS

- The contract helicopter pilots should always maintain a safe distance between the helicopter and any horses that are being gathered, and between the helicopter and the ground.

- The capture pens should be constructed so that pen configurations include wider sections instead of narrow lanes for temporary holding of animals that have just been captured. This configuration gives passive animals a circular escape from aggressive animals.

- The trap should be constructed with solid side panels in the final capture pen to prevent horses from getting their heads or legs outside of the pen and to discourage horses from attempting to climb out of the enclosure

- The use of existing barb wire fence as a stage for a jute wing should be discouraged. If barb wire fence must be used, any areas where the horses will be actively driven should be covered with jute to prevent injury.

SHORT-TERM HOLDING FACILITIES

- Areas of solid footing should always be provided in short-term holding corrals to allow animals a place to lie down. The overcrowded and wet muddy conditions throughout the pens at Salt Lake Regional Wild Horse and Burro Center in Herriman, Utah, were unacceptable. The conditions posed a health risk for the horses, and did not meet the standard for horse welfare at the time of the task force team visit.

- When equids undergo any procedure that requires general anesthesia, a surgical plane of anesthesia should be present before the skin is incised to insure a pain-free surgery. Additional anesthetic medications should be administered as necessary to achieve and maintain a surgical plane of anesthesia. A uniform surgical anesthesia protocol should be in place and reviewed with all contract veterinarians concerning medical procedures at all BLM horse management sites.

- Foot trimming schedules should be created and customized for each facility in accordance with environmental conditions and periodic inspections to reduce the likelihood of excessively long hooves.

- Horse population numbers in short-term holding facilities should be matched with the capacity of the pens at the facility. Population numbers should be adjusted as needed seasonally to avoid overcrowding when extreme weather is expected or present. The AAEP recommends the BLM utilize the facility manager, the contract veterinarian for the facility, and an APHIS veterinarian familiar with the site to create guidelines and limits for total horse numbers for each site. The Salt Lake Regional facility had an overpopulation of horses for the weather conditions at the time of the task force visit.

- The BLM and its facility managers should consult with experts on biosecurity and adopt best practices for controlling outbreaks and spread of the bacteria Streptococcus equi, var. equi, commonly known as strangles, and other infectious diseases.

RECORDS

- The task force encourages current efforts to produce a centralized database to track the history of all horses in the BLM program. The records should include positive or negative trends in adoption programs and socially productive programs like those in place at certain prisons.

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Bureau of Land Management
Internet Adoption Program

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Theodore Roosevelt National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/THRO/NRR—2014/776



ON THE COVER
River Bend Overlook in the North Unit of Theodore Roosevelt National Park
Photograph by: (Shannon Amberg, SMUMN GSS)

Theodore Roosevelt National Park

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Natural Resource Report NPS/THRO/NRR—2014/776

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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Acronyms and Abbreviations

BBS – Breeding Bird Survey

BCR – Bird Conservation Region

CCC – Civilian Conservation Corps

dNBR – Differenced Normalized Burn Ratio

EAB – Emerald Ash Borer

EPA – Environmental Protection Agency

EPMT – Exotic Plant Management Team

FMP – Fire Management Plan

GIS – Geographic Information System

GPRA – Government Performance and Results Act

IMBCR – Integrated Monitoring in Bird Conservation Regions

IRMA – Integration of Resource Management Applications

LMNG – Little Missouri National Grassland

NGPN – Northern Great Plains Inventory and Monitoring Network

NPS – National Park Service

NRCA – Natural Resource Condition Assessment

RMBO – Rocky Mountain Bird Observatory

SMUMN GSS – Saint Mary's University of Minnesota GeoSpatial Services

SWE – Snow Water Equivalent

THRO – Theodore Roosevelt National Park

USFS – United Stated Forest Service

USGS – United States Geological Survey

WCS – Weighted Condition Score

WICA – Wind Cave National Park

WNDD – Wyoming Natural Diversity Database

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation about the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA, including the report and accompanying map products, will help THRO managers to develop near-term management priorities; engage in watershed or landscape scale partnership and education efforts; conduct park planning (e.g., Resource Stewardship Strategy); and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key park resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota – GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and processes that are currently of the greatest concern to park management at THRO. The final project framework contains 17 resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved examining exisiting literature and short- or long-term datasets, as well as expertise from NPS and other outside agency or organization scientists to provide summaries of current condition and trends in featured resources. When possible, existing data for the established measures of each component is compared to designated reference conditions. A weighted scoring system was applied to calculate the current condition of the components. Weighted condition scores, ranging from zero to one, were divided into three categories of condition: low concern, moderate concern, and significant concern. These weighted condition scores help determine the overall current condition of each resource. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, as well as unpublished park information and perspectives of park resource managers, and present a current condition designation when appropriate. Each component assessment was subjected to review by THRO park resource managers and NPS Northern Great Plains Network Inventory and Monitoring specialists.

In a number of cases, data are unavailable or insufficient for many of the measures of the featured components in this assessment. In other instances, data that establishes reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. Thus, in these cases, it was not possible to assign condition for these components. Current condition was not able to be determined for 10 of the 17 components (58%) due to these significant data gaps.

For those components with more available data, the overall conditions assigned varied. For some components, enough data exist to determine a trend in condition over time; however, for others the lack of long-term or comparable data prevented the determination of trends. Several components were determined to be in good condition with a stable trend, including air quality, the prairie dog population, water quality, and fire. Flooding on the Little Missouri River in the

park was determined to have a condition of moderate concern but with a stable trend, meaning the condition is not believed to be degrading or improving from past conditions. Native grasslands and woody draws were also determined to be of moderate concern, but a lack of historical data does not allow for designating a trend in condition over time. A detailed discussion of these designations is presented in Chapter 5 of this report.

Several threats and stressors were identified as park-wide influences on the condition of resources in THRO. Those of primary concern include establishment of non-native and invasive species, increased oil and gas industry development, and air pollution, especially increased emissions from nearby oil, gas, and power plant development.

Major changes in vegetation communities, from native to more non-native species, could have a significant impact on the animal species that use these communities for habitat. A more complete understanding of the prevalence of non-natives in the different vegetation communities throughout the park would help managers strategize about potential management actions.

Land development around THRO is mainly associated with the growth and expansion of the oil and gas industry. This development has increased exponentially in western North Dakota and around THRO over the last decade. Such development affects different aspects of park resources, including impacts to viewsheds with the building of new structures that can be seen from various points in the park, impacts to soundscapes with increased industrial activity and vehicle traffic at development sites, and greater stresses to air quality from increased vehicle and industrial emissions.

This assessment serves as a review and summary of available data and literature for featured components in the park. The information presented here may serve as a baseline against which any changes in condition of components in coming years may be compared. Establishing a number of monitoring programs would begin to fill in data gaps for the resources viewed as important by THRO managers and would help managers better understand the current state of these resources throughout the park. Of those components that had sufficient available information, current condition was determined to be either good or of moderate concern. Understanding this can help managers prioritize management objectives and better focus conservation strategies.

Chapter 1 NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks". For these condition analyses they also report on trends (as possible), critical data gaps, and general level of confidence for study findings. The resources and indicators emphasized in the project work depend on a park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators for that park, and availability of data and expertise to assess current conditions for the things identified on a list of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement, not replace, traditional issue and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

NRCAs Strive to Provide…

Credible condition reporting for a subset of important park natural resources and indicators

Useful condition summaries by broader resource categories or topics, and by park areas

- are multi-disciplinary in scope[1]
- employ hierarchical indicator frameworks[2]
- identify or develop logical reference
- conditions/values to compare current condition data against[3,4]
- emphasize spatial evaluation of conditions and GIS (map) products[5]
- summarize key findings by park areas[6]
- follow national NRCA guidelines and standards for study design and reporting products

Although current condition reporting relative to logical forms of reference conditions and values is the primary objective, NRCAs also report on trends for any study indicators where the underlying data and methods support it. Resource condition influences are also addressed. This can include past activities or conditions that provide a helpful context for understanding current

[1] However, the breadth of natural resources and number/type of indicators evaluated will vary by park.
[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition reporting by broader topics and park areas.
[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions.
[4] Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers").
[5] As possible and appropriate, NRCAs describe condition gradients or differences across the park for important natural resources and study indicators through a set of GIS coverages and map products.
[6] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on a area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

park resource conditions. It also includes present-day condition influences (threats and stressors) that are best interpreted at park, watershed, or landscape scales, though NRCAs do not judge or report on condition status per se for land areas and natural resources beyond the park's boundaries. Intensive cause and effect analyses of threats and stressors or development of detailed treatment options is outside the project scope.

Credibility for study findings derives from the data, methods, and reference values used in the project work—are they appropriate for the stated purpose and adequately documented? For each study indicator where current condition or trend is reported it is important to identify critical data gaps and describe level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject matter experts at critical points during the project timeline is also important: 1) to assist selection of study indicators; 2) to recommend study data sets, methods, and reference conditions and values to use; and 3) to help provide a multi-disciplinary review of draft study findings and products.

NRCAs provide a useful complement to more rigorous NPS science support programs such as the NPS Inventory and Monitoring Program. For example, NRCAs can provide current condition estimates and help establish reference conditions or baseline values for some of a park's "Vital Signs" monitoring indicators. They can also bring in relevant non-NPS data to help evaluate current conditions for those same Vital Signs. In some cases, NPS inventory data sets are also incorporated into NRCA analyses and reporting products.

In-depth analysis of climate change effects on park natural resources is outside the project scope.

However, existing condition analyses and data sets developed by a NRCA will be useful for subsequent park-level climate change studies and planning efforts.

NRCAs do not establish management targets for study indicators. Decisions about management targets must be made through sanctioned park planning and management processes. NRCAs do provide science-based information that will help park managers with an ongoing, longer term effort to describe and quantify their park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource

Important NRCA Success Factors…

Obtaining good input from park and other NPS subjective matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

planning[7] and help parks report to government accountability measures[8].

Due to their modest funding, relatively quick timeframe for completion and reliance on existing data and information, NRCAs are not intended to be exhaustive. Study methods typically involve an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in our present data and knowledge bases across these varied study components.

NRCAs can yield new insights about current park resource conditions but in many cases their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is credible and has practical uses for a variety of park decision-making, planning, and partnership activities.

Over the next several years, the NPS plans to fund a NRCA project for each of the ~270 parks served by the NPS Inventory and Monitoring Program. Additional NRCA Program information is posted at: http://www.nature.nps.gov/water/NRCondition_Assessment_Program/Index.cfm.

NRCA Reporting Products…

Provide a credible snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)

Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)

Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public
("resource condition status" reporting)

[7] NRCAs are an especially useful lead-in to working on a park Resource Stewardship Strategy (RSS) but study scope can be tailored to also work well as a post-RSS project.

[8] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

Chapter 2 Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

Theodore Roosevelt National Park (THRO) consists of three separate units: North Unit, Elkhorn Ranch, and South Unit. THRO was first protected as the Roosevelt Regional State Park in 1934, when the Civilian Conservation Corps (CCC) camps were sponsored by the North Dakota State Historical Society and the National Park System (NPS 1986). On 25 April 1947, the state park became Theodore Roosevelt National Memorial Park with the passage of Public Law 38 (61 Stat. 52) (NPS 1986). The North Unit and the land west of the Little Missouri River, including the Elkhorn Ranch Unit, the petrified forest, and some land that was earlier designated "recreation demonstration area" (RDA), were added to the park in 1948 (NPS 1986). Several years later, on 10 November 1978, the memorial park was designated Theodore Roosevelt National Park by Public Law 95-625 (92 Stat. 3467) (NPS 1986).

2.1.2 Geographic Setting

THRO encompasses 28,509 hectares (70,447 acres) (NPS 2011a), making it one of the larger national parks in the Northern Great Plains Network (NGPN) (Gitzen et al. 2010). The park consists of three units, the North Unit (9,740.91 hectares [24,070.32 acres]), the South Unit (18,679.71 hectares [46,158.57 acres]), and the Elkhorn Unit (88.22 hectares [218 acres]) (NPS 1986, NPS 2011a). All units are connected by the Little Missouri River (NPS 1986). The park contains 33.79 km of the Little Missouri River, and 432.59 km of intermittent streams (Gitzen et al. 2010). THRO is bordered on the south by the town of Medora, in Billings County with a population of 783 people (U.S. Census 2010). The Little Missouri National Grassland, managed by the U.S. Forest Service, are adjacent to THRO.



Photo 1. River Bend Overlook, North Unit of THRO (Photo by Shannon Amberg, SMUMN GSS, 2010).

The park is covered by predominantly native grassland (40%), forest (21%), barren ground (21%), and shrubland (14%) (Von Loh et al. 2000). However, over 400 species of plants and trees have been identified in the park, several of which are considered sensitive or vulnerable (NPS 2012a).

THRO is a Class I airshed authorized by the Clean Air Act, and is one of the few national parks to maintain long-term air quality monitoring stations within the park (Gitzen et al. 2010). The NPS and state agencies operate some of the monitoring stations in THRO and those found in the NGPN (Pohlman and Maniero 2005).

The geologic features within the park were formed by river and rainfall erosion, uplift, and sediment deposition from the Black Hills and the Rocky Mountains (KellerLynn 2007, Tweet et al. 2011). The soils in the Great Plains are commonly nitrogen poor and, for a majority of the year, retain little moisture (Seastedt 1995).

THRO has several geological features of interest. Most of the park is located on the unglaciated Missouri Plateau, which gives the park its appearance (including the mountains, plateaus, and badland formations) (Trimble 1993, as cited by NPS 2007a). The North Unit of the park has the "third largest concentration of petrified wood in the United States" (NPS 2011b, as stated by the superintendent, Valerie J. Naylor). The park's other geological features include concretions and cap rocks (photo 2), glacial erratics, oxbows, pediments, sheet-wash erosion, sandstone and silcrete, and terraces (NPS 2007a).



Photo 2. Concretion formations in the North Unit of THRO (Photo by Shannon Amberg, SMUMN GSS, 2010).

THRO has a variable climate with windy conditions year-round (NPS 2011c). The park experiences warm summers with high temperatures above 30°C (86°F) (May through September). In the winter months (December through February), the low temperatures have been known to drop below -18°C (0°F). The majority of precipitation occurs from mid to late spring with an annual average of 37 cm (14.6 in) a year (Table 1; NPS 2011c).

Table 1. Monthly temperature and precipitation normals (1948-2010) for THRO (Station 325813, Medora, North Dakota) (High Plains Regional Climate Center 2011).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°C)													
Max	-2.7	1.1	6.4	14.6	21.2	26.2	30.7	30.5	23.9	16.3	6.4	-0.4	14.5
Min	-16.7	-13.1	-7.8	-1.4	4.8	9.9	12.7	11.6	5.3	-0.83	-7.5	-13.9	-0.39
Average Precipitation (cm)													
Total	0.9	0.9	1.6	3.3	5.8	7.9	5.3	3.4	3.4	2.4	1.3	0.9	37.4

2.1.3 Visitation Statistics

On average, THRO receives about 523,885 visitors annually, who come to participate in activities such as sightseeing, hiking, and camping (NPS 2011d). In 2010, the park had an annual visitor count of 623,748 (NPS 2011a). The park receives the majority of visitors during the summer months (June through August) with numbers in the 100,000s (NPS 2011a).

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

According to Griffith (2010), THRO falls into the Northwestern Great Plains ecological region. This region alone has the widest latitudinal range in North America, and it is characterized by its semiarid climate, grasslands, lack of forests, and moderately short topographic features (CEC 1997). The Great Plains region is habitat for an unusually large amount of sensitive, threatened, and endangered species (CEC 1997).

THRO is located approximately midway along the length of the Little Missouri River watershed, which stretches from northeastern Wyoming into central North Dakota; the Little Missouri River flows primarily northeast from the headwaters northeastern Wyoming into North Dakota and terminates at the Sakakawea Reservoir in central North Dakota (Berkley et a. 1998). The Little Missouri River flows through nine miles of the park's South Unit, 14 miles of the North Unit, forms the boundary of the Elkhorn Unit, and bisects the park's designated wilderness (Berkley et al. 1998). The Little Missouri River is entirely free-flowing and represents the major surface water resource throughout the park (Berkley et al. 1998).

2.2.2 Resource Descriptions

THRO is located in a grassland biome. The grasslands of the Great Plains region are also known as mixed prairie. Dominant plant species in the park include blue grama (*Bouteloua gracilis*), green needlegrass (*Nassella viridula*), western wheatgrass (*Pascopyrum smithii*), and needle-and-thread (*Hesperostipa comata*) (Von Loh et al. 2000).

The park supports 34 different species of mammal, 151 bird species, 21 fish species, and 15 herpetofauna species (NPS 2012b). Porcupine (*Erethizon dorsatum*), beaver (*Castor canadensis*), black-tailed prairie dogs (*Cynomys ludovicianus*), prairie sharptail grouse (*Pedioecetes phasianellus*), great horned owl (*Bubo virginianus*), and golden eagle (*Aquila chrysaetos*) are just a few mammal and bird species found in the park (NPS 1999, NPS 2012b). THRO is one of the few NPS-managed areas in the western United States where there is a free-roaming feral

horse (*Equus* caballus) population (NPS 2011e). These feral horses have been found in western North Dakota for decades; their existence has dated back to the mid 19th century (NPS 2011e). THRO has a large variety of ungulate species, including bison (*Bison bison*), elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), bighorn sheep (*Ovis canadensis*), and pronghorn (*Antilocapra americana*) (NPS 1994, NPS 2012b).

2.2.3. Resource Issues Overview

Air contamination is a concern for the park staff at THRO. Serious air pollutants in the region include nitrate, sulfate, and ammonium because their levels have increased (Pohlman and Maniero 2005). The push to develop and obtain more gas and oil resources is the main factor influencing this increase in Montana, North Dakota, and Wyoming (Pohlman and Maniero 2005). In the past, the air quality in THRO has been excellent, with the exception of a few cases, which were caused by wildfires and were short-lived (NPS 2008).

Several non-native plant species have become problematic in the park. These include leafy spurge (*Euphorbia esula*), yellow sweetclover (*Melilotus officinalis*), brome grasses (*Bromus* sp.), Canada thistle (*Cirsium arvense*), Kentucky bluegrass (*Poa pratensis*) and crested wheatgrass (*Agropyron cristatum*) (NPS 1999, 2008). The spread of exotic plant species has been known to alter fire regimes by increasing leaf litter layers. When applicable, THRO managers intend to restore the fuel loads as well as the plant community and composition to ranges of natural variability using prescribed fires and various chemical and mechanical exotic plant treatment methods (NPS 2008).

<u>Managed Species</u>

Bison, elk, and feral horses are three intensively managed species in THRO. Fences surrounding each of the North and South Units of the park serve two purposes: to keep the park's bison and feral horses within park boundaries, and to keep domestic cattle on surrounding lands from entering the park (NPS 1994). Due to the management intensity, park staff has opted not to assess these species as traditional components in the NRCA.

Bison

For almost 10,000 years, plains bison (Photo 3) were a keystone element of the Great Plains, providing food and materials for Native Americans and the European settlers that arrived in the 18th and 19th centuries (NPS 2006). It is not certain how many bison were present in North America prior to European settlement, but estimates are in the millions (NPS 2009). Today, there are a few remnant wild populations in North America, but most populations occur in parks, preserves, or on private ranches. Currently only 11 bison herds exist in federally protected lands (Halbert et al. 2007). There are now two bison herds in THRO, one in the North Unit of the park and one in the South



Photo 3. Plains bison in THRO (Photo by Shannon Amberg, SMUMN GSS, 2010).

Unit. In 2000-2001, the park estimated the bison population at 312 and 371 bison in the North and South Units respectively, and population estimates for 2009 were about 300 for both the North and South Units.

Marlow et al. (1984) determined a bison carrying capacity between 200-500 animals in the South Unit of THRO and 100-250 animals in the North Unit, based on factors such as potential droughts, overgrazing, and competition with other grazing ungulates for resources. The lack of natural predators and large area of available open space has forced management to implement culling to maintain a healthy population. Bison occasionally are exported to other national parks, Native American tribal lands, or zoos, or are transferred through the Inter-Tribal Bison Cooperative and other federal, state and non-profit entities (Dratch and Gogan 2010). A total of 2,992 bison were removed from THRO between 1962 and 2008 (NPS 2009).

Roundups of the bison herds take place within each unit of the park every 3-5 years (NPS 2009, M. Oehler, pers. comm., 2011). After examination of age, weight, sex, and presence of disease, each animal is assigned an identification number, and the number of animals to remove is determined according to a forage allocation model. Genetic variability is a major management goal of the NPS as inbreeding can cause decreased heterozygosity, adaptive response (ability of herd to adapt to environmental changes), and population viability (Franklin 1980, as cited by Halbert et al. 2007). Monitoring and management of bison populations are expected to continue in THRO.

Elk

Elk (Photo 4) resided throughout the North Dakota Badlands until extirpation in the late 1800s (NPS 2010). In 1985, the NPS reintroduced 47 elk from Wind Cave National Park (WICA) to the South Unit of THRO. Following reintroduction, the elk population grew rapidly, exceeding the NPS-established maximum population threshold by 1993 (NPS 2010). In 2010, THRO developed an Elk Management Plan and Environmental Impact Statement to guide management actions of the large herd and mitigate negative effects on other park resources.



Photo 4. Bull elk with cows in THRO (NPS Photo).

The Elk Management Plan established a goal of 100-400 individuals in the elk herd. This goal allows maintenance of the mixed-grass prairie system in a lightly grazed state (NPS 2010). The estimated herd population size in 2010 in THRO was approximately 950 individuals; at this population size, many different negative outcomes become possible. High-density elk populations often exhibit poor body condition and reproductive success. In addition, added stress on plant communities causes decreased forage availability, which in turn affects other species in the population's ecosystem. The large elk population and the looming negative effects on the THRO ecosystem prompted action in the form of a volunteer-based elk reduction effort.

From October 2010 to January 2011, park staff assisted volunteers by leading them to elk and instructing them to harvest appropriate animals (adult cow elk). The initial reduction effort resulted in the removal of 406 animals from the park. In the fall of 2011, another volunteer-based reduction resulted in the removal of 462 animals. The park intends to monitor carefully elk population numbers and demographics in the future; this information then will be used to tailor specific reduction efforts carried out by NPS employees.

Feral Horses

Modern horses (*Equus*) (Photo 5) evolved on the North American continent but became extinct nearly 10,000 years ago around the end of the Pleistocene epoch (NPS 2011d). Horses were re-introduced to North America in the 16th century by Spanish explorers; Native Americans spread these animals across the continent, with horse populations eventually numbering in the thousands of individuals (McLaughlin 1989, NPS 2011d). The herd at THRO is a small, isolated population, which is comprised of descendents of local ranch stock that either escaped captivity or were abandoned by their owners. Marlow et al. (1992) examined feral horse distribution and habitat use in the park and found that the herd generally isolated itself to the southeastern and eastern portion of the South Unit.

When THRO was established in 1947, several hundred horses were present in the park (McLaughlin 1989). Park land was used by area ranchers to graze their horses in the 1940s and 50s; during this time horses were considered a trespass livestock and removal was a priority. The park's goal was to eliminate horses from the South Unit (McLaughlin 1989). The decision was made in the late 1960s to maintain the horse population as a cultural demonstration herd at a maximum of about 40 horses (NPS 1978). In 1978, the population grew to 65-70 horses in the fenced South Unit. Marlow et al. (1992) calculated a feral horse carrying capacity of 50 to 90 individuals for the South Unit of THRO, as a larger population would possibly lead to significant decline in certain forage plant species. The feral horse herd is managed now as a cultural demonstration herd to preserve the historical context of the horses' presence in the park (NPS 2011d; Oehler, pers. comm., 2011). The current target population size is between 50-90 individuals (NPS 2011d). However, the herd currently numbers 135 individuals (Oehler, pers. comm., 2011).



Photo 5. Feral horses in the South Unit of THRO (NPS photo).

To guard against overpopulation, the herd is rounded up every 3-5 years, during which time horses are selected to be removed from the herd and sold at auction. In addition, THRO wildlife biologists have recently initiated field trials on a temporary contraception vaccination for females aged 2 years and older (Oehler, pers. comm., 2011). The park plans to continue management of feral horse populations in order to limit herd size.

Other Ungulates
Rocky Mountain bighorn populations are also present in the park; the park plans to restore bighorn population sizes, but fences for bison and feral horses may limit the bighorn to less suitable habitat (NPS 1994). Deer and pronghorn populations are also present; however, the population sizes primarily are monitored and occasionally surveyed (NPS 1994). As for the predatory mammal species, the park monitors these populations for vector-borne diseases (NPS 1994).

Viewshed
A viewshed is the area that is visible from a particular location. The National Park Service Organic Act (16 U.S.C. l) implies the need to protect the viewsheds of National Parks, Monuments, and Reservations. At THRO, viewsheds are of particular importance because a primary reason visitors frequent the park is to view the landscape. Views from within the park are expansive in some areas, with NPS and non-NPS lands being the primary visible features. Currently, the oil and gas industry is expanding in western North Dakota, which is a cause of concern for the viewsheds in THRO, due to rapidly expanding industrial development.

Due to the current dynamic nature of the landscape surrounding the park, a detailed viewshed analysis is not appropriate for this document. The evidence of oil and gas development is increasing in North Dakota and this makes the viewshed from the park variable in the short-term. Therefore, conducting an all-inclusive viewshed analysis at this time is not appropriate, because the data would likely be irrelevant quickly.

Even though a park-wide viewshed analysis is not appropriate at this time, THRO regularly uses viewshed analyses to provide specific data regarding anthropogenic development concerns. Developed data enrich the understanding of anthropogenic effects on the park's viewsheds. These data allow park management to make informed decisions and pursue appropriate actions regarding development.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance
THRO has several management plans, including the most recent Elk Management Plan (2010), the Centennial Plan (2007), the Fire Management Plan (2008), the Water Resources Management Plan (1998), the Resource Management Plan (1994), and the General Management Plan (1987). Each plan has its own objectives and goals to improve the park's resources and increase public awareness.

The Elk Management Plan was proposed to ensure long-term preservation and protection of park resources. When the elk population increased after its reintroduction, the non-managed herd strained plant communities by over grazing; as of 2010, there were approximately 900 elk in the South Unit of the park (NPS 2010). The objectives for the elk management plan are as follows:

- Prevent negative effects to the biotic and abiotic components of the park and adjacent lands.
- Construct and execute actions parallel to the direction and limits set by the NPS Management Policies 2006.

- Determine indicators to assist and direct the management of elk.
- Maintain the long-term viability of the elk population while limiting herd manipulation in the park.
- Incorporate management flexibility to take action after obtaining information on disease or other factors that may adversely affect the elk population.
- Offer opportunities to educate the public about the challenges of elk management when limiting that management to park land.
- Collaborate with the stakeholders (e.g., federal agencies, state agencies, and private companies) by sharing data on the elk population and it management.
- When applicable, improve the hunting opportunities on the areas of land surrounding the park.

In 2007, the park celebrated its 60th anniversary. Its theme was "60 years of Preservation, Tradition, and Inspiration" (NPS 2007b). Now, the park's plan for the next decade is to revise its mission and purpose to be connected better with the American public (NPS 2007b). The goals for the centennial plan are as follows:

- Enhance the condition of the park by improving its resources and assets.
- Educate and motivate children to give back to the environment by becoming future conservationists.
- Alter park operations to minimize adverse impacts on the environment.
- Inspire the public to become environmentally conscious.
- Encourage all to participate in a shared environmental stewardship.
- Focus national, regional, and local tourism efforts to reach diverse audiences and young people and to attract visitors to lesser-known parks.
- Create stimulating media to introduce and excite youth and their families to the national parks.

The THRO Wildland Fire Management Plan (NPS 2008) was an addition to the resource management plan. Fire is an important factor that plays a large role in the development of most terrestrial ecosystems in North America (NPS 2008). This plan is becoming more intensive and of greater importance in the park; the objectives of the Wildland Fire Management Plan (NPS 2008) are:

- Decrease the frequency and severity of fires caused by humans.
- Promote the occurrence of wildland fire in ecosystems dependent on its effects.
- Control and utilize fire as a management tool.
- Protect the park components (e.g., life, property and resources) from adverse effects of unwanted fire.

- Prevent adverse effects from fire suppression on the ecosystem.

THRO created the Water Resources Management Plan in 1998 with the purpose of guiding park managers in assessing the water resources (NPS 1998). The park, being located in a semiarid ecosystem of the northern Great Plains, is particularly concerned with their water resources (Berkley et al. 1998). Maintaining plant and animal community diversity is dependent on water availability. The Water Resources Plan (1998) objectives include:

- Manage the park's water resources to maintain an optimal level of species diversity and native plant composition.
- Revive and protect the park's natural springs and developed wells for native wildlife.
- Assure that any development within the park will not negatively impact the water resources and water-dependent environments.
- Become knowledgeable about water quality to be able to actively contribute to the local and state water management plans while also striving for the optimal level of water quality standards for the park.
- Protest the water rights applications that would negatively impact the park and contribute to water rights adjudications involving the park lands so that the NPS water rights and water-related resources remain protected.
- Obtain a sufficient amount of information to adequately manage the park's water resources while also following the NPS inventory and monitoring requirements.
- Follow NPS Floodplain Management Guidelines to insure minimal damage (e.g., injury, property) while also encouraging the occurrence of natural hydrologic and geomorphic processes of floods.
- Create and update maps of the wetlands and riparian areas to make it easier to monitor and maintain ideal habitat conditions for the park's wildlife.
- Educate the public and increase their awareness of the adverse effects done on water resources due to human impacts.
- Protect the native fish species (e.g., rare, threatened, and endangered) found in the park and surrounding areas by creating and applying effort to a cooperative management plan.
- Identify and assess the NPS water-related resources and any factors outside the park that may cause an impact.
- Ensure minimal impact on surface and ground water resources when permitting oil and gas operations done on lands adjacent to the park.

The Resource Management Plan (NPS 1994) is a supporting document of the original General Management Plan (NPS 1987), so that it would include both the 83 natural and 17 cultural resources important to the park (NPS 1994). The plan identifies resources and their components and indicates measures to be taken and methods to be used in management. The park's goal is to restore and maintain the resources and processes that form the park's ecosystem (NPS 1994). The Resource Management Plan had the following objectives:

- Create a tactical plan that recognizes and establishes priorities for resource management and research needs.
- Manage the park as a natural badlands ecosystem, influenced by human activities over time, allowing natural processes to continue.
- Prevent negative impacts on essential resources of the park by bearing in mind the effects that visitors and park managers may have on the natural and cultural resources with everyday activities.
- Create an information system for the Little Missouri Badlands ecosystems to protect the natural resources and ecological processes native to each ecosystem.
- Ensure the roadways are maintained and in satisfactory condition to make resource management (e.g., natural and cultural) more efficient.
- Follow all appropriate laws, NPS guidelines, and management plans to properly manage natural and cultural resources inside the park.
- Maintain resources in the park that are historically connected with Theodore Roosevelt (e.g., his life and experience in the Badlands).
- Guarantee that a sufficient collections management program is developed for the park's natural and cultural resources.

One of the earliest management plans for THRO is its General Management Plan (NPS 1987). The General Management Plan provides the necessary strategies to guide management, use, and development of the park for the next 10 years (NPS 1987). This plan addresses resource management (e.g., flood protection, bison management, historic building preservation, and visitor use needs) (NPS 1987).

2.3.2 Status of Supporting Science

The Northern Great Plains Inventory and Monitoring Network (NGPN) identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. In 2010, the NGPN completed and released a Vital Signs monitoring plan (adapted from Gitzen et al. 2010, Table 2).

Table 2. NGPN Vital Signs selected for monitoring in THRO (adapted from Gitzen et al. 2010).

Category	Vital Signs Currently Monitored by NPGN parks, Other NPS Entities, or Other Federal or State Agencies	Vital Signs for Which NGPN Will Develop and Implement Monitoring Protocols in the Future
Air and climate	• Ozone • Wet and dry deposition • Visibility and particulate matter • Air contaminants • Weather and climate	
Geology and soils		• Stream and river channel characteristics
Water	• Surface water dynamics	• Surface water chemistry • Aquatic contaminants • Aquatic microorganisms • Aquatic macroinvertebrates
Biological integrity	• Exotic plant early detection • Raptors • Prairie dogs • Ungulates • Riparian lowland plant communities • Upland plant communities	• Land birds
Human use	• Treatments of exotic infestations • Visitor use	
Landscapes (ecosystem pattern and process)	• Fire and fuel dynamics,	• Land cover and use • Extreme disturbances • Soundscape • Viewshed • Night sky

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Chapter 3 Study Scoping and Design

This NRCA is a collaborative project between the National Park Service (NPS) and Saint Mary's University of Minnesota Geospatial Services (SMUMN GSS). Project stakeholders include the THRO resource management team and NGPN Inventory and Monitoring Program staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1 Preliminary scoping

A preliminary scoping meeting was held on 31 August 2010. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the THRO NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to THRO managers. Certain constraints were placed on this NRCA, including the following:

- Condition assessments are conducted using existing data and information.
- Identification of data needs and gaps is driven by the project framework categories.
- The analysis of natural resource conditions includes a strong geospatial component.
- Resource focus and priorities are primarily driven by THRO resource management.

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid THRO resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including: THRO resource staff, IRMA (Integration of Resource Management Applications), Inventory and Monitoring Vital Signs, NGPN staff, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.

- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.

- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.

- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.

- Utilize "gray literature" and reports from third party research to the extent practicable.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

As defined by SMUMN GSS in the NRCA process, a "framework" is developed for a park or preserve. This framework is a way of organizing, in a hierarchical fashion, bio-geophysical resource topics considered important in park management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

"Components" in this process are defined as natural resources (e.g., prairie dogs), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more "measures" that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain "stressors" which are also considered during assessment. A "stressor" is defined as any agent that imposes adverse changes upon a component. These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation (adapted from GLEI 2010).

During the THRO NRCA scoping process, key resource components were identified by NPS staff and are represented as "components" in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, of greatest concern or of highest management priority in THRO. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A "reference condition" is a benchmark to which current values of a given component's measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an

established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., an elk herd of less than 200 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference in which human activity and disturbance was not a major driver of ecological populations and processes, such as "pre-cattle/sheep grazing" or "pre-fire suppression." In cases where reference conditions were less clearly defined, peer-reviewed literature, ecological thresholds, and consultation with resource staff were used to define appropriate reference conditions more clearly. In these instances, efforts were made to utilize existing research and documentation of historical conditions to identify the range of natural variation for reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science's "State of Our Nation's Ecosystems 2008" (Heinz Center 2008). Key resources for the park were adapted from the NGPN Vital Signs monitoring plan (Gitzen et al. 2010) and natural resource reports from THRO. This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The NRCA framework was finalized in August 2011 following acceptance from NPS resource staff. It contains a total of 17 components (Table 3) and was used to drive analysis in this NRCA. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions. The THRO framework also contains several components that are contextually important natural resource topics in the park; these include feral horses, bison, elk, and viewshed. During scoping, it was agreed that these topics would be addressed in Chapter 2 of the report.

Table 3. THRO natural resource condition assessment framework.

THRO National Park
Natural Resource Condition Assessment Framework

Component	Measures (Significance level)	Stessors	Reference Condition
Ecosystem Extent and Function			
Disturbance Regimes			
Fire	Frequency (3), severity (2), number of acres burned (2-3), fire origin (1-2)(e.g., prescribed, lightning, human-caused, etc.), intensity (2), seasonality (2)	Climate change, fire suppression, development	Management objectives for the park as stated in the fire management plan
Erosion/wind and water	Changes in landscape features (3), amount of material removed (erosion rates) (3)	Increase in frequency of heavy rain or wind events, decreased soil moisture over time, climate change	No established reference condition
Flooding (Little Missouri)	Frequency (3), magnitude (3), Snowpack (3), Duration (2), effects of upstream water withdrawal on summer flows (3)	Drought conditions, climate change, water retention in stock dams (in upriver tribs and draws), drawdown from nearby development (golf course)	Range of variation since the beginning of data collection (1904 and 1935 respectively for Medora and Watford City, ND)
Biotic Composition			
Ecological Communities			
Native grasslands	Species composition (3), distribution (3), prevalence of non-natives (3)	Non-native/exotic species, changes in fire regime, juniper encroachment, Grazing effects	Ideally, composition and distribution of grasslands prior to European settlement; Hansen et al. (1984) and Hansen and Whitman (1938)
Juniper forests (slope forests)	Density and distribution (both rated as 3)	Non-native/exotic species, fire	Ideally, composition and distribution of juniper forests prior to European settlement; Ralston (1960) and Von Loh et al. (2000)
Floodplain forests	Species composition & abundance (3), changes in species distribution (3), Cottonwood Woodland Area-Age Distribution (3), non-native species abundance (3)	Non-native/exotic species, changes in flooding regime, juniper encroachment, ice jams impacting streambanks	Ideally, composition and distribution of floodplain woodlands prior to European settlement; Girard (1989), Everitt (1968), Von Loh et al. (2000), Johnson (1994),
Woody draws	Species composition & abundance (2), distribution (3), prevalence of non-natives (2)	Non-native/exotic species, ungulate foraging, browsing/grazing effects, Disease, EAB	Ideally, composition and distribution of woody draws prior to European settlement; Hansen et al. (1984)
Upland shrubland communities	Species composition (2), distribution (including changes)(3), prevalence of non-natives (2)	Non-native/exotic species, disease (Dutch elm; Emerald ash borer), browsing/grazing effects,	Ideally, composition and distribution of these communities prior to European settlement; Hansen et al. (1984)
Aquatic communities	Diversity and abundance of native fish (3), Diversity and abundance of macroinvertebrates (2)	Non-natives/exotic species, changes in water quality	The range of abundance and diversity of native fish and macroinvertebrates in the park; cross-reference of historic fish lists

	Component	Measures (Significance level)	Stessors	Reference Condition
Grazing animals				
	Prairie dogs	Extent of dog colonies (3)	Disease (plague), food availability	No established reference condition
Birds				
	Breeding Birds	Species richness (3), number of species of conservation concern (2), raptor species richness (2)	Loss of forest habitat (cottonwoods and juniper encroachment in upland habitats)	The characteristics of the breeding bird population from the nearby Little Missouri National Grassland (LMNG), established bird routes similar to routes recently
Environmental Quality				
	Air Quality	Mercury deposition (3), ozone (3), nitrogen & sulfur deposition (3), visibility (3), particulate matter (3)	Development of coal power plants; oil and gas development; smoke from wildfires and agricultural burning	EPA standards for Class I air shed
	Water Quality	Temperature (3), turbidity (3), specific conductance (3), sensitive macroinvertebrate species (3), pH (3), fecal coliform (3)	Erosion, livestock ranching, development up stream (specifically, the effects of the golf course upstream on WQ in park), nutrients	EPA water criterion; Water Resources Division water criterion; North Dakota Department of Health water criterion
	Soundscape	Occurrence of human-caused and unnatural sounds (3), natural ambient sound levels (1)	Oil drilling and other development, road traffic (especially near wilderness and Elkhorn Ranch site)	A natural experience, or a soundscape not influenced by unnatural sounds
	Dark night skies	V magnitude (3), ambient light pollution (3)	Point source light pollution, particulates, air quality	Absence of anthropogenic light pollution in accordance with National Park Service management policies
Physical Characteristics				
Hydrologic & Geologic				
	Surface Water Availability	Precipitation (2), prevalence (locations) of seeps and springs (2), flow rates of man-made water developments (2)	Juniper encroachment, water retention in stock dams, ice jamming (impact to streambank and veg), flooding (or lack thereof),	For precipitation -- historic period of record (pre-2000) for each of the three weather stations surrounding THRO; no established reference condition for prevalence or flow
	Paleontological Features	Distribution and abundance (3), protection of collections (2)	Theft, decay due to exposure from erosion, degradation due to development	No established reference condition

3.2.2 General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study, however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time THRO staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. GIS data were provided by NPS staff (NGPN and THRO). Access was also granted to NPS online data and literature sources, such as NatureBib, NPSpecies, and IRMA . Additional data and literature were also acquired through online bibliographic literature searches and inquiries on various state and federal government websites. Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality regarding the resource components identified at the scoping meeting.

Data Development and Analysis

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available and recommendations from NPS reviewers and sources of expertise including NPS staff from THRO and NGPN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

Scoring Methods and Assigning Condition

A set of measures are useful in describing the condition of a particular component, but all measures may not be equally important. A "significance level" represents a numeric categorization (integer of 1-3) of the importance of each measure in explaining the condition of the component; each significance level is defined in Table 4. This categorization allows measures that are more important for determining condition (higher significance level) of a component to be more heavily weighted in calculating an overall condition.

Table 4. Scale of measure significance used in determining overall condition.

Significance Level (SL)	Description
1	Measure is of low importance in defining the condition of this component.
2	Measure is of moderate importance in defining the condition of this component.
3	Measure is of high importance in defining the condition of this component.

After each component assessment is completed (including any possible data analysis), a condition level is calculated for each measure. This is based on a 0-3 integer scale and reflects the data mining efforts and communications with park experts (Table 5).

Table 5. Scale used in determining condition level of individual measures.

Condition Level (CL)	Description
0	Of **NO** concern. No net loss, degradation, negative change, or alteration.
1	Of **LOW** concern. Signs of limited and isolated degradation of the component.
2	Of **MODERATE** concern. Pronounced signs of widespread and uncontrolled degradation.
3	Of **HIGH** concern. Nearing catastrophic, complete, and irreparable degradation of the component.

After the significance levels (SL) and condition levels (CL) are assigned, a weighted condition score (WCS) is calculated via the following equation:

$$WCS = \frac{\sum_{i=1}^{\#\ of\ measures} SL_i * CL_i}{3 * \sum_{i=1}^{\#\ of\ measures} SL_i}$$

The resulting WCS value is placed into one of three possible categories: condition of low concern (WCS = 0.0 – 0.33); condition of moderate concern (WCS = 0.34 - 0.66); and condition of significant concern (WCS = 0.67 to 1.00). Figure 1 displays all of the potential graphics used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern and green circles a condition of low concern. Gray circles are used to represent situations in which there is currently insufficient data to make a statement about the condition of a component. The arrows inside the circles indicate the trend of the condition of a resource component. An upward pointing arrow indicates the condition of the component has been improving in recent times. A right-pointing arrow indicates a stable condition or trend and an arrow pointing down indicates a decline in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. A gray, triple-pointed arrow is reserved for situations in which the trend of the component's condition is currently unknown.

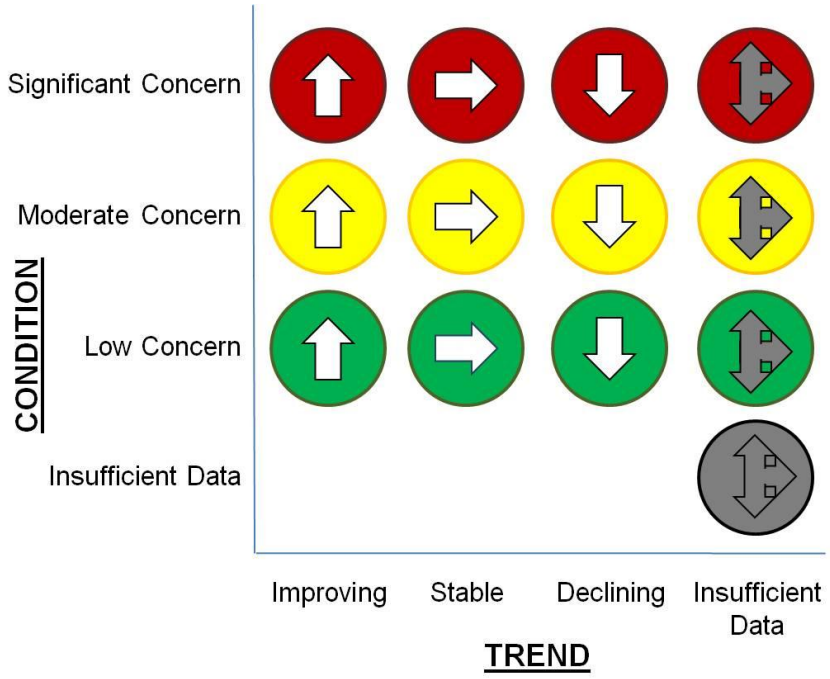


Figure 1. Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

Preparation and Review of Component Draft Assessments

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts and THRO staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literature are limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or conference call with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessment were forwarded to component experts for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by THRO resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and resource experts.

Format of Component Assessment Documents

All resource component assessments are presented in a standard format. The format and structure of these assessments is described below.

Description
This section describes the relevance of the resource component to the park and the context within which it occurs in the park setting. For example, a component may represent a unique feature of the park, it may be a key process or resource in park ecology, or it may be a resource that is of high management priority in the park. Also emphasized are interrelationships that occur among a given component and other resource components included in the broader assessment.

Measures
Resource component measures were defined in the scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions/Values
This section explains the reference condition determined for each resource component as it is defined in the framework. Explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or SMUMN GSS analysts, an explanation of how they were developed is provided.

Data and Methods
This section includes a discussion of the data sets used to evaluate the component and if or how these data sets were adjusted or processed as a lead-up to analysis. If adjustment or processing of data involved an extensive or highly technical process, these descriptions are included in an appendix for the reader or a GIS metadata file. Also discussed is how the data were evaluated and analyzed to determine current condition (and trend when appropriate).

Current Condition and Trend
This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps or plates that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. Due to their low importance, measures that are assigned a significance level of 1 do not receive an in-depth analysis and are not addressed in the current condition section. These measures are briefly discussed in the overall condition section of the document (see below).

Threats and Stressor Factors
This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressor based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps
This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff that wish to prioritize monitoring or data gathering efforts.

Overall Condition
This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise
This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component.

Literature Cited
This is a list of formal citations for literature or datasets used in the analysis and assessment of condition for the resource component. Note, citations used in appendices and plates referenced in each section (component) of Chapter 4 are listed in that section's "Literature Cited" section.

3.3 Literature Cited

Gitzen, R., M. Wilson, J. Brumm, M. Bynum, J. Wrede, J. Millspaugh, and K. Paintner. 2010. Northern Great Plains Network vital signs monitoring plan. Appendix B: conceptual ecological models. Natural Resource Report NPS/NGPN/NRR-2010/186. National Park Service, Fort Collins, Colorado.

Great Lakes Environmental Indicators Project (GLEI). 2010. Glossary, Stressor. http://glei.nrri.umn.edu/default/glossary.htm (accessed 9 December 2010).

The H. John Heinz III Center for Science, Economics, and the Environment. 2008. The state of the nation's ecosystems 2008: Measuring the land, waters, and living resources of the United States. Island Press, Washington, D.C.

Stoddard. J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. J. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications. 16(4):1267-1276.

Chapter 4 Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the 17 key resource components identified in the project framework. Each component assessment is organized into the following sections:

1. Description
2. Measures
3. Reference Condition
4. Data and Methods
5. Current Condition and Trend (including threats and stressor factors, data needs/gaps, and overall condition)
6. Sources of Expertise
7. Literature Cited

Components appear in the order they are listed in the project framework (Table 3):

4.1 Fire

4.2 Wind and water erosion

4.3 Flooding (Little Missouri River)

4.4 Native grasslands

4.5 Juniper forests

4.6 Floodplain forests

4.7 Woody draws

4.8 Upland shrubland communities

4.9 Aquatic communities

4.10 Prairie dogs

4.11 Breeding birds

4.12 Air quality

4.13 Water quality

4.14 Soundscape

4.15 Dark night skies

4.16 Surface water availability

4.17 Paleontological features

4.1 Fire

4.1.1 Description

Fire plays a major role in the ecological processes of North American prairies (Umbanhowar 1996), and historically, fires have been important naturally occurring events in THRO. These fires created natural disturbances that are important for maintaining healthy native plant communities in the prairie landscape. Mixed grass prairie, the primary vegetative cover in THRO, is approximately 0.61-1.22 m (2 to 4 ft) tall and grows quickly then dies back each year (NPS 2008). However, small trees and shrubs grow primarily on north aspects and within woody draws in the park. Fire in mixed grass prairie tends to limit the growth of trees and shrubs to places where finer fuels are less continuous and natural fire breaks exist (e.g., drier, rocky breaks, draws, and riparian areas) (NPS 2008).



Photo 6. Firefighters igniting a prescribed fire in THRO (NPS photo).

Fires that are naturally ignited (i.e., wildfires starting from lightning strikes) have been quickly suppressed for the majority of the park's existence (NPS 2010a). However, wildland fires are allowed to burn under certain conditions and in particular geographic areas of the park (e.g., fire management unit no. 2 in the North Unit of the park) as described in the Fire Management Plan (FMP) (NPS 2008). Fire was reintroduced to THRO in 1999 through prescribed burns, as a native plant community management strategy (NPS 2010a). Generally, THRO uses prescribed fire as a management tool for reducing fuel loads and stimulating the growth and health of native plant communities adapted to fire. However, each fire is set to accomplish individualized resource management objectives, which are identified for each fire (project) plan (NPS 2008). The rough terrain and low vegetation densities within the park, which consequently contribute to low fuel densities, limit the extent to which fire can spread (NPS 2010a). Prescribed fires account for the vast majority of the burned area in the park with approximately 93% of the total acreage burned within THRO from 1999 to 2010 (see Appendix A for information on individual fires).

4.1.2 Measures

- Frequency
- Severity
- Extent (area burned over time)
- Fire origin (e.g., prescribed, lightning, human-caused, etc.)
- Intensity
- Seasonality

- Change in native vegetation after prescribed fire

4.1.3 Reference Conditions/Values

Given that reference conditions (i.e., natural fire regime parameters) are not well established and that prescribed fire has nearly completely replaced natural fire starts in THRO, the fire management goals for the park will serve as the reference condition. As a part of fire management in THRO, the NPS can chose from multiple options: wildland fire suppression, wildland fire use, prescribed fire, and non-fire fuel treatments. The 2008 THRO fire management plan (NPS 2008) contains several objectives. The objectives relevant to the use of wildland fires to meet resource objectives include:

1) permit wildland fire use (lightning-caused) in areas where fire dependency has been scientifically proven and the fuel load and vegetation composition are within the range of natural variability,

2) use fire to restore plant community structure, composition and maintain cultural landscapes similar to those before European settlement,

3) allow wildland fire use within the constraints of policy (DO-18) and the Environmental Assessment/Assessment of Effect for the Fire Management Program of Theodore Roosevelt National Park.

Objectives relevant to the use of prescribed fires in order to meet management objectives include:

1) create and/or maintain defensible wildland fire use boundaries,

2) where applicable, restore fuel loads and plant community structure and compositions to ranges of natural variability comparable to pre-European settlement using prescribed fire and wildland fire use,

3) restore cultural landscapes similar to those present before European statement,

4) minimize the occurrence of unnaturally intense fires through reduction of hazard fuels by prescribed burning,

5) avoid prescribed fires and wildland fire use that would reduce air quality in Medora, North Dakota between Memorial Day and Labor Day,

6) train park staff and cooperators to conduct safe, objective-oriented prescribed fires and wildland fire use consistent with DO-18 requirements,

7) provide opportunities for public understanding of fire ecology principles, smoke management, and wildland fire program objectives, and

8) monitor and evaluate the effectiveness of the preserved fire program.

Generally, fire managers aim to reduce the cover and density of non-native forbs and grasses while encouraging native plant species growth; reduce the cover and density of silver sagebrush (*Artemisia cana*), and western snowberry (*Symphoricarpos occidentalis*); and reintroduce fire to fire-adapted ecosystems in the park. However, each fire is set to achieve a particular set of goals, and these may vary based on landscape position, fire history in the area, weather conditions (e.g., wind, temperature, and humidity), a variety of fuel dynamics, and availability of fire suppression resources such as trained personnel and materials.

4.1.4 Data and Methods

Fire data captured in GIS were obtained from the park for fires that occurred within and near THRO from 1946 to 2010 (NPS 2010b). The attributes from the GIS data were used to assess the past and current condition of fire. Monitoring Trends in Burn Severity (MTBS 2011) provided burn severity data for two fires, specifically highlighting the acreage burned in each severity class.

A series of prescribed fire monitoring reports were used to document the extent of most fires in THRO and the intensity and severity of each burn.

Wienk et al. (2007) provided a program review of the Northern Great Plains Fire Ecology Program, focusing on research efforts from 1997-2007. This report provided information about native and non-native vegetation responses to different fire treatments over time.

4.1.5 Current Condition and Trend

Fire in THRO is monitored and managed to achieve a number of objectives, including restoring fire-adapted ecosystems within the park (NPS 2008). The measures used to assess the current condition of THRO fire are compared to the historic fire regime and current management objectives for fire on the landscape. Fire frequency is assessed by comparing the current fire frequency with the historic frequency (prior to European settlement of the region). Historic fire frequency is often determined through examination of fire-scars on trees and stumps and by charcoal research. However, the primary vegetation type in THRO is mixed grass prairie and little fire scar data are available to determine historic fire frequency. In an investigation of fire history in Great Plains National Parks, Guyette et al. (2011) found little evidence of fire scars in juniper in the South Unit of THRO. The authors suggested that, because of reduced spread of fire on the landscape due to natural fire breaks, fire scar history methods would likely not be appropriate for describing the history of fire events in the region. Therefore, the pre-European settlement fire frequency (i.e., fire return interval), extent (area), severity, and seasonality are not well understood in THRO. Wright and Bailey (1980) estimate fire frequency in the northern mixed prairie of the Badlands to be 5 to 30 years. While most historic fires originated from lightning strikes, historic fire frequency estimates may be confounded by evidence, according to pioneer settlers' reports, that Native Americans intentionally and unintentionally set fires (NPS 1999).

Official documentation of fires did not begin in THRO until 1949 (NPS 1999). From 1949 to 1999, all fires were either accidental or caused by lightning; since 1999, the park has increasingly used prescribed fire as a management tool. Since then, resource managers and fire researchers have continued to record fire origin, frequency, area burned, and seasonality (dates) of fires. In many cases, only area burned has been recorded. These primarily have been

monitored through field reconnaissance and provide a basic assessment and overview of each fire (NPS 2003). Intensity and severity are assessed during prescribed burns and by examining the post-fire effects on the plant communities.

Frequency

Guyette et al. (2011) suggest pre-European settlement human-caused fires were rare in the THRO area because of the low human population density and the variation in topography, which inhibited natural fires. Wright and Bailey (1982) estimate that fire should burn every 5 to 10 years in prairie grasslands with rolling topography, and every 20 to 30 years in topography with breaks and rivers; the latter is characteristic of the THRO landscape.

THRO began recording fire dates in 1949 (NPS 1999). Natural wildfires (lightning-caused) are permitted to burn in areas where fire dependency is proven (NPS 2008). However, management suppresses all human-caused fires (non-prescribed) and does not allow natural wildfires to burn more than a few acres if there is direct threat to human life, private property, and park cultural resources (NPS 2008). Therefore, fire frequency or fire-return interval is primarily determined by burn prescriptions. However, because of the discontinuous, patchy fuel sources and sparsely vegetated topography within THRO, some sites may have mean fire-return intervals between 150 and 400 years (NPS 2003). NPS (1999) reported 90 fires in THRO between 1949 and 1993. Since that time, (through 2010) the number of fires has increased to 157, with most fires being prescribed burns. In1999, prescribed fire was used for the first time in THRO, and since then an average of 4.1 fires occurred per year. Refer to Table 6 for fire frequency, area, and origin by major burn unit. The fire history dataset containing fire origin (cause), area, date, name, and burn unit from 1946 to 2010 is available in Appendix A.

Table 6. Number of fires and area burned in THRO by origin and park unit (1984 to 2010) (NPS 2010b).

Origin / Burn Unit	Number of fires	Percent of fires[a]	Acres burned	Hectares burned	Percent of Area
Human	**25**	**23.5**	**78.0**	**31.6**	**1.0**
North Unit	6	18.9	8.0	3.2	
South Unit	19	27.1	70.0	28.3	
Lightning	**28**	**26.4**	**760.2**	**307.6**	**8.8**
Elkhorn Ranch Unit	1	25.0	158.0	63.9	
North Unit	10	31.2	76.5	31.0	
South Unit	17	24.3	525.7	212.7	
Prescribed	**49**	**46.2**	**7,813.7**	**3,162.1**	**90.0**
Elkhorn Ranch Unit	3	75.0	18.1	7.3	
North Unit	14	43.8	3,385.9	1,370.2	
South Unit	32	45.7	4,409.8	1,784.6	
Unknown	**4**	**<0.1**	**21**	**8.5**	**0.2**
North Unit	2	0.1	19.0	7.7	
South Unit	2	<0.1	2.0	0.8	
Totals:	**106**	**100.0**	**8,672.9**	**3,509.8**	**100.0**

[a] Percentages for origins use the park-wide total and each unit is calculated by the total within that unit.

THRO uses prescribed fire to meet goals for vegetation management and to mimic the natural historic fire regime as closely as possible. However, the number of prescribed fires that can

occur depends largely on the funding available each year. Thus, areas of THRO may not see fire for 100 to 200 years (R. Skalsky, pers. comm., 2011).

Severity

Fire (or burn) severity is a term used to describe the physical and chemical changes to the soil, the conversion of vegetation and fuels to inorganic carbon, and structural or compositional transformations that create new microclimates and species assemblages (Key and Benson 2006). Severity is measured by the amount of organic matter loss both above and below the surface of the ground after a fire (Keeley 2008).

One method for measuring burn severity is to compare LandSat imagery prior to and after a fire to determine a Differenced Normalized Burn Ratio (dNBR). The dNBR data, which represent continuous values, are separated into six categories. MTBS (2011b) classifies the six severity categories as unburned to low, low, moderate, high, increased greenness, and no data. According to MTBS (2011a), an analyst evaluates the dNBR data range and determines where significant thresholds exist to discriminate between severity categories. In Sorbel and Allen (2005), the accuracy of the dNBR method was tested by sampling Composite Burn Index (CBI) plots established on the ground in recently burned areas. CBI methods involve scoring burn severity based on 22 variables including soil cover/color change, duff and litter consumption, percent of colonizers, percent of altered foliage, and percent of canopy mortality (Sorbel and Allen 2005). A comparison of CBI scores and dNBRs for the same areas shows that dNBR is "a suitable measure and predictor of burn severity" (Sorbel and Allen 2005, p. 9). MTBS (2011b) provided burn severity data in which acreage of severity categories were derived for the Little Missouri II and Southeast Corner fires within THRO (Table 7).

Table 7. Burn severity for the Little Missouri II and Southeast Corner fires (MTBS 2011).

Year	Fire Name	Unburned to Low Severity	Low Severity	Moderate Severity	High Severity	Increased Greenness
2002	Little Missouri II					
Acres		369	467	505	97	7
Hectares		149	189	204	39	3
% composition		25.5	32.3	34.9	6.7	0.5
2004	SE Corner					
Acres		149	454	320	0	0
Hectares		60	184	130	0	0
% composition		16.2	49.2	34.7	0	0

Immediate post-burn severity is also measured by fire monitoring personnel. Severity for some prescribed burns can be found in THRO prescribed burn reports. The recent prescribed fire reports cite mostly "low" and "moderate" severity with fewer occurrences of "scorched" severity (which is less severe than the "low" category) (Lund 2007, Mitchell 2007, Koller and Freeman 2008, Freeman 2008). Low and moderate severity is a result of the fast-burning nature of THRO grassland fires (NPS 1999). When a fire is behaving in a manner that is counter to the management goals for the fire, the prescribed burning can be stopped, as was the circumstance for the Horse Camp fire of 2007 (Mitchell 2007).

Extent - Area Burned

NPS (1999) suggests that, in comparing the historic presence of fire on the landscape to present fire, the largest difference is probably in the area or extent of fires. Currently, large landscape fires are not allowed to burn due to widespread agricultural land use and a landscape containing many human-created firebreaks (e.g., roads). In addition to land use changes, fire that once was used commonly by Native-American cultures and in cattle ranching practices has since ceased (NPS 1999).

Wildland fires, typically caused by lightning, rarely burn more than a few acres (Appendix A) (C. Sexton, pers. comm., 2011). Where fire dependency is proven for vegetation communities, wildland fires are allowed to burn if fuel load and vegetation composition are within the range of natural variability (NPS 2008). According to the NPS (2008), the preferred strategy for managing fire in the majority of the park is to allow natural processes to occur in order to perpetuate and maintain various ecosystems to the maximum extent possible. Naturally-ignited fires may burn so long as human life and property are protected and all wildland fires are limited to burning in a manner consistent with national policy. Fire is suppressed in the Elkhorn Ranch unit and prescribed fire is implemented when it is determined that it can accomplish predetermined resource objectives (NPS 2008). Appendix A displays the areas burned in THRO from 1946 to 2010.

Fire Origin

Fires in the park are typically started by humans (non-prescribed), lightning, or are prescribed burns conducted by fire management and natural resource personnel (NPS 2003, Guyette et al. 2011) (Appendix A). Another possible ignition source exists in the form of lignite (low-grade coal seams) (NPS 1999). THRO experiences very few lightning-ignited fires (0.00075 fires/km^2/yr) (Schroeder and Buck 1970, also reviewed by Guyette et al. 2011). Higgins (1984) found that between 1949 and 1981, THRO experienced an average of 1.09 lightning-caused fires per year. Lightning-caused fires occur most frequently in July and August (Hull Sieg and Fletcher 1998). Prescribed fire now accounts for the vast majority of area burned in THRO. From 1999 to 2010, prescribed fires accounted for 49 of the 106 fires, and 90% of the area burned. However, lightning-caused fires have been allowed to burn over larger areas in the last decade and appear more frequent in recent decades (Table 8). Table 6 shows the origin of recorded fires in the park from 1999 to 2010.

Table 8. Lightning-caused fire numbers and area by decade in THRO (NPS 2010b).

Decade	No. of lightning-caused fires	Area	
		acres	hectares
1950s	15	308	125
1960s	15	45	18
1970s	11	403	163
1980s	39	699	283
1990s	39	1,185	480
2000s	50	6,746	2,730

Intensity

Fires in mixed-grass prairie ecosystems are generally fast-burning surface fires that tend to leave a mosaic of burned and unburned vegetation (NPS 1999). One goal of THRO fire management is to minimize the occurrence of unnaturally intense fires by reducing hazard fuels. Intensity is the energy or magnitude of heat produced by a fire (Key and Benson 2006, Keeley 2008). Intensity is an indicator to fire managers of the potential effects of fire on soil and vegetation (i.e., fire severity) during prescribed burns. Intensity can be measured in two ways: downward penetration to the soil, or upward spread to vegetation and the atmosphere. Both measures are dependent on residual flame time and are a function of fuel and weather conditions (Key and Benson 2006). Mineral soil surface temperatures from grassland headfires increase as the amount of uncompacted fine fuels increases (Wright and Bailey 1982). Headfires spread with the wind, sometimes uphill; these are different from backfires, which are generally low and burn back into the wind slowly (Wright and Bailey 1982). When fuel availability on grasslands in the Great Plains range from 1,685 to 7,865 kg/ha, the average soil temperature during burning ranged from 102° to 388° C (215° to 730°F). Wright and Bailey (1982) suggest that the highest soil surface temperatures occur from local accumulations of loosely arranged fuel types and strong winds created by fire. Air temperature, relative humidity, and soil moisture do not appear to affect surface soil temperature in grassland fires (Britton and Wright 1971, as cited by Wright and Bailey 1982).

Grasses have a high surface area to volume ratio and moisture is easily lost or gained as combustible material is exposed to the air. These properties result in grass fires that spread quickly and end abruptly (Anderson 1982). Grassland fuels also burn with faster rates of spread than other fuels during similar observed weather conditions (Anderson 1982). THRO contains grassland fuel model 1 (Anderson 1982), where spread of fire is controlled by cured and almost cured herbaceous fuels that are fine, porous, or continuous. As wind speed increases, model 1 develops the fastest rate of spread within grassland models based upon the fine fuels, fuel load, and fuel depth relations. The fast rates of spread produce short periods of intense heat production in THRO (NPS 1999).

Seasonality

The season in which a fire burns affects the diversity, density, and composition of the plant community (Biondini et al. 1989). Burning in different seasons can affect plants and animals differently due to their sensitivity to disturbance at various phenological or reproductive stages and seasonal differences in moisture regimes at the site (NPS 2003). Biondini et al. (1989) found plot diversity of forb species in northern mixed-grass prairies decreased after fall and spring burns and remained the same following a summer burn. This same trend was also evident in areas left unburned. However, plots left unburned and those burned in the summer showed large decreases (54% and 60%, respectively) in density. Smaller declines in density were found in plots burned in the fall and spring (9% and 19%, respectively) (Biondini et al. 1989). Across the landscape, unburned, spring, and summer burn areas had random distribution patterns of forb regrowth, while plots burned in the fall showed high forb clustering (Biondini et al. 1989).

The fire season in THRO is primarily April through September. Prescribed fires usually are conducted in either spring or fall, though fire can be used at any time of year to achieve a particular management objective (NPS 1999). Wienk et al. (2007) generally recommends late summer or fall prescribed burning for areas dominated by native plant species in NGPN park

units. However, Wienk et al. (2007) suggest that for areas dominated by cool-season species (e.g., Kentucky bluegrass [*Poa pratensis*], smooth brome [*Bromus inermis*], or crested wheatgrass [*Agropyron cristatum*]) spring burning tends to be more effective in reducing non-native species cover.

Natural fires caused by lightning generally occur in the late spring to early autumn season (NPS 1999). Since prescribed fire has been used in THRO, most larger fires (≥10 acres or 4 ha) have occurred in spring (April and May) and in late summer/fall (August, September, and October) (Table 9). Smaller fires (<10 acres) occur throughout the year. Other small fires occurring outside these months are typically accidental human-caused fires and suppressed lightning-caused fires.

Table 9. Number of fires by month for fires ≥ one acre and those ≥ 10 acres in THRO (NPS 2011b).

Number of fires	January	February	March	April	May	June	July	August	September	October	November	December
Period of record 1949 to 2010												
≥ 1 acre	1	4	7	23	16	16	17	29	11	11	-	2
≥ 10 acres	-	-	3	18	6	3	3	10	7	6	-	-
Period of record 1984 to 2010												
≥ 1 acre	1	4	4	20	11	12	6	13	6	8	1	2
≥ 10 acres	-	-	1	16	6	1	1	4	3	6	-	-

Changes in Native Vegetation after Prescribed Fires

Management goals for prescribed fires may include to reduce 1-hour dead and down fuels, decrease cover of non-native grasses, and increase cover of native grasses, forbs, and sedges. Accomplishing vegetation goals and obtaining anticipated results from prescribed fire depends largely on such variables as weather and moisture conditions (R. Skalsky, pers. comm., 2011). In particular, managers at THRO use prescribed fire to stimulate or manage the growth of the following native species: western wheatgrass (*Pascopyrum smithii*), green needlegrass (*Nassella viridula*), needle-and-thread (*Hesperostipa comata*), grama grasses (*Bouteloua* spp.), and common yarrow (*Achillea millefolium*).

Presently, the park contains too few monitoring plots to accurately and statistically measure changes in native vegetation in response to prescribed fires. However, the monitoring plots may provide possible trend and some insight to the degree of change, though no clear, causal relationships can be surmised. Rod Skalsky (pers. comm., 2012) observes that fire clearly impacts deciduous and brush species, but it is difficult to differentiate with any degree of certainty if changes in grasslands are due to fire, to grazing post-fire, or both. While it is most likely the latter, this complex relationship is difficult to measure statistically (Skalsky, pers. comm., 2012). Since 2011, the NGP Fire Ecology Program has been installing more sample plots within burn units at THRO in ordrer to increase precision and statistical confidence (D. Swanson, pers. comm., 2012). In addition, combined monitoring efforts and data from the NGP Fire

Ecology Program and the NGP I&M Program will allow for greater statistical confidence in the future, allowing some of the variables to be statistically differentiated. For example, it is postulated that variables such as interannual total precipitation and seasonal precipitation may have the largest impact on resultant herbaceous diversity and cover. Likewise the timing of prescribed fires in terms of the park's recent precipitation levels (i.e., whether the park is in a wet, normal, or droubt cycle) may significantly impact subsequent herbaceous species composition and cover (Swanson, pers. comm., 2012).

The NGP Fire Ecology Program established fire monitoring units in 1998 and 1999 based on dominant plant species. The NGP Fire Ecology Program established individual post-fire vegetation objectives for each monitoring unit. Each unit (named by dominant plant species) may be represented in several different burn units (e.g., I-94, Jones Creek, Little Missouri, River Corridor). Likewise, some burn units may contain various vegetation types, and therefore distinct monitoring units. There are 27 fire-monitoring plots in THRO (NPS n.d.). From 1999 to 2010, 22 prescribed fires occurred, most in spring (Table 10). Wienk et al. (2007) summarized work completed by the NGP Fire Ecology Program from 1997 to 2007 for the prescribed burns in THRO and is presented in Table 10.

Table 10. Prescribed fire dates, season, and area burned in THRO (from Wienk et al. [2007] and updated using NPS [2011b]).

Unit	Date(s)	Season	Size (acres)	Size (hectares)
Little Missouri	9/21/99	Fall	650	263
SE Corner	4/19/99	Spring	475	192
SE Corner	4/11/00	Spring	331	134
NW Corner	10/18-21/01	Fall	700	283
Little Mo II	5/13/02	Spring	800	324
Peaceful Valley	5/29/02	Spring	18	7
Skyline Vista	10/9/02	Fall	534	216
I-94	10/10/02	Fall	300	121
Cottonwood CG	4/25/03	Spring	250	101
I-94	5/2/03	Spring	250	101
SE Corner	4/23/04	Spring	910	368
Monitoring results of the above prescribed fires are listed in the following section, the prescribed fires listed below are not yet reported for all monitoring unit types				
Horsecamp	4/24/07	Spring	92	37
Loop 1	4/17/07	Spring	17	7
Loop 2	4/17/07	Spring	25	10
Loop 3	4/17/07	Spring	6	2
Loop 4	4/17/07	Spring	44	18
Loop 5	4/24/07	Spring	40	16
Radiotower	10/04/07	Spring	95	38
Loop 6	4/13/08	Spring	40	16
Loop 7	4/13/08	Spring	93	38
Loop 8	4/13/08	Spring	20	8
Loop 9	4/13/08	Spring	70	28
NW Corner 1	10/09/08	Spring	70	28
NW Corner 2	10/09/08	Spring	327	132
NW Corner 3	10/09/08	Spring	297	120
Elkhorn Ranch 1	5/07/09	Spring	3	1
Elkhorn Ranch 2	5/07/09	Spring	11	4
Elkhorn Ranch 3	5/07/09	Spring	4	2
Juniper Campground	No date	Spring	150	61
Loop Unit 1	No date	Spring	11	4
North Loop Burn	5/03/09	Spring	150	61
SE Corner 6	4/22/10	Spring	250	101
Sheep	9/14/11	Fall	3641	1474
Longhorn Flats	9/16/11	Fall	460	186

D. Swanson (pers. comm., 2012) suggests that project based plot monitoring is more informative to park managers on whether objectives are met for each prescribed fire, since prescribed fires occur in both the spring and fall and occur under different temperatures and moisture conditions. Starting in 2011, the NGP Fire Ecology Program has been installing a greater number of plots within each burn unit to address changes to the vegetation composition and cover at the project level.

Crested Wheatgrass (AGCR)

Monitoring units for the non-native crested wheatgrass only exist within the Southeast Corner / I-94 prescribed burn unit. Crested wheatgrass and the invasive smooth brome are the dominant

species found in this mostly non-native vegetation unit. The I-94 prescribed fire objectives were to burn 60-90% of project area and reduce fuel loads by 50-85% immediately after the burn. The goals for changes in post-burn vegetation are as follows:

Immediate post-burn:

- Burn 60-90% of project area;
- Reduce fuel load by 50-85%.

Two years post-burn:

- Reduce non-native grasses by at least 20%;
- Increase native grass cover by at least 20%;
- Keep hardwood mortality to less than 10%.

Five year post-burn:

- Maintain a reduction of non-native species;
- Maintain the increase in native species.

Two-year objectives were partially attained in that non-native grasses decreased by 43%. However, native grasses decreased by 39%. Five-year objectives were not met as non-native grasses were only 11% lower than the pre-burned state and native grasses were 5% lower than the pre-burned state. Western wheatgrass was unchanged after one year and decreased two years after the burn. Precipitation is suspected to have affected the re-growth percentages (Wienk et al. 2007).

The Southeast Corner prescribed fire of 1999 had a pre-burn objective to reduce 1-hour decadent fuels by at least 70%. Paintner and Pindel (1999) state this goal was not met and suggest that it may have been unrealistic. Thorstenson and Schmitt (2004) indicate that 70-90% of the area burned during the 2004 Southeast Corner prescribed fire and the immediate fuel load goal was met in blocks (sections of the fire) F, G, and H.

Silver sagebrush shrubland (ARCA)
Four prescribed fire units contain plots for this monitoring unit; two plots burned in 1999 and two in 2002.

Immediate post-burn objectives:

- Burn 60-90% of the available project area.

Two years post-burn:

- Reduce silver sagebrush density by 40-60%;
- Increase native herbaceous cover by 20%;
- Reduce non-native cover by 25%, and increase native perennial grass cover by at least 25%.

Five years post-burn:

- Maintain the reduction of shrub density;
- Increase native species;
- Maintain a reduction in non-native species.

The reduction of silver sagebrush density was reached for the two-year post-burn objectives, while the increase and reduction goals of native and non-native species were not met. However, five years post-burn, non-native grass cover decreased by 55%, while native grass and forb cover increased by 18% and 45%, respectively (Wienk et al. 2007).

Cottonwood/Rocky Mountain juniper forest (PODE)
Of the three plots installed for monitoring these forests, two have been burned. Post-burn vegetation objectives are:

Immediate post-burn:

- Reduce total fuel loading by 60-80%.

Two years post-burn:

- Reduce total brush density by 30-50%;
- Reduce conifers by 50-70%,
- Acceptable mortality of deciduous overstory trees was 20%.

The Little Missouri II fire decreased total fuel loads by 17% immediately post-burn and total fuel load actually increased by 38% at five-year post-burn measurements. However, significant decreases in pole-sized stems/acre (from ~90 stems/acre pre-burn to ~15 stems/acre year five) were realized at 5 years in this burn unit for cottonwood and very few overstory trees were reduced. Conifers were not evaluated in Wienk et al. (2007) for this burn unit.

Green needlegrass mixed-grass prairie (STVI)
Ten plots were installed for the monitoring of this unit; three have burned in the Southeast Corner unit and three have burned in the Northwest Corner unit. The Southeast Corner unit is dominated by Kentucky bluegrass, whereas the Northwest Corner unit is a more appropriate unit to assess the condition of green needlegrass plots, as native species are dominant (Wienk et al. 2007). Post-burn vegetation objectives are:

Immediate post-burn:

- Reduce thatch by 20-30%.

Two years post-burn:

- Reinvigorate native species and decadent vegetation;
- Reduce brush species;
- Restore and maintain native plant communities;
- Reduce non-native cover by at least 20 to 30%;
- Increase native perennial grass cover by at least 20 to 30%;

- Reduce brush by 20 to 30%;
- Increase native herbaceous and shrub cover by 20 to 30%.

Immediate visual estimates of the Northwest Corner fire in 2001 found that about 50% of the thatch was removed (Rehman and Thorstenson 2001). Based on the Northwest Corner prescribed fire monitoring report, none of the two-year objectives were met (Wienk et al. 2007). While non-native grass cover was reduced by 53%, non-native forb cover increased by 100%. Five years after burning, native grass cover had increased by 40% (Wienk et al. 2007).

Snowberry shrub land (SYOC)
As of 2007, one plot was installed to monitor this mixed-grass prairie vegetation type.

Immediate post-burn:

- Reduce silver sagebrush density by 40-60%.

Two year post-burn:

- Reduce non-native cover by at least 25%;
- Increase native perennial grass cover by at least 25%;
- Reduce silver sage by 50%;
- Reduce total fuel load by 75%.

Immediate post burn goals were inconclusive and silver sage reduction was the only two-year post burn objective attained (Wienk et al. 2007).

A park-wide summary of fire monitoring plots in THRO through 2007 indicated that 16 plots were burned and 15 of them were visited five years post-burn (Figure 2) (Wienk et al. 2007).

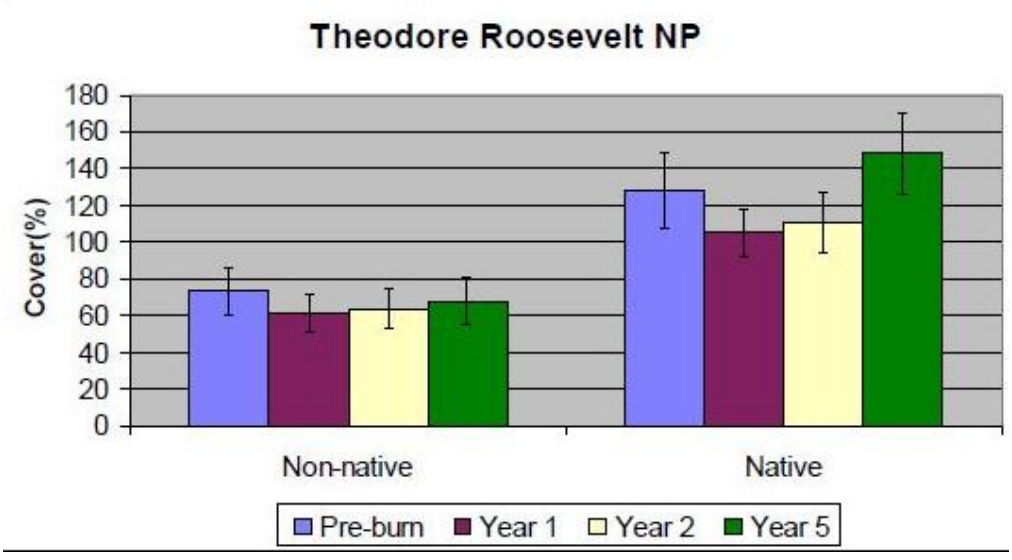


Figure 2. Pre-burn and post-burn percent cover of native and non-native plant species (average of 15 monitoring plots). Reproduced from Wienk et al. (2007).

Since Wienk et al. (2007), several treatments (fires) have been conducted in THRO. Decreases in the percent cover of nonnative grasses and increases in both native grass and sedges occurred in the Southeast Corner burn unit (which contains three green needlegrass monitoring plots) (Figure 3). Kentucky bluegrass showed the most notable decrease in cover of five major non-native grasses.

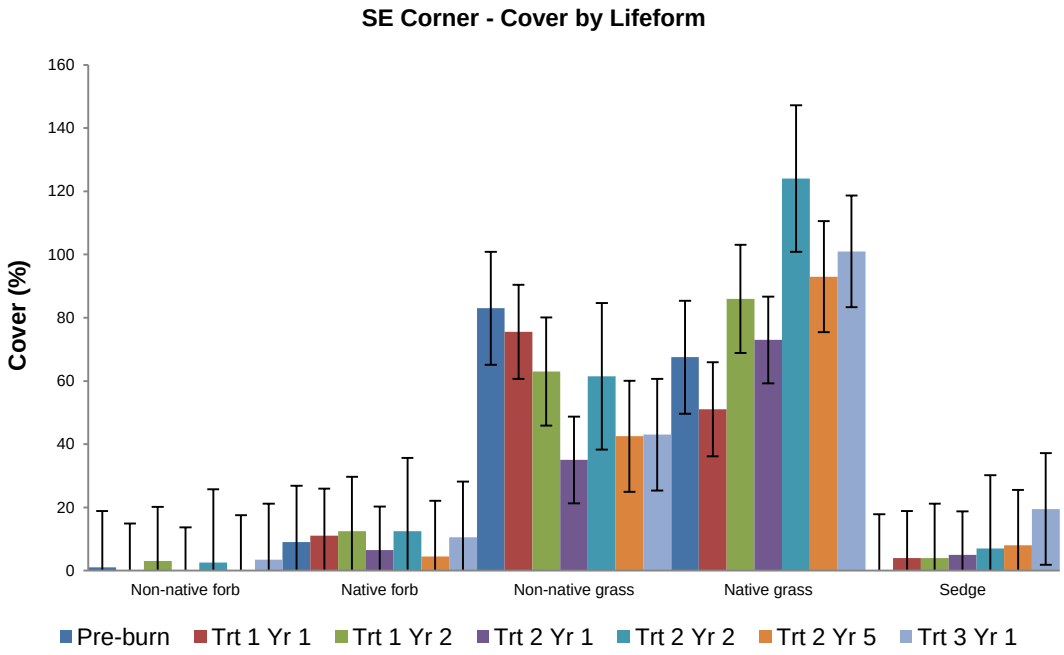


Figure 3. Southeast Corner burn unit changes in percent cover by life form following multi-year, multi-burn, prescribed fire treatments in THRO.

Similar decreases in non-native grasses and increases in native grasses and sedges also were reported in the Northwest Corner burn unit following multiple fire treatments (Figure 4). However, it is not clear how the additional influence of livestock and ungulate grazing may influence the results of any post-burn measurements.

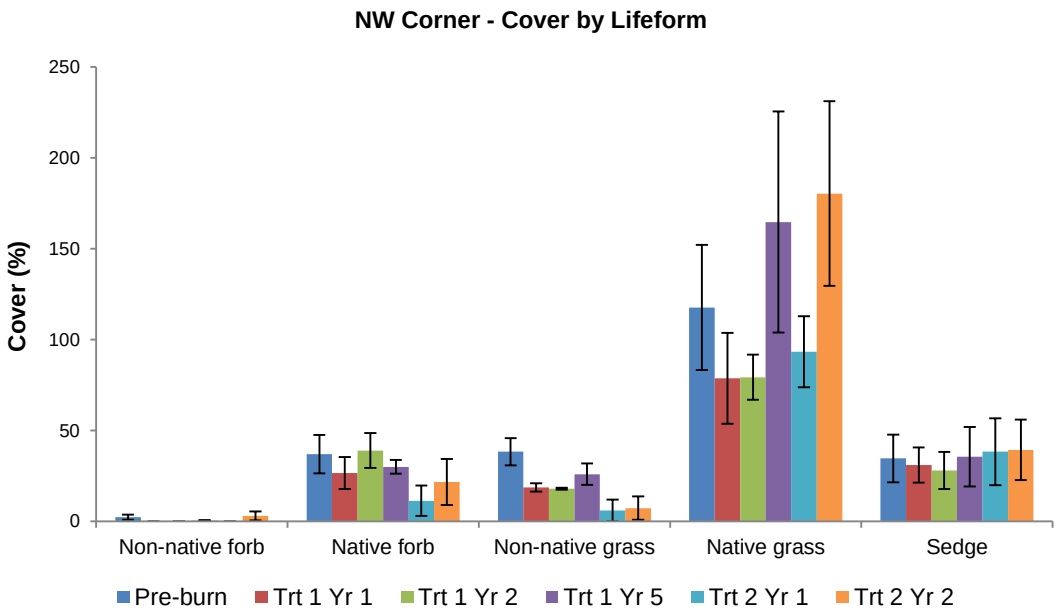


Figure 4. Northwest Corner burn unit changes in percent cover by life form following multi-year, multi-treatments (fires) in THRO.

Overall, shrub density objectives for both silver sagebrush and western snowberry were achieved in the Little Missouri burn unit, though at ten years post-burn, a slight increase occurred in silver sagebrush density from initial post-burn measurements (Figure 5).

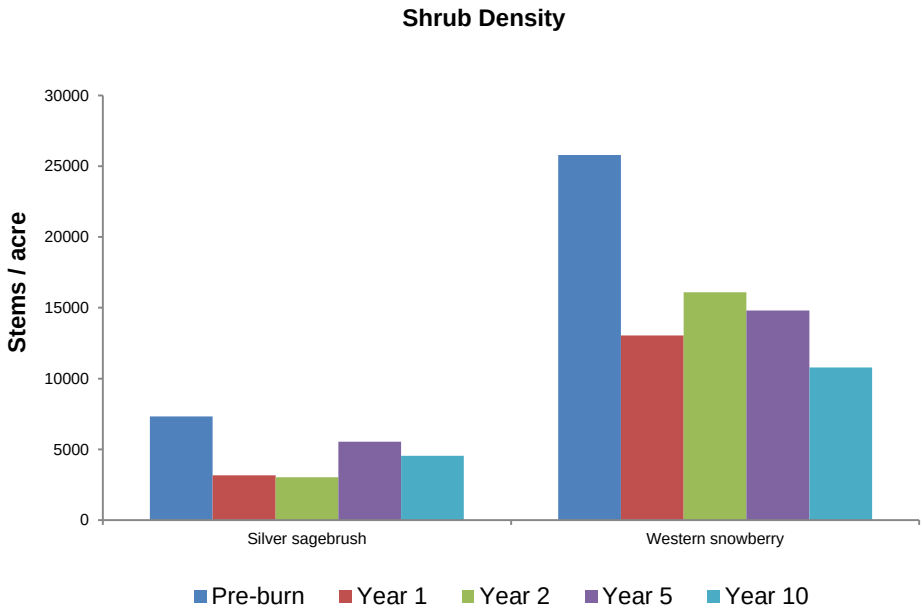


Figure 5. Shrub density changes post-fire in the Little Missouri burn unit.

Threats and Stressor Factors

Fire suppression and development adjacent to the park were identified by park managers as threats or stressors to the fire regime in THRO. Throughout the early to mid-1900s, fire suppression was practiced throughout the northern Great Plains region to protect private property and resources. This prevents the natural extent and frequency from occurring, especially in the case of large landscape-scale fires.Suppression of nearly all unplanned fires continues as a part of the THRO Fire Management Plan, creating a situation in which the fire regime is almost completely dependent upon prescribed burning and non-fire fuel treatments.

Increased development adjacent to the park increases the opportunity for fires occurring within the park to destroy private property or structures and threaten human life should a fire escape park boundaries. This increased risk to private property elevates the need to suppress natural fires and requires deliberate, careful planning of prescribed fires in the park in order to achieve fire management goals while preserving park structures and private property. As a result, large-scale fires are rare in the region and occur at a lower frequency.

Data Needs/Gaps

Immediate monitoring and reporting of burn intensity and severity will assist managers to further understand fire's effects on vegetation. Continued capture/delineation of fire perimeters using GPS data (adding to 10 years of consistent data collection) will give managers a clear understanding of fire history in each burn unit, and will illustrate areas of the park that have not experienced prescribed fire for long periods. Continued and consistent monitoring of established vegetation plots will provide a better understanding of the fire effects on vegetation as well as a way to determine if management objectives are being met. With additional plots within burn units and in combining NGP Fire Ecology Program and NGP I&M data vegetation plots may also allow managers to correlate different fire management parameters (e.g., season, fuel loads, or weather conditions) with the desired vegetation outcomes.

Overall Condition

Fire over the last several decades in THRO has been managed either through suppression (accidental fires or in some cases of lightning-caused) or through prescribed fires. While the following measures characterize the present-day fire regime in the park, prescribed fire has almost completely replaced natural-start fires. Prescribed fires are set to achieve desired effects on vegetation and soils. Therefore, the effects of fire may be considered a more important measure of fire's condition in THRO than various parameters of fire occurrence in the park. The desired effects vary by individual burn unit, monitoring unit, and by fire. Understanding how fire parameters (e.g., intensity, severity, flame length, wind) influence the effects of burning will assist park staff in meeting their management objectives.

Frequency

The *Significance Level* for frequency is a 3. A fire behavior model suggests that the park should have fire-return intervals of 5 to 30 years. However, some areas of THRO do not burn for 100 to 200 years. For this reason, *Condition Level* for frequency is a 2, indicating the component is of moderate concern.

Extent - Area Burned
The *Significance Level* for area burned is a 3. There is not a target established for number of acres to be burned annually in the park. However, some areas in the park have not experienced fire in over 200 years, and the declining fuel budget is likely to further decrease the average extent burned per year (R. Skalsky, pers. comm., 2011). Thus, the *Condition Level* for extent of area burned is a 2, indicating the condition is of moderate concern.

Intensity
The *Significance Level* for intensity is a 2. Intensity is measured by the rate of spread and flame length. Prescribed fires are heavily monitored and managed during burns and wildfires are monitored and sometimes suppressed, depending on location, suppression support, and weather conditions. Since managers extinguish fires that are behaving unfavorably, the *Condition Level* for intensity is a 0, indicating the component is of no concern.

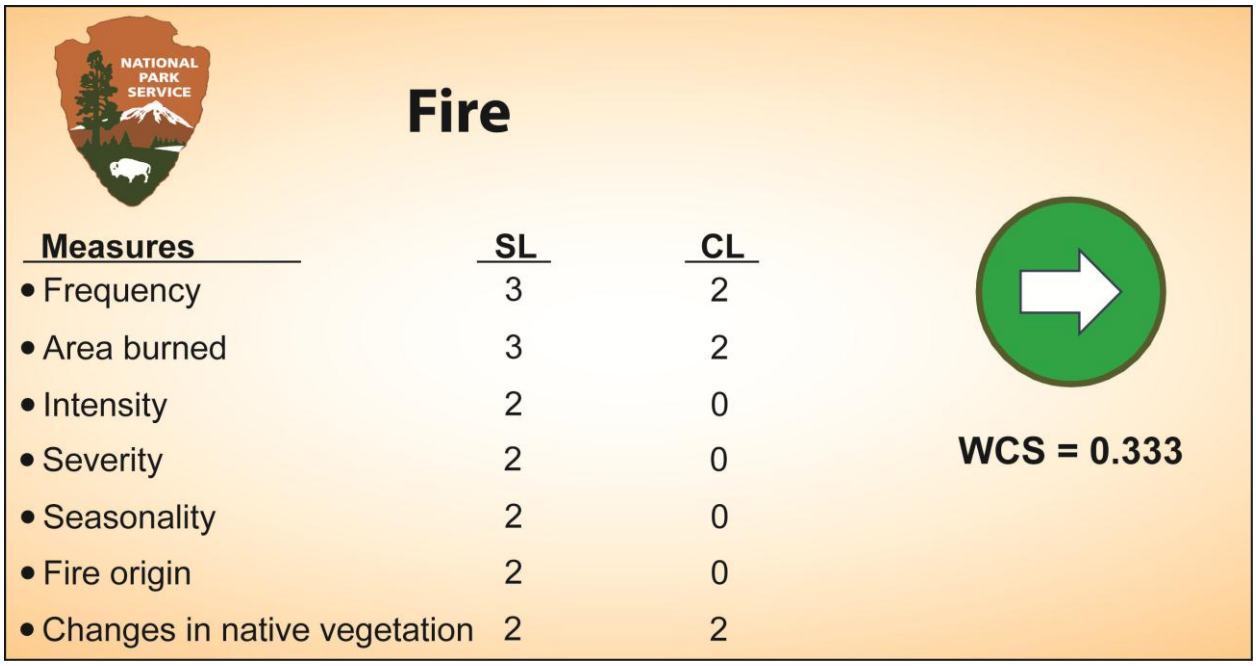
Severity
The *Significance Level* for severity is a 2. Fires that burn too hot will destroy vegetation completely and damage soils; thus, personnel will extinguish a prescribed fire that has the potential to become too severe. The majority of fires in THRO had a reported severity of "scorched", "low", or "moderate," largely due to the controlled nature of the fires. The *Condition Level* of severity is a 0, indicating the component is of no concern. This is because fire personnel generally control severity, and to date overall severity has been low.

Seasonality
The *Significance Level* for seasonality is a 2. Prescribed fires usually occur in the fall and spring but fire can be used during any season to meet management goals. Since most fires in THRO are prescribed, and wildfires only burn a few acres at a time and have minimal effects on vegetation park-wide, the *Condition Level* for seasonality is a 0, indicating no concern. The appropriate season in which to use prescribed fire to achieve a particular set of objectives (e.g., reducing non-native cool season grasses) continues to be a topic of research. Fire effects monitoring results will aid in answering this general research question.

Fire Origin
The *Significance Level* for fire origin is a 2. The *Condition Level* for fire origin is a 0, indicating no concern because 93% of the acres burned since 1984 are of prescribed origin. Since 2000, only five human-caused fires have occurred in the park, burning a total of six acres. Wildfires generally are suppressed because they are less predictable, and therefore pose threats to property within and adjacent to THRO; however, larger areas have burned from 1999 to 2010 due to natural wildfire.

Changes in Native Vegetation
The project team defined the *Significance Level* for changes in native vegetation as a 2. The *Condition Level* for changes in native vegetation is also a 2, indicating that the component is of moderate concern. Weather and moisture variables affect both the way prescribed fires burn and the results from prescribed fires. Most immediate prescribed fire goals have been met, while two-year and five-year goals are sometimes met. Some progress has been realized as is evidenced by 10-year post-fire effects (e.g., continued reductions in shrub densities).

Weighted Condition Score
The *Weighted Condition Score* (WCS) for the fire component is 0.333 indicating the condition is in good condition with a stable trend.



4.1.6 Sources of Expertise
Rod Skalsky, Fire Management Officer, THRO
Dan Swanson, Fire Ecologist, WICA
Chad Sexton, Geographic Information Systems Analyst, THRO

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4.2 Wind and Water Erosion

* During initial project scoping, project stakeholders identified wind and water erosion as important processes within the park, but little or no data exist to examine their current condition. Thus, no data will be summarized nor will the condition of erosion be assessed. Rather, a brief overview of the component and a description of potential measures, threats, and stressors are provided for the primary purpose of inclusion in a future assessment when appropriate data are available.

4.2.1 Description

Wind and water erosion are natural processes that have shaped the landscape of THRO, particularly the dramatic geological formations of the badlands. Erosion rates on the badlands slopes of western North Dakota have been estimated at 0.28-1.04 cm/year (Tinker 1970 and Bluemle 1975, as cited by Von Loh et al. 2000). Factors that influence erosion rates include lithology, slope gradient (steepness), and vegetative cover (Butler et al. 1985, KellerLynn 2007). The presence of bentonite (a clay material that swells when wet) in a rock formation increases its susceptibility to erosion. Bentonite is common in the Sentinel Butte Formation of THRO, where most landsliding occurs in the park (KellerLynn 2007). Slope gradient influences water infiltration, especially of runoff water, therefore affecting erosion rates (Butler et al. 1985). Finally, vegetative cover plays a key role in protecting surfaces from wind, rainsplash, and runoff (Wei et al. 2009, Munson et al. 2011).

One significant erosional process of concern to park managers is mass wasting, which is the downslope movement of soil and rock material by gravity (e.g., landslides, slumping, soil creep) (NPS 2003, KellerLynn 2007). This movement, sometimes sudden and dramatic, can threaten park roads, trails, and visitor facilities (NPS 1986). For example, significant slumping due to above normal precipitation in 2011 led to the closure of a portion of road in the North Unit through Cedar Canyon, as it was deemed unsafe for visitors (Laurie Richardson, THRO Botanist, e-mail communication, 2012). Mass wasting in THRO occurs primarily as landslides and soil creep (Biek and Gonzalez 2001). Evidence of landslides is common in the North Unit, where "rotational slumps" are apparent in several locations (Photo 7). Large slumps with hummocky surfaces occur along the Little Missouri River, with the largest occurring on the north flank of the Achenbach Hills near Achenbach Spring (Biek and Gonzalez 2001). Another notable rotational slump can be found north of the river between the east entrance and Juniper Campground. The largest landslides in the South Unit occur along the eastern escarpment, on the eastern flank of the Petrified Forest Plateau, and around Buck Hill. Also in the South Unit, soil creep is common on steep slopes of the Bullion Creek Formation with north or northeast aspects (Biek and Gonzalez 2001).

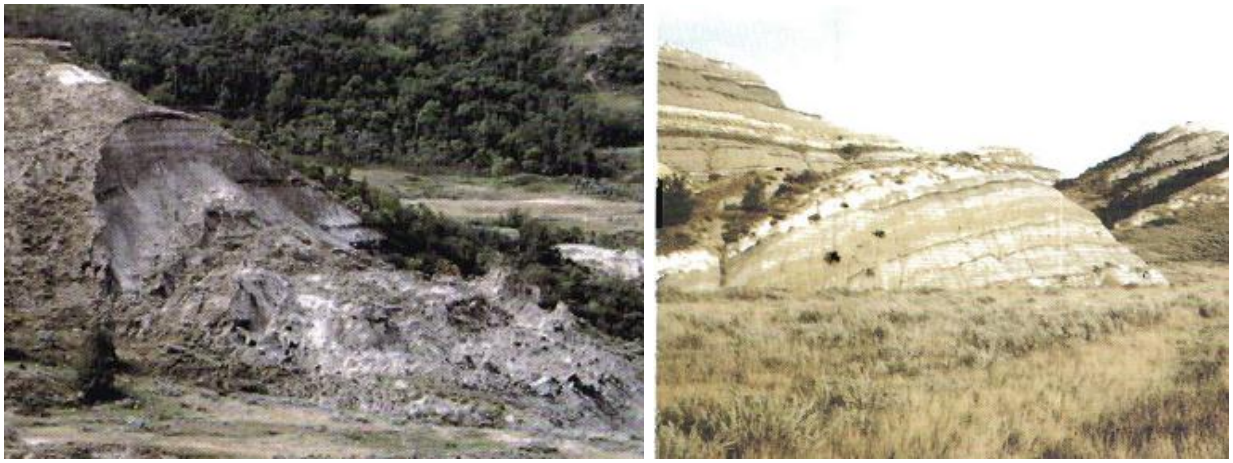


Photo 7. A small landslide in Sentinel Butte strata (left) and a large rotational slump in the North Unit (right) (Biek and Gonzalez 2001).

Other erosional processes in the park include rill and gully erosion, common in basal sandstone of the Sentinel Butte formation, and piping (KellerLynn 2007). Piping occurs "when surface runoff erodes vertically downward through poorly lithified sediments", creating a network of tunnels, small caves, and pseudokarst features that channel runoff underground (Biek and Gonzalez 2001, p. 56). It is common in poorly lithified bedrock and associated colluvial, alluvial, and landslide deposits, which regularly occur at or near the bottom of steep badlands slopes (Biek and Gonzalez 2001). These pipes can eventually collapse, potentially causing subsidence or rockslides that could threaten nearby roads or structures.

Another erosion-related threat to the park is the exposure of lignite beds (also known as "brown coal"), which can ignite when exposed to air and trigger fires (Biek and Gonzalez 2001). Once ignited at the surface, lignite often burns back into the hillside or formation, creating an empty space into which overlying beds settle or collapse. Significant burning and subsidence occurred in the Buck Hill area from the early 1950s through the 1970s (Biek and Gonzalez 2001). No lignite beds were burning in THRO as of 2007, but several small fires occurred in the South Unit's northeastern corner during the late 1980s and early 1990s (KellerLynn 2007). However, outcrops of lignite are a constant concern for the park's fire management program and can influence park planning and management (KellerLynn 2007).

4.2.2 Measures

- Changes in landscape features
- Amount of material removed (erosion rates)

4.2.3 Reference Conditions/Values

A reference condition for wind and water erosion in the park has not been determined.

4.2.4 Data and Methods

Information regarding erosion in the park was primarily found in Biek and Gonzalez (2001) and the THRO Geologic Resources Evaluation Report (KellerLynn 2007). Numerous journal articles were consulted regarding the impact of climate on erosional processes.

4.2.5 Current Condition and Trend

Changes in Landscape Features
Wind and water erosion are constantly changing the landscape of THRO. However, no research or consistent monitoring of these changes has occurred.

Amount of Material Removed (Erosion Rates)
To date, no current or historical data are available for erosion rates in the park.

Threats and Stressor Factors
Climate is a critical factor in erosional processes, especially in semiarid regions (Kuehn 2003, Graham 2008). According to Wei et al. (2009, p. 308), "rainfall is the initial and essential driving force for natural runoff generation and erosion variation." Climate variables also impact vegetation patterns, which in turn influence erosion across the landscape. An increase in precipitation generally is thought to increase erosion rates (as reviewed by O'Neal et al. 2005). A decrease in precipitation therefore would be expected to reduce erosion rates; however, a reduction in precipitation could reduce vegetative cover, increasing the surface area exposed to rainfall and runoff (Clarke and Rendell 2010). A reduction in vegetative cover may increase the soil's exposure to wind erosion as well (Munson et al. 2011). The frequency of precipitation can also impact erosional processes. Wei et al. (2007) found that rainfall regimes with strong intensities and low frequencies induced more severe runoff and soil erosion than regimes with weak intensities and high frequencies.

In semi-arid badlands like those found at THRO, "the ephemeral nature of precipitation and runoff means that change is particularly associated with extreme events" (Faulkner 2008, p. 92). Rain often comes in sudden showers that can drop several inches per hour (Opdahl et al. 1975, as cited by KellerLynn 2007); the resulting runoff typically causes rapid erosion. Heavy downpours have increased in frequency and intensity across the U.S. over the past several decades, a trend that is expected to continue throughout this century (Karl et al. 2009).

Erosion also can be exacerbated by road construction and trail use. Movement is still occurring in landslide deposits under several roads in the park, causing buckled pavement and dips in the roads (Biek and Gonzalez 2001). For example, the North Unit's scenic drive crosses several landslide deposits between the Concretion Pullout and the Highway 85 junction. In the South Unit, the park road crosses landslides near the Ridgeline Trail trailhead and along the Buck Hill road (Biek and Gonzalez 2001, KellerLynn 2007). Disturbance caused by repair activities such as placing fill, regrading, or rerouting drainage in these deposits may actually increase instability (Biek and Gonzalez 2001, KellerLynn 2007). Intense trail use or poor trail design often result in soil erosion and trampled vegetation (NPS 1994). In some places, trails have become deep channels that actually concentrate runoff, further exacerbating erosion. The eroded material can then impact vegetation and soils in previously undisturbed areas along the trail (NPS 1994).

Data Needs/Gaps
No research has been conducted in the park regarding either changes in landscape features or erosion rates. A multi-year study of erosion rates using a variety of sampling techniques (e.g., survey stakes and pins, sediment erosion traps, photogrammetry, LiDAR) is currently underway at Badlands National Park in South Dakota (Stetler and Benton 2011). The results of this study,

which is scheduled for completion in 2012, could help THRO design an erosion survey and monitoring plan.

Overall Condition

Due to a lack of information and data regarding erosion rates and erosional landscape changes in the park, the overall condition of wind and water erosion cannot be assessed at this time.

4.2.6 Sources of Expertise

Bill Whitworth, Chief of Resources, THRO

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4.3 Flooding (Little Missouri River)

4.3.1 Description

The Little Missouri River is a tributary of the Missouri River, which begins in northeastern Wyoming and flows through all three units of THRO (through 14 km of the South Unit, 23 km of the North Unit, and through Elkhorn Ranch) (Miller 2005, KellerLynn 2007). Peak flows of the Little Missouri River in the 20th century were lower than in previous centuries; regardless, they have subsequently altered floodplain formation (Miller and Friedman 2009). These overall decreases in peak flows are postulated to be a result of climatic shifts (changes in precipitation and temperature), as the Little Missouri River is mostly unregulated (Miller and Friedman 2009). Despite the overall decrease in peak flow magnitude, several park features (Cottonwood and Juniper Campgrounds, Peaceful Valley Ranch, South Unit Park Headquarters, and portions of park roads) are located within the 100-year floodplain, leaving a 1% chance each year that these features will be in the river's inundation zone (KellerLynn 2007). In May 2011, the Little Missouri River experienced significant flooding in THRO and the surrounding area following heavy spring rain events.



Photo 8. Record flooding on the Little Missouri River in May 2011 as viewed from the MP 27 loop road in the South Unit, THRO (NPS photo).

The National Weather Service defines a flood as "any high flow, overflow, or inundation by water which causes or threatens damage (NWS 2012)." The National Weather Service defines gage heights that correspond to flooding events at certain gages. For the Little Missori River, two gages are most relevant to THRO, one at Medora and one near Watford City (Plate 1). The gage heights that represent flooding events at these sites do not correspond to flooding events in the park for all high-water events though; in 2011, a high-water event occurred that caused substantial flooding in the park, yet the gage height at Watford City did not correspond to a flood event as defined by the National Weather Service.

4.3.2 Measures

- Frequency
- Magnitude
- Duration
- Effects of upstream water withdrawal on summer low flows
- Snow pack

4.3.3 Reference Conditions/Values

The reference condition for flooding is the range of variation since the beginning of data collection (1904 and 1935 for Medora and Watford City, ND, respectively).

4.3.4 Data and Methods

Literature provided by THRO (Emerson and Macek-Rowland 1986; KellerLynn 2007; Miller 2005; Miller and Friedman 2009) and USGS stream gage statistics (USGS 2011a, b, c) were the main sources of information for this assessment. Two USGS gage sites were utilized for this assessment: Little Missouri River at Medora, ND (USGS Station No. 06336000) and Little Missouri River at Watford City, ND (USGS Station No. 06337000). The Medora gage is indicative of streamflow characteristics near the South Unit and the Watford City gage is indicative of streamflow in the North Unit; there is no stream gage near the Elkhorn Ranch Unit of THRO.

4.3.5 Current Condition and Trend

Frequency

Peak flows in the Little Missouri River occur in late March and early April of each year, with periodic summer high flows occurring in May through July. Spring peak flows are generally a result of snowmelt, but can also result from rain and the breaking up of river ice; summer high flows are generally the result of intense thunderstorms (Miller and Friedman 2009). High-flow events causing significant floodplain destruction occur every five to ten years on the Little Missouri River (Miller and Friedman 2009). Frequent flooding increases erosion and causes changes to the channel area, which is important for establishment and regeneration of cottonwoods (*Populus deltoides*).

Magnitude

Over the last century, there has been a reduction in the magnitude of peak flows on the Little Missouri River (Miller and Friedman 2009). Since the Little Missouri River is largely unregulated, climatic factors, such as temperature and precipitation, are thought to be the primary driver in the overall reduction in peak flow magnitude during the 20th century.



Photo 9. Flooding on the Little Missouri in May 2011 as viewed from the Medora Overlook in the South Unit, THRO (NPS photo).

Discharge has been monitored since 1935 (North Unit) and 1904 (South Unit), and the overall average annual peak flow of the Little Missouri River was 15,122 cfs (mean discharge = 535 cfs) (Miller 2005, Miller and Friedman 2009). However, there are many gaps in the available data for the South Unit. The largest recorded instantaneous peak flow of the

Little Missouri River occurred in 1947, with a peak discharge of 110,000 cfs (Miller and Friedman 2009). This 1947 flood was seven times larger than the average annual peak flow on the Little Missouri River, and reached a peak height of 20.5 ft at Medora, 5.5 ft above the National Weather Service 15-foot Flood Stage (USGS 2011a). The second largest recorded flood occurred in 1950, with a peak discharge of 60,000 cfs. Recently, in May of 2011, a high-water event occurred; stage height of this event reached 16.70 feet and discharge reached 30,000 cfs at the Watford City gage (USGS 2012). At the same time, the stage height exceeded the flood stage (15 ft) at Medora, reaching a height of 20.39 ft with a discharge of 35,100 cfs. For the period of recorded streamflow, "peak flows along the Little Missouri River have declined over time and the active channel area has decreased by 38% since 1939" (Miller and Freidman 2009, p. 754). Peak discharge is an important driver of erosion and channel migration (Miller 2005), which are both necessary for cottonwood establishment. Therefore, a decrease in flood magnitude could be problematic for cottonwood forests. Table 11 displays peak discharge for the Little Missouri River at the North and South Units of THRO, along with other tributaries of the Little Missouri River. Annual peak flow data recorded at the Medora, ND and Watford City, ND gages are included in Appendices A and B, respectively.

Table 11. Flood discharges for the Little Missouri River and tributaries in THRO. Discharges in cfs; maximum water-surface elevations are in feet above sea level (asl) (Emerson and Macek-Rowland 1986).

	Peak recorded discharge	Maximum water-surface elevation	Date	100-year flood discharge	500-year flood discharge
North Unit	110,000 cfs	1,953.03 ft asl	25 March 1947	78,800 cfs	113,500 cfs
South Unit	65,000 cfs	2,267.25 ft asl	23 March , 1947	65,300 cfs	99,300 cfs
Elkhorn Ranch	No data	No data	n/a	69,000 cfs	103,000 cfs
Knutson Creek	No data	No data	n/a	31,800 cfs	
Paddock Creek	No data	No data	n/a	13,500 cfs	
Squaw Creek	No data	No data	n/a	24,600 cfs	

North Unit

Figure 6 represents peak discharge at the Watford City USGS stream gage near the North Unit of THRO. This stream gage gathers continuous data, with no data gaps, making overall trends discernable. Since 1980, no higher peak discharges have occurred, such as those seen in 1947, 1950, 1952, and 1972.

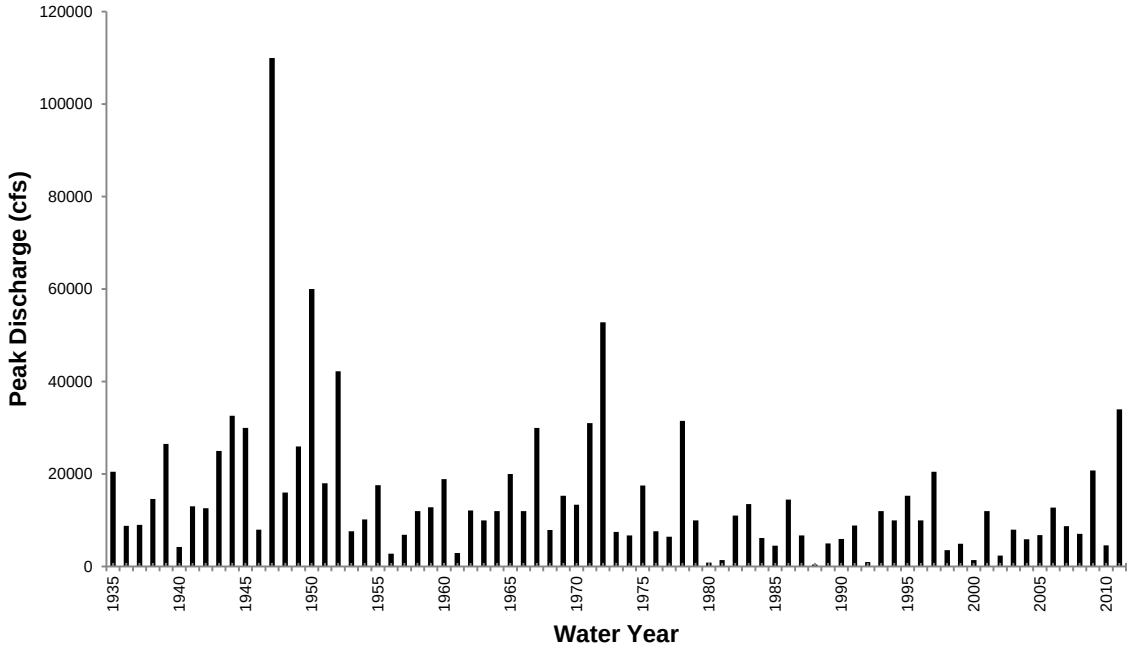


Figure 6. Peak discharge (cfs) for the Little Missouri River near Watford City, ND (USGS Station No. 06337000) from 1935-2010 (USGS 2011c, 2012).

The National Weather Service determined the flood stage at Watford City to be 20 ft (USGS 2011b). At Watford City, the Little Missouri River has only reached flood stage twice since 1935 (in 1947 and 1950) (USGS 2011b). The peak gage height for 1947 and 1950 were 24 and 21.42 ft, respectively (USGS 2011b). However, there seem to be many years with high peak gage heights, but relatively low peak discharge. J. Hughes (pers. comm.) indicated a potential reason for some of the discrepancies is that the gage near Watford City has changed location on numerous occasions.

South Unit

Figure 7 represents peak discharge at the USGS Medora stream gage near the South Unit of THRO at Medora, ND. The stream gage data for this location has many multi-year data gaps. For approximately 25 years (from the mid-1970s until 2000), there are no USGS stream gage statistics available. In addition, there are multi-year data gaps in years prior to 1945. It is difficult to draw any conclusions about peak discharge trends from the data that are available, due to the large data gaps.

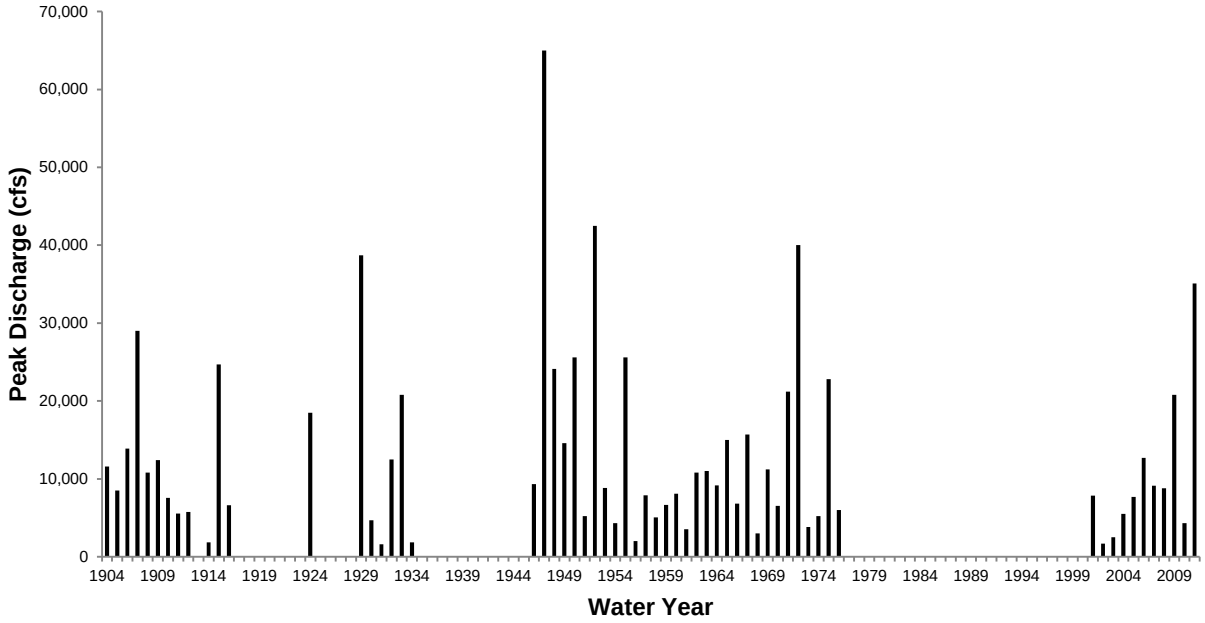


Figure 7. Peak discharge (cfs) for the Little Missouri River at Medora, ND from 1904-2010 (USGS Station No. 06336000) (USGS 2011c, 2012).

The National Weather Service determined the flood stage at Medora to be 15 ft (USGS 2011a). At Medora, the Little Missouri River has reached flood stage seven times since 1904 (in 1904, 1929, 1947, 1952, 1972, 2009, and 2011) (USGS 2011a, 2012). The peak gage heights for 1947, 2011, 1972, 1952, and 1929 were the highest recorded, with respective gage heights of 20.50, 20.39, 18.68, 18.35, and 17.20 ft (USGS 2011a). Interestingly, the 1950 peak gage height passed flood stage in Watford City, but did not in Medora. All years that passed flood stage at Medora (aside from 1947) did not pass flood stage in Watford City, which could be due to the difference in flood stage heights (15 versus 20 ft). As expected, all flow events that surpassed flood stage heights at Medora correspond to years with a higher-than-normal peak discharge; further investigation is needed to determine the actual effects of these high-water events in the park.

Snowpack

Snowpack is often measured in snow water equivalent (SWE). SWE is the water depth that would hypothetically result in the event that the entire snowpack melted at one time (NRCS 2009). This estimate is based off snow depth and snow density information, gathered from SNOTEL sampling locations. Snowpack is directly related to the amount of water entering river systems, and is therefore important to understand when analyzing flooding. The nearest SNOTEL sampling station to the Little Missouri River is located at Cole Canyon, in Sundance, Wyoming. This SNOTEL station is located approximately 60 km east of the headwaters of the Little Missouri River, and should provide a general trend of the changes in snowpack in the last 40 years. Figure 8 displays SWE averages from 1971-2000 and 2001-2009 at Cole Canyon. The 2001-2009 averages are all smaller than the 1971-2000 averages, with 2001-2009 May averages at approximately 1/3 of the 1971-2000 May averages. While it may not be appropriate to draw further conclusions, this general decreasing trend in snowpack could be associated with the

conclusions of Miller and Friedman (2009), that climate is the primary driver for the recent decrease in peak flow magnitudes on the Little Missouri River.

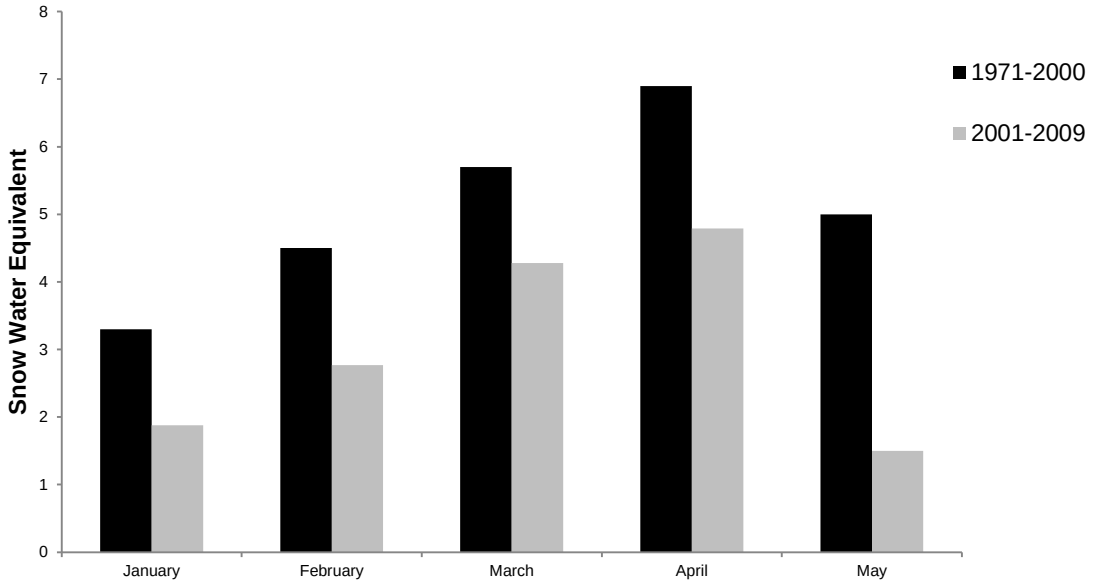


Figure 8. Snow water equivalent averages from 1971-2000 and 2001-2009 at Cole Canyon, Sundance, Wyoming (NRCS 2009).

Duration

The duration of a flood event is related largely to the volume of water received by the stream from precipitation and snowmelt events and the location of where runoff enters the stream. Spring floods are generally longer in duration than summer floods. A positive correlation between duration and magnitude exists, with larger floods having longer durations; a flood of higher magnitude will have more water, so it will take a longer period of time for the saturated soil and upstream tributaries to drain back to normal levels. Contrastingly, summer floods are much shorter, as they are generally a result of intense rain and thunderstorms. While duration appears to be important in forming the total channel area, peak magnitude appears to be the most important factor (Miller 2005).

Effects of upstream water withdrawal on summer flows

Jeff Hughes (pers. comm., 2012) indicated that he is gathering information on water rights and permits for water withdrawal on the Little Missouri River. Currently, the Theodore Roosevelt Medora Foundation has a permit to withdraw 11 cfs from the Little Missouri River (3 miles upstream of the South Unit of THRO) between 1 March and 1 July. The Medora Foundation permit and other similar operations upstream of THRO may affect flow in the Little Missouri River and the NPS Water Rights Branch is currently collecting available information on the number of water users and the amount of water diverted and withdrawn from the Little Missouri River system to determine if adverse impacts could be occurring at the park.

Threats and Stressor Factors

The climate around THRO is semi-arid, with extreme temperatures in the summer and winter months (Miller 2005). On average, the Little Missouri watershed receives 35.6 cm (14 in) of precipitation per year, and approximately 76 cm (30 in) of snowfall (average from 1939-2003) (Miller 2005). In the last 100 years, there has been a reduction in peak flows, and because the Little Missouri is largely unregulated, the cause of this reduction is thought to be related to climate. Climate is related directly to precipitation and snowpack, which directly influence the amount of water moving through the Little Missouri River system. This reduction in peak flows is correlated strongly with a reduction in erosion (Miller 2005), which poses a risk for cottonwood regeneration.

Water retention in stock dams (in upriver tributaries and draws) can change the flooding patterns of the Little Missouri River. There is no current literature explaining the effects of water retention in stock dams in upriver tributaries and draws of the Little Missouri River. Other potential concerns include upstream irrigation practices and withdrawals associated with hydraulic fracturing.

Data Needs/Gaps

Peak magnitude and peak gage height for the Medora gage has major data gaps throughout the entire period of data collection (1904-present). J. Hughes (pers. comm., 2012) indicated that the Medora and Watford City gage locations are largely similar, and statistical models (using the Watford City gage data) likely could be used to predict the missing years for the Medora gage.

J. Hughes (pers. comm., 2012) is currently investigating the amount and extent of water permits near the Little Missouri River, to get a better idea of the amount of water taken from the river. This information would be beneficial in understanding upstream drawdown statistics.

Research investigating the number, location, and extent of stock dams in the upstream tributaries of the Little Missouri River would be beneficial to get a better idea of how these might be affecting floods near THRO.

Overall Condition

Frequency

The project team defined the *Significance Level* of frequency as a 3. As a result of snowmelt, spring floods are still occurring, and summer floods from intense rain and thunderstorms are also occurring; thus, a *Condition Level* of 1 (low concern) was assigned for the frequency measure.

Magnitude

The project team defined the *Significance Level* of magnitude as a 3. While the spring and summer peak flows are still occurring on the Little Missouri, Miller and Friedman (2009) point out that the peak flows have dropped over the last century, likely due to climate change. The decrease in magnitude, coupled with concerns regarding climate change, result in a *Condition Level* of 2 (moderate concern) for the magnitude measure.

Snowpack

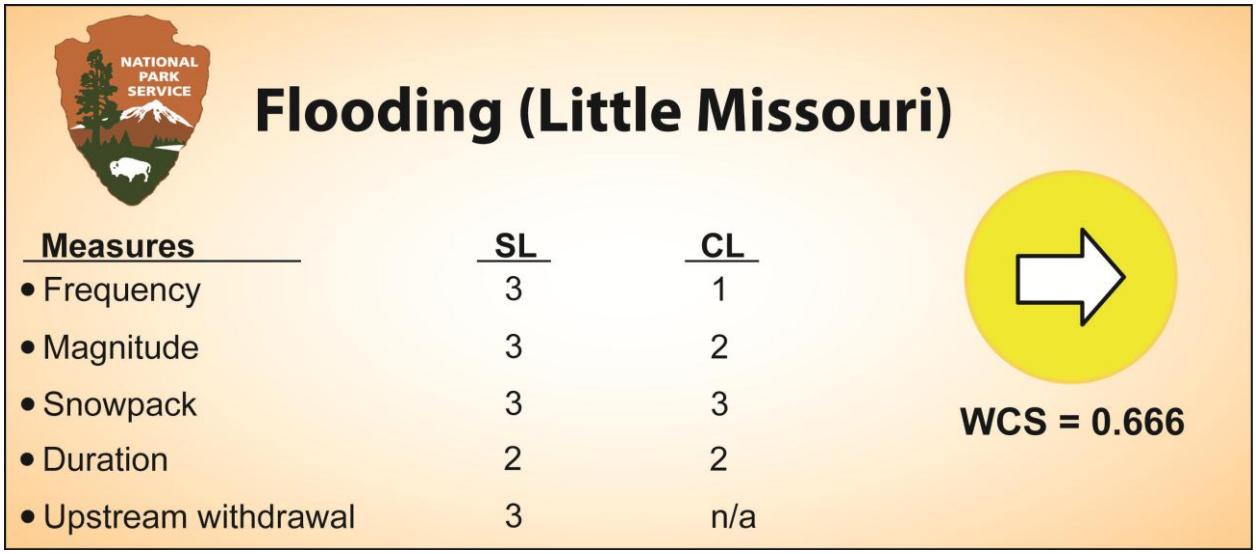
The project team defined the *Significance Level* of snowpack as a 3. Snowpack is the main driver of spring peak flows, and while some years still see heavy snowpack, there has been an overall

decrease in SWE over the last 40 years. Snowpack was given a *Condition Level* of 3 (significant concern) because of these overall decreasing trends.

Duration
The project team defined the *Significance Level* of duration as a 2. Duration is largely a product of magnitude, meaning that a decrease in flood magnitude over the last century has contributed to a decrease in flood duration as well. The project team assigned a *Condition Level* of 2 (moderate concern) for the duration measure.

Effects of Upstream Water Withdrawal on Summer Flows
The project team defined the *Significance Level* of effects of upstream water withdrawal on summer flows as a 3. However, there are no current data on the amount of water withdrawn from the Little Missouri River. Thus, a *Condition Level* for this measure could not be determined.

Weighted Condition Score
While spring and summer peak flows are still occurring, decreases in snowpack have resulted in lower magnitude and duration of peak flows. The overall *Weighted Condition Score* of flooding was 0.666, meaning it is of moderate concern.



4.3.6 Sources of Expertise
Jeff Hughes, Hydrologist, NPS Water Resources Division

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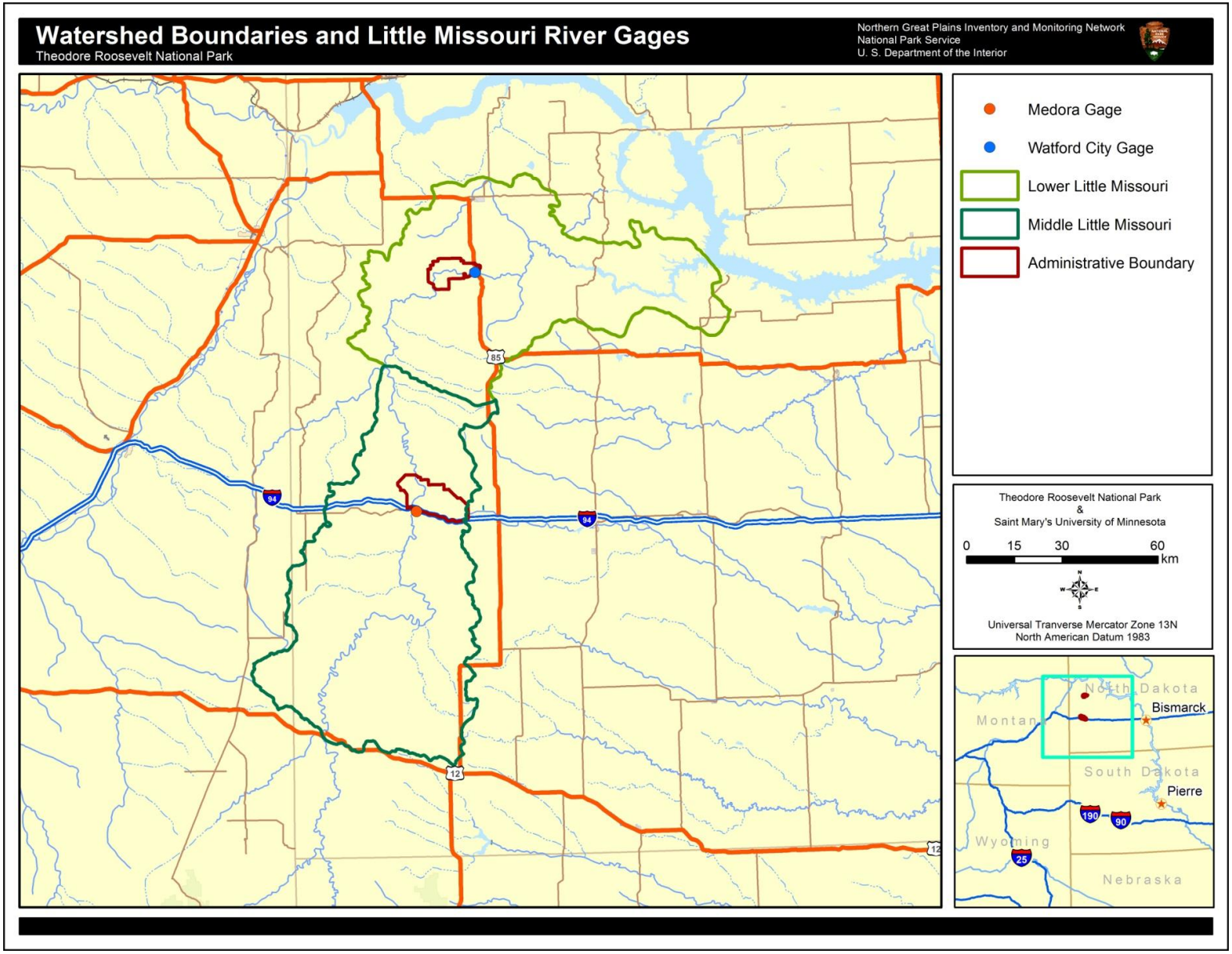


Plate 1. Watershed boundaries and Little Missouri River gages.

4.4 Native Grasslands

4.4.1 Description

Prior to the drought of the 1930s, the mixed-prairie grasslands of the northern Great Plains region were used extensively for grazing and agriculture, including the area that now makes up THRO. The establishment of THRO in 1947 allowed grassland communities within the park to revert to their natural state (Stubbendieck and Willson 1986). Today, native grasslands within THRO are widely distributed across areas with deeper soils such as plains, valleys, buttes, sand hills, and ridges. Grasslands also are interspersed with shrublands and woodlands throughout the park, and grasses sometimes comprise the understory of various woody habitats (Von Loh et al. 2000). Native grasslands support a wide variety of wildlife, from bison and elk to prairie dogs and numerous bird species (NPS 2010a). The most abundant native grass species in THRO include needle-and-thread (*Hesperostipa comata*), blue grama (*Bouteloua gracilis*), and threadleaf sedge (*Carex filifolia*). Von Loh et al. (2000) identified six grassland alliances in THRO (five native and one introduced). The native grassland communities found in the park are listed in Table 21.



Photo 10. Native grassland in the Peaceful Valley in THRO (Photo by Shannon Amberg, SMUMN GSS, 2010).

Table 12. Native grassland communities of THRO (Von Loh et al. 2000).

Common Name	NVCS Association or Complex
Needle-and-Thread Herbaceous Alliance	*Hesperostipa comata – Bouteloua gracilis – Carex filifolia* Herbaceous Vegetation
Western Wheatgrass Herbaceous Alliance	*Pascopyrum smithii – Bouteloua gracilis – Carex filifolia* Herbaceous Vegetation; *Pascopyrum smithii – Nassella viridula* Herbaceous Vegetation
Little Bluestem - Sideoats Grama Herbaceous Alliance	*Schizachyrium scoparium – Bouteloua* (*curtipendula, gracilis*) *– Carex filifolia* Herbaceous Vegetation
Prairie Sandreed Grass Herbaceous Alliance	*Calamovilfa longifolia – Carex inops* ssp. *heliophila* Herbaceous Vegetation
Prairie Cordgrass Temporarily Flooded Herbaceous Alliance	*Spartina pectinata – Carex* spp. Herbaceous Vegetation

4.4.2 Measures

- Species composition
- Distribution

- Prevalence of non-natives

4.4.3 Reference Conditions/Values

The ideal reference condition for this component is the composition and distribution of grasslands prior to European settlement. However, no information is available from this historical period. The earliest description of native grasslands within THRO comes from Hansen et al. (1984), who identified three grassland habitat types in the park: *Hesperostipa comata*/*Carex filifolia*, *Pascopyrum smithii*/*Carex filifolia*, and *Schizachyrium scoparium*/*Carex filifolia*. These descriptions will be used as reference conditions for species composition in the respective grassland types present in the park today. An earlier work by Hanson and Whitman (1938) focused on grasslands in western Northern Dakota and included these three grasslands, as well as a *Calamovilfa longifolia* grassland. Although not specific to the park, these descriptions also can be used as secondary reference conditions for species composition.

4.4.4 Data and Methods

The USGS-NPS Vegetation Mapping Program document (Von Loh et al. 2000) was a major source of information for this component. The NPS Inventory and Monitoring (I&M) Program implemented this project to map and categorize the vegetation of THRO using aerial photography GIS analysis. Multiple sources documented the occurrence of non-natives in the park's grasslands: Hansen et al. (1984), Trammell (1994), Von Loh et al. (2000), and THRO GIS data (NPS n.d.)

4.4.5 Current Condition and Trend

Species Composition

Many of the park's native grasslands have similar species compositions, but with variation in which species are dominant. The most common native grassland type in THRO is the Needle-and-Thread Herbaceous Alliance, which consists of Needle-and-Thread – Blue Grama – Threadleaf Sedge Herbaceous Vegetation. In addition to these three grasses, other common species include Junegrass (*Koeleria macrantha*), western wheatgrass (*Pascopyrum smithii*), prairie sagewort (*Artemisia frigida*), purple coneflower (*Echinacea angustifolia*), prairie coneflower (*Ratibida columnifera*), and the non-natives field brome (*Bromus arvensis*) and yellow sweetclover (*Melilotus officinalis*) (Von Loh et al. 2000).

The Prairie Cordgrass Temporarily Flooded Herbaceous Alliance is characterized by prairie cordgrass (*Spartina pectinata*) and sedge species (*Carex* spp.) Other species in this community include western wheatgrass, foxtail barley (*Hordeum jubatum*), and several non-native grasses. Curly-cup gumweed (*Grindelia squarrosa*), wild bergamot (*Monarda fistulosa*), and white aster (*Aster ericoides*) are commonly associated forbs, although species richness is generally low in cordgrass stands (Von Loh et al. 2000).

In THRO, the Prairie Sandreed Grass Herbaceous Alliance consists of Prairie Sandreed – Long-stolon Sedge Herbaceous Vegetation. In these grasslands, prairie sandreed (*Calamovilfa longifolia*) is associated with threadleaf sedge, little bluestem (*Schizachyrium scoparium*), needle-and-thread, and prairie sagewort. Several stands in the South Unit include porcupine grass (*Hesperostipa spartea*) as a co-dominant graminoid species (Von Loh et al. 2000).

The Little Bluestem-Sideoats Grama Herbaceous Alliance, dominated by little bluestem, is rare within the park. Other species regularly found with little bluestem include sideoats grama (*Bouteloua curtipendula*), threadleaf sedge, prairie sandreed, porcupine grass, and various forbs (Von Loh et al. 2000).

The Western Wheatgrass Alliance is divided further into two associations. The Western Wheatgrass – Blue Grama – Threadleaf Sedge Herbaceous Vegetation Association is dominated by western wheatgrass with blue grama and prairie sagewort as major secondary species on drier sites and green needlegrass (*Nasella viridula*) on more mesic sites (Von Loh et al. 2000). Silver sagebrush is also common, but typically with less than 25% coverage. In the Western Wheatgrass – Green Needlegrass Herbaceous Vegetation Association, western wheatgrass and green needlegrass are codominant, although western wheatgrass is more abundant on drier sites and green needlegrass increases on more mesic sites. Other common species include blue grama and white sagebrush (*A. ludoviciana*). The exotic species Kentucky bluegrass, yellow sweetclover, and leafy spurge are often found in both associations (Von Loh et al. 2000). Table 13 summarizes the most abundant species in each of these grassland communities.

In 2011, the Northern Great Plains Inventory & Monitoring program established and surveyed vegetation in 21 plots in THRO as part of a larger, multi-year vegetation survey (Ashton et al. 2012). Early results indicate western wheatgrass was the most common species across the plots. In $1m^2$ plots, an average of 10 and 12 species were found in the North and South Unit, respectively.

Table 13. The native grasslands of THRO and the most abundant species in each community, as surveyed by Von Loh et al. (2000).

Grassland community	Most abundant species
Needle-and-Thread Herbaceous Alliance	*Hesperostipa comata, Bouteloua gracilis, Carex filifolia*
Western Wheatgrass – Blue Grama – Threadleaf Sedge Herbaceous Vegetation	*Pascopyrum smithii, Bouteloua gracilis, Nasella viridula, Artemisia cana*
Western Wheatgrass – Green Needlegrass Herbaceous Vegetation	*Nassella viridula, Pascopyrum smithii*
Little Bluestem - Sideoats Grama Herbaceous Alliance	*Schizachyrium scoparium, Bouteloua curtipendula, Carex filifolia*
Prairie Sandreed - Long-stolon Sedge Herbaceous Vegetation	*Calamovilfa longifolia, Carex filifolia*
Prairie Cordgrass Temporarily Flooded Herbaceous Alliance	*Spartina pectinata, Pascopyrum smithii, Hordeum jubatum*

Distribution

Native grasslands cover over 10,000 ha of THRO. Their distribution is shown in Plate 2,

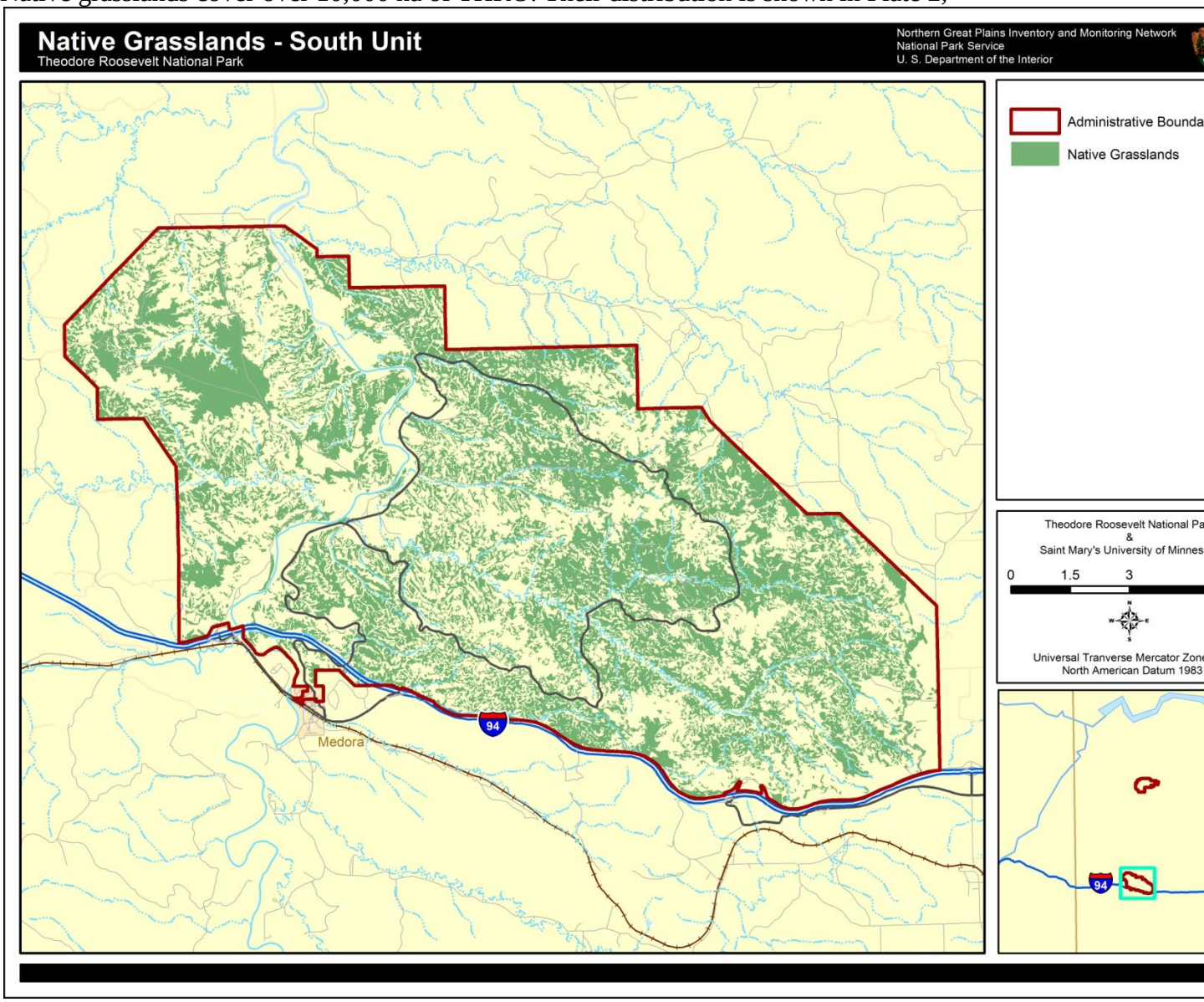


Plate 3, and Plate 4. Needle-and-thread grasslands are the most widely distributed type, with western wheatgrass grasslands a distant second. Needle-and-thread occurs in dry areas on plains, flats on buttes, plateaus, on top of mesas, and dry hillsides (Von Loh et al. 2000). Large areas of these grasslands occur on the Petrified Forest Plateau and Big Plateau in the South Unit, and on the Achenbach Hills of the North Unit. The Western Wheatgrass Herbaceous Alliance generally is found in broad floodplains, moist swales, and slopes below badland formations where runoff water is available (Von Loh et al. 2000).

The Little Bluestem-Sideoats Grama Herbaceous Alliance occurs in small patches on moist north and east facing slopes, but is also common in the understory of several shrubland types, particularly creeping juniper (*Juniperus horizontalis*) (Von Loh et al. 2000). Prairie Sandreed Grass Herbaceous Alliance grasslands occur in small stands on knolls, hilltops, slopes, and at the

heads of mesic draws in both the North and South Units of THRO, often on gravelly or sandy soils. Finally, the Prairie Cordgrass Temporarily Flooded Herbaceous Alliance is found sporadically in the Little Missouri River floodplain and is most noticeable near Scenic Drive in the North Unit. This vegetation occurs in areas where the water table is close to the surface or in depressions holding water following flood events (Von Loh et al. 2000). The area covered by each grassland alliance in the park is shown in Table 14.

Table 14. Area (in hectares) covered by native grasslands in THRO. GIS data from Von Loh et. al. (2000).

Common Name	North Unit	South Unit	EHR	Total
Needle-and-Thread Herbaceous Alliance	2,182.8	7,126.4	3.5	9,312.7
Western Wheatgrass Herbaceous Alliance	369.5	832.2	0.8	1,202.5
Little Bluestem - Sideoats Grama Herbaceous Alliance	75.6	9.4	--	85.0
Prairie Sandreed Grass Herbaceous Alliance	12.8	44.6	--	57.4
Prairie Cordgrass Temporarily Flooded Herbaceous Alliance	11.6	--	--	11.6

Prevalence of Non-natives

In addition to the five native grasslands, Von Loh et al. (2000) mapped an Introduced Grassland Alliance in the park. This alliance covered 146 ha in the North Unit and 192 ha in the South Unit for a park-wide total of 338 ha (Plate 5 and Plate 6). Kentucky bluegrass is one of the most widespread exotic grasses in THRO, dominating the eastern portion of the South Unit. This species is present on many of the more moist areas in the park where western wheatgrass would be expected to occur (Von Loh et al. 2000). The other dominant non-native grasses in the park are crested wheatgrass and smooth brome. Additional non-native species documented in THRO's grasslands as of 2000 are listed in Table 15. More recent non-native plant survey efforts have not identified the plant community where each species has been found. A full list of non-native plant species in the park (many of which are likely found in native grasslands) can be found in Appendix C. Grassland areas sampled in the park during 2011 as part of an NGPN plant community monitoring program averaged 17% (±12.4%) non-native species cover in the North Unit and 16% (±15.7%) in the South Unit (Ashton et al. 2012).

Table 15. Non-native species documented in THRO grasslands (Hansen et al. 1984, Trammell 1994, Von Loh et al. 2000).

Common Name	Scientific Name
Field brome	*Bromus arvensis*
Cheatgrass	*Bromus tectorum*
Lambsquarters	*Chenopodium album*
Barnyard grass	*Echinochloa* spp.
Leafy spurge	*Euphorbia esula*
False flax	*Camelina microcarpa*
Prickly lettuce	*Lactuca serriola*
Yellow sweetclover	*Melilotus officinalis*
Alfalfa	*Medicago sativa*
Dandelion	*Taraxacum officinale*
Yellow salsify	*Tragopogon dubius*

Threats and Stressor Factors

Non-native plants have invaded the native grasslands of THRO and have become dominant in some areas of the park. In addition to altering native species composition, non-natives can alter natural processes such as fire, nutrient cycling, and erosion (Von Loh et al. 2000). As of 1994, 36 non-native plant species had been observed within the park during field surveys (Trammell 1994). By 2011, over 60 non-native species were documented in the park with many more thought to be present (Appendix C). The most problematic and aggressive non-native plants in THRO are leafy spurge and Canada thistle (*Cirsium arvense*). In 2011, THRO and EPMT staff chemically treated infestations of Canada thistle in North Unit grasslands and leafy spurge in South Unit grasslands (L. Richardson, pers. comm., 2012). Non-native grasses introduced from pasture lands include crested wheatgrass, Kentucky bluegrass, and smooth brome (Von Loh et al. 2000).

Fire suppression is another threat to the park's native grasslands. Fire is one of the most important processes in the maintenance of grassland systems (Anderson 1990), as it reduces competition from woody species. Frequent fires are important for maintaining native species diversity and also positively impact other grassland components, such as nutrient cycling and productivity (Collins and Wallace 1990). Fire suppression often leads to juniper and other woody species encroachment into native grasslands (NPS 1994, 2010b) and can favor non-native plants over native species (Whisenant and Uresk 1990). Fire was viewed as a danger to people, property, and resources for much of the 20th century and was suppressed all across the Great Plains (NPS 2010b). Fire returned to the landscape of THRO in the form of prescribed burns in the late 1990s. Further discussion of fire in THRO is found in section 4.1 of this assessment. Overgrazing is not currently a threat to the park's grasslands (L. Richardson, pers. comm., 2012).

Data Needs/Gaps

While the park is monitored annually for non-native species, Von Loh et al.'s (2000) vegetation mapping project remains the most comprehensive survey conducted in the park. In 2011, a plant community composition and structure monitoring was initiated by the NGPN and baseline data was gathered in all network parks. Twenty-one plots (16 upland and five riparian) were sampled in THRO (Ashton et al. 2012). Over time, this monitoring data will allow for a better comparison of current grassland condition to earlier reports (e.g., Hanson and Whitman 1938, Hansen et al.

1984). An updated vegetation mapping effort would also help to identify the extent of juniper and other woody encroachment into park grasslands.

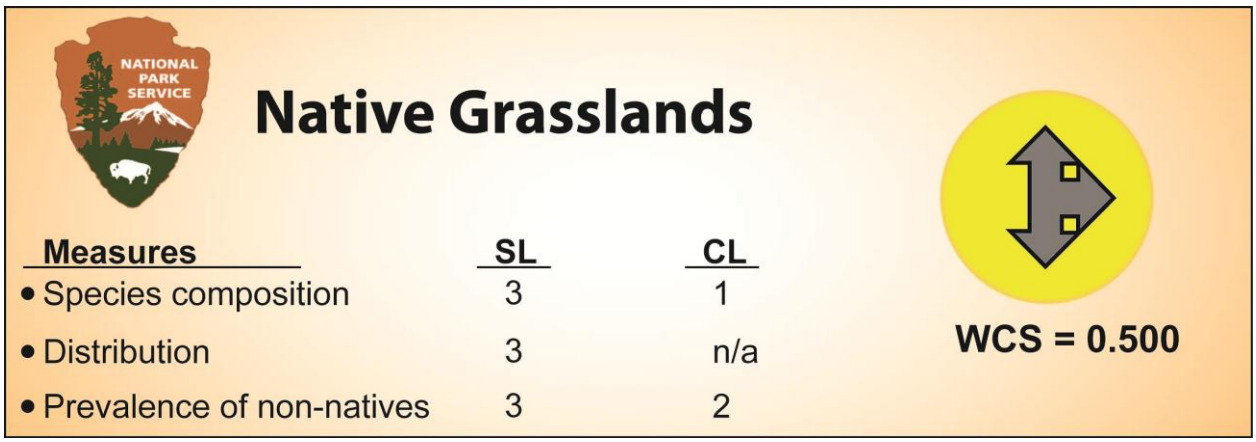
Overall Condition

Species Composition
During initial scoping meetings, THRO staff assigned the measure of species composition a *Significance Level* of 3. Von Loh et al.'s (2000) grassland species composition descriptions are slightly different than those in Hansen et al. (1984) and Hanson and Whitman (1938). While Von Loh et al.'s (2000) description of the needle-and-thread herbaceous alliance is very similar to Hanson and Whitman (1938), it differs from Hansen et al. (1984) who reported very little blue grama and more western wheatgrass in the *Hesperostipa comata*/*Carex filifolia* habitat type. Hansen et al. (1984) also reported minimal blue grama and green needlegrass in the *Pascopyrum smithii*/*Carex filifolia* habitat type, two grasses that were key "secondary species" in Von Loh et al.'s (2000) descriptions. Some of these differences could be natural variation due to climate variability, fire regime, and land use shifts (e.g., grazing). These differences are worth further investigation and this measure is therefore assigned a *Condition Level* of 1 indicating low concern. In the future, data from the NGPN plant community monitoring can be used to assess this measure.

Distribution
A *Significance Level* of 3 was assigned to the measure of distribution. Since there are no historic or more recent distribution maps that are directly comparable to Von Loh et al.'s (2000) distribution data, a *Condition Level* cannot be assigned. Data from the NGPN plant community monitoring may also be useful in assessing this measure in the future.

Prevalence of Non-natives
A *Significance Level* of 3 was assigned to the prevalence of non-native species measure. Non-native grasses have become dominant in several areas within THRO and have the potential to expand further into native grasslands. Several other non-native species, particularly the aggressive leafy spurge, have been documented in the park's native grasslands. This measure was assigned a *Condition Level* of 2, indicating moderate concern.

Weighted Condition Score
The *Weighted Condition Score* (WCS) for native grasslands in THRO is 0.500, indicating moderate concern. The trend is currently unknown, although the new network vegetation monitoring program should help to fill this gap in the near future.



4.6.1 Sources of Expertise

Laurie Richardson, Botanist, THRO

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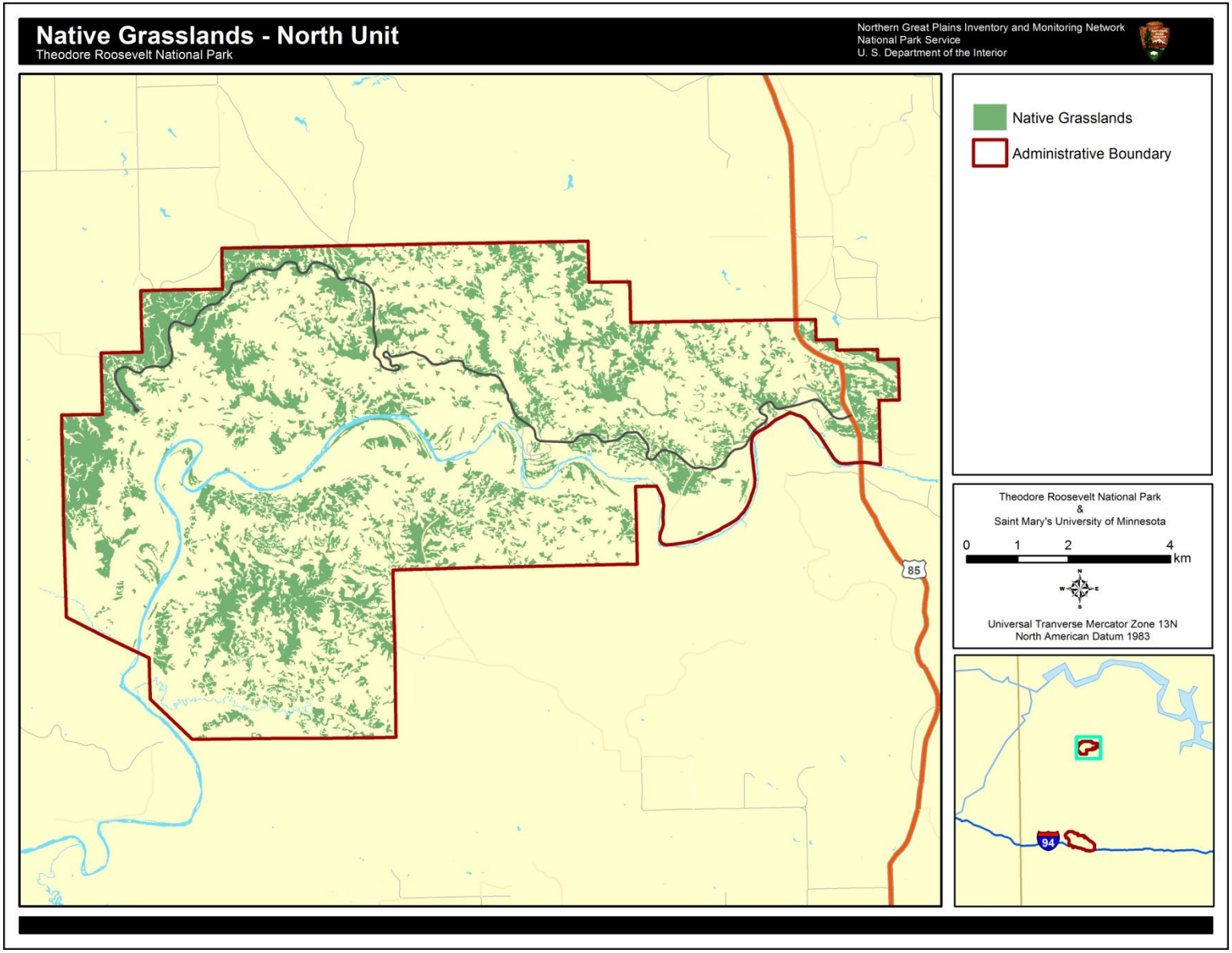


Plate 2. Native grassland alliances in the North Unit of THRO.

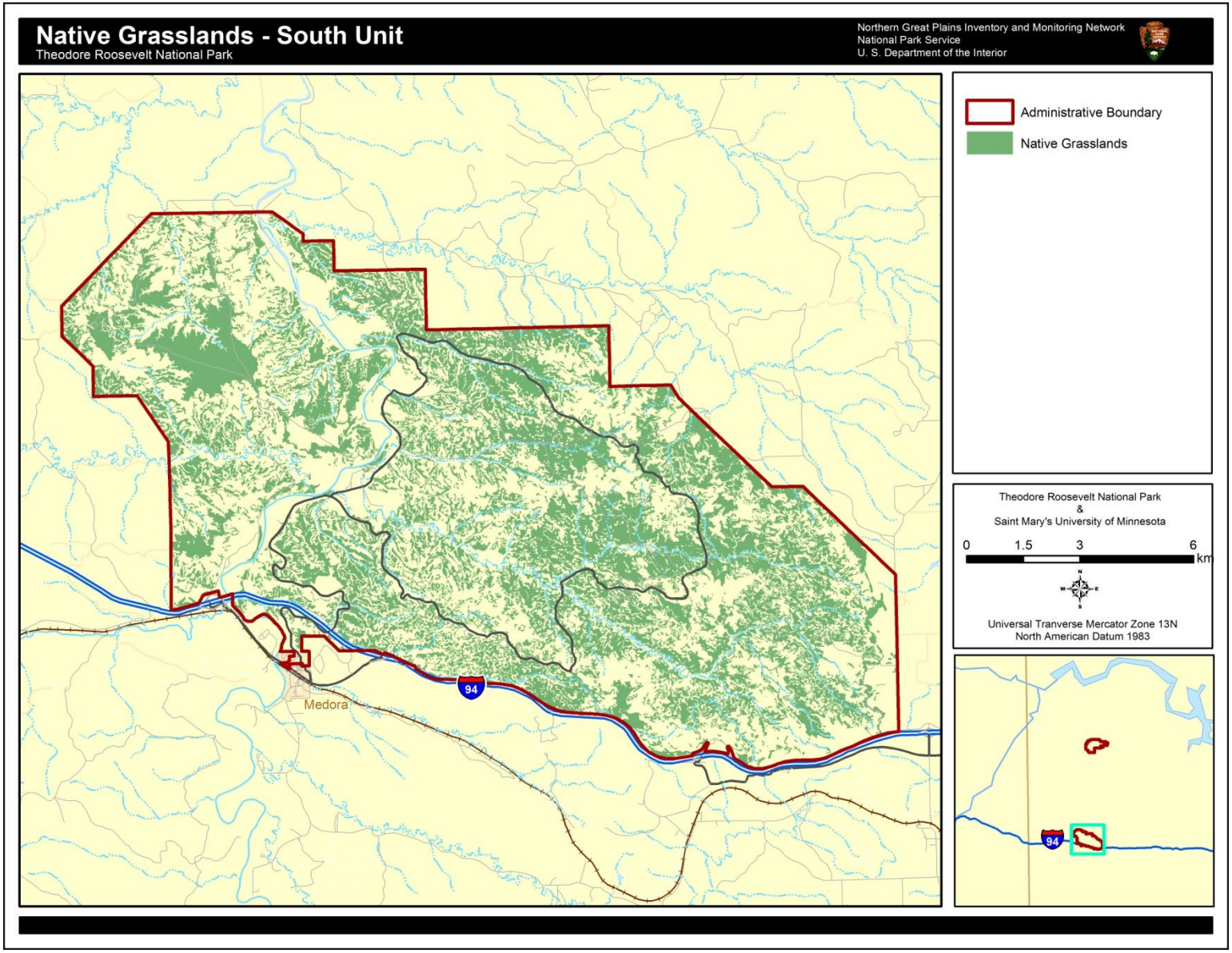


Plate 3. Native grassland alliances in the South Unit of THRO.

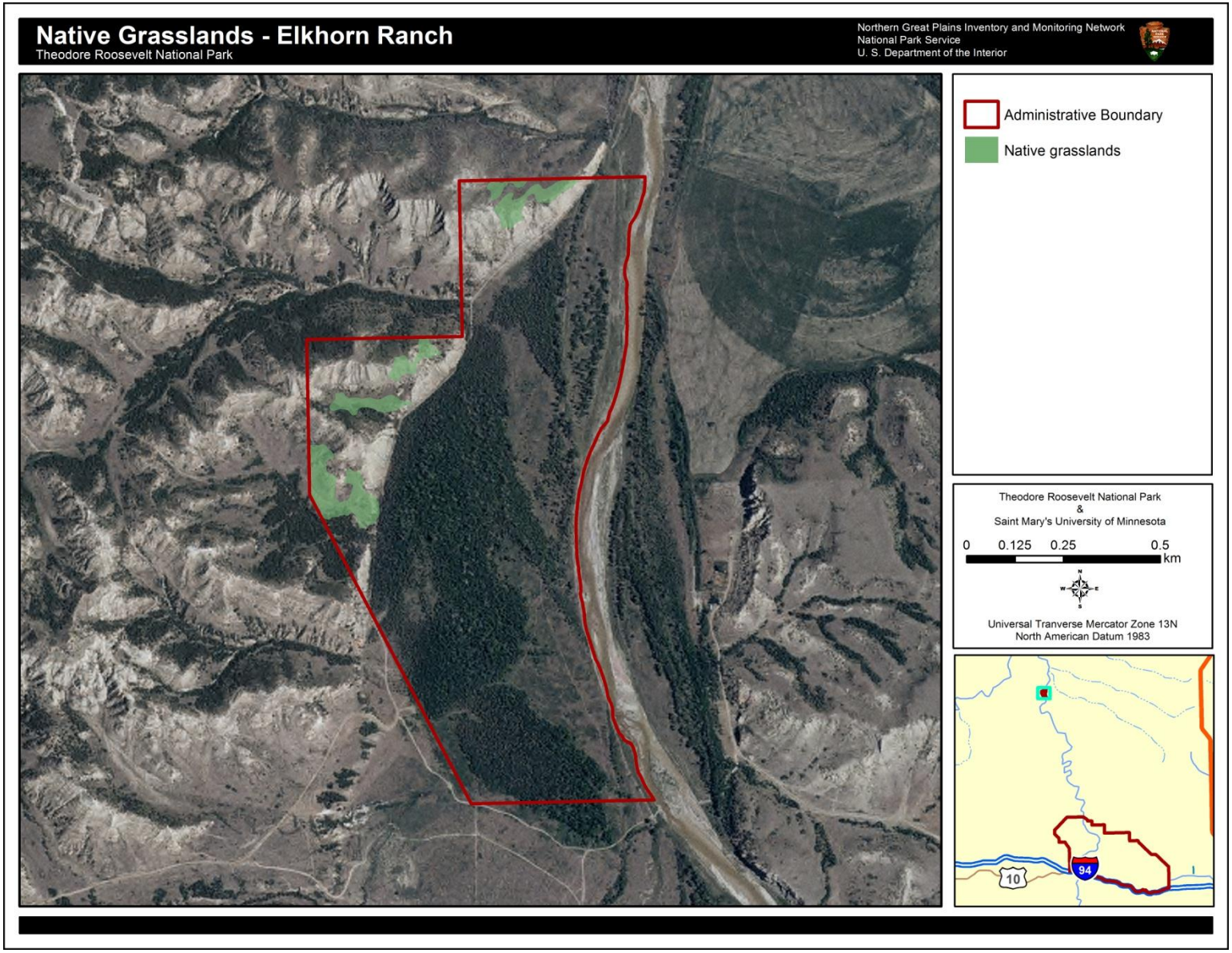


Plate 4. Native grassland alliances in the Elkhorn Ranch Unit of THRO.

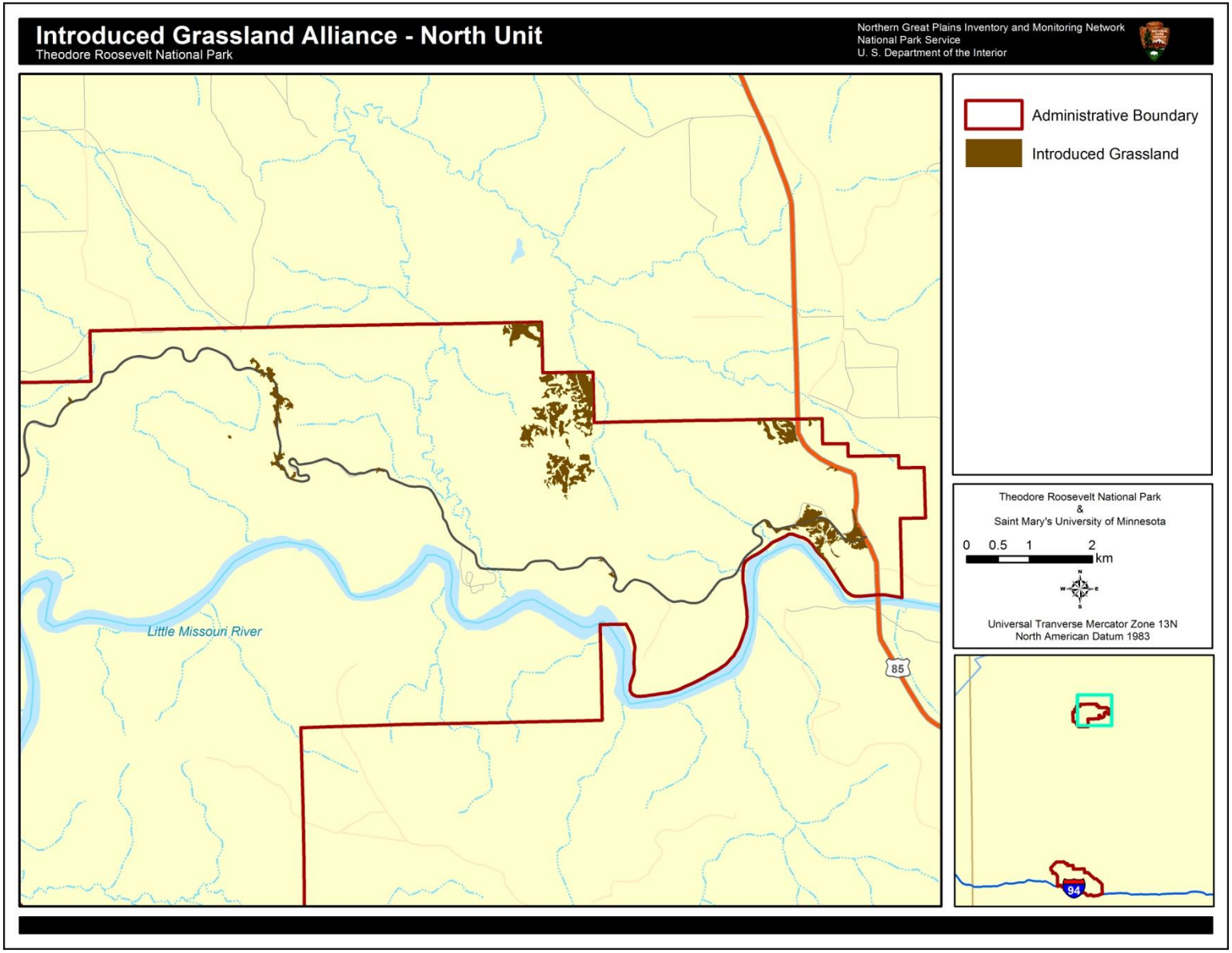


Plate 5. The introduced grassland alliance in the North Unit of THRO.

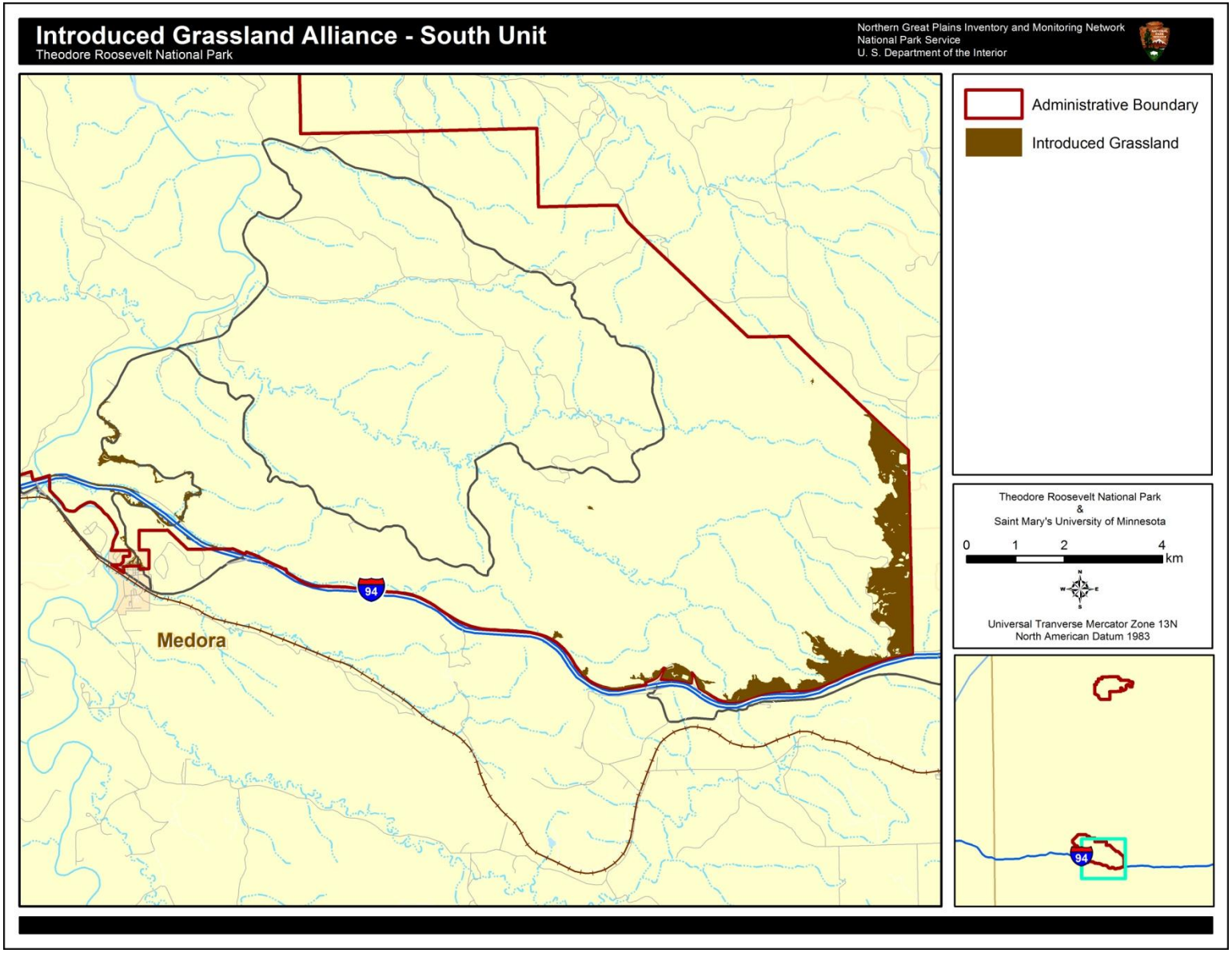


Plate 6. The introduced grassland alliance in the South Unit of THRO.

4.5 Juniper Forests

4.5.1 Description

Juniper forests are considered a distinct vegetation type in THRO and occur primarily on north-facing hill slopes in the park. This forest type, dominated by Rocky Mountain juniper (*Juniperus scopulorum*), is the most common wooded plant community in the park (NPS 2010a). Juniper forests are important for slowing erosion on slopes and are the preferred habitat for elk (*Cervus elaphus*) in THRO (NPS 2010a). Berry-like cones produced by junipers are a critical food source for several bird species in the park, including Townsend's solitaires (*Myadestes townsendi*), cedar waxwings (*Bombycilla cedrorum*), Bohemian waxwings (*B. garrulus*), and American robins (*Turdus migratorius*) (NPS 2010a).



Photo 11. Rocky Mountain juniper in THRO (Photo by Shannon Amberg, SMUMN GSS 2010)

Juniper forests in the park often are wooded densely with thick tree canopies (Von Loh et al. 2000). Green ash (*Fraxinus pennsylvanica*) and chokecherry (*Prunus virginiana*) are also common but at much lower densities. Characteristic understory species include little-seed ricegrass (*Oryzopsis micrantha*), mosses and lichens, and false Solomon's seal (*Maianthemum stellatum*) (Hansen et al. 1984, Von Loh et al. 2000).

4.5.2 Measures

- Distribution
- Density

4.5.3 Reference Conditions/Values

The ideal reference condition for this component would be the composition and distribution of juniper forests prior to European settlement. However, no information is available from this historical period. The earliest description of THRO's juniper forests comes from Ralston (1960), who studied the structure and ecology of "north slope juniper stands" in the area. This source will act as the reference condition for density in this assessment. For the distribution measure, Von Loh et al.'s (2000) 1996-97 vegetation mapping data will serve as the reference condition.

4.5.4 Data and Methods

Von Loh et al. (2000) used remote sensing to map vegetation in THRO and provided the majority of information regarding juniper forests in the park, particularly regarding distribution. Ralston (1960) also provided stand density data for several juniper forests in the park. Density measurements were calculated using the quarter method (Cottam and Curtis 1956) in 12 juniper stands in the North and South Units of THRO (Ralston 1960).

4.5.5 Current Condition and Trend

Distribution

Rocky Mountain juniper often covers steep north-facing slopes in the badlands, facing away from direct sun where there is less surface insolation, conditions are cooler, snow remains longer in the spring, and moisture evaporates less readily (Godfread 1994). It is widely distributed across THRO, most often forming dense woodlands in drainages and draws, but also occurring on ridges, hill tops, and slumps on side slopes (Von Loh et al. 2000). Nelson (1961) states that this vegetation type generally is found on slopes of scoria or clay, and that juniper will generally cover the slope from its base to the summit.



Photo 12. Juniper forests in the North Unit of THRO (Photo by Shannon Amberg, SMUMN GSS 2010).

Plate 7, Plate 8, and Plate 9 display the area covered by the Rocky Mountain juniper alliance as of 2000 in the North, South, and Elkhorn Ranch Units of THRO, respectively. Based on GIS data, this vegetation alliance is slightly more widespread in the North Unit. GIS data are also available for the distribution of the *Juniperus scopulorum*/*Oryzopsis micrantha* habitat type in the park as of 1984 (Norland 1984). Although not directly comparable due to slight methodology differences, a comparison of total juniper forest area in 1984 and 2000 suggests that these forests have expanded over time. According to 1984 GIS data, the *Juniperus scopulorum*/*Oryzopsis micrantha* habitat type covered approximately 1,000 ha of THRO (just under 500 ha in the South Unit and just over 500 ha in the North Unit). By 2000, GIS data show Rocky Mountain juniper woodland covering approximately 3,800 ha of the park (about 2,200 ha in the South Unit and 1,600 ha in the North Unit) (Von Loh et al. 2000).

Density

No recent information is available regarding the density of THRO's juniper forests specifically. Stand density data is being gathered as part of the NGPN plant community monitoring, but this monitoring has just completed its first year.

Ralston (1960) calculated densities for 12 juniper stands in THRO

Table 16). Stands with the highest density also exhibited the greatest reproduction rates. Density appeared to be related to fire intensity, with stands exposed to higher intensity fires actually showing higher densities (Ralston 1960).

Table 16. Tree densities for THRO juniper stands sampled in 1960 (Ralston 1960).

Stand	Density (trees per acre)			
	Ash	Juniper	Total	Juniper saplings (trees/m^2)
101	19.5	759	778.5	0.30
102	--	1286	1286	--
103	--	970.37	970.37	0.20
104	34.3	880.7	915.00	0.2875
105	154.8	619.6	774.4	0.325
106	134	844	978	0.1125
107	292	770	1062	--
109	11.44	903.56	915	0.25
110	1041.7	852.3	1894	--
111	134	763	897	0.162
112	23	906	926	0.10
116	177.4	1241.6	1419	--

Threats and Stressor Factors

Non-native plant species constitute a threat to the juniper forests of THRO. These species can impact native species composition and alter natural processes such as fire, nutrient cycling, and erosion (Von Loh et al. 2000; as reviewed by Brooks et al. 2004). THRO and EPMT staff have been chemically treating infestations of Canada thistle in North Unit juniper forests and leafy spurge and Canada thistle in South Unit forests annually for nearly a decade (NPS n.d.). Other non-natives documented in juniper stands are field brome, yellow sweet clover, Kentucky bluegrass, lambsquarters, dandelion, and yellow salsify (Hansen et al. 1984, Trammell 1994, Von Loh et al. 2000).

Rocky Mountain juniper generally is considered intolerant of fire. Particularly intense fires can kill all but the largest junipers in a stand (Scher 2000). However, without fire juniper woodlands will expand and eventually encroach into other native plant communities (Burkhardt and Tisdale 1976, NPS 2010b). The majority of Rocky Mountain juniper stands sampled during the THRO vegetation mapping program showed evidence of historic burns (Von Loh et al. 2000). Some evidence suggests that juniper stands that experienced fires of a certain intensity actually increased in stand density and reproduction over time (Ralston 1960).

Data Needs/Gaps

Density and other stand structure data is lacking for THRO's juniper forests and could help managers better understand the juniper encroachment occurring in the park. NGPN plant community monitoring will contribute some stand density information over time. Also, the distribution of juniper has not been mapped since 2000. Updated distribution data would help identify any vegetation changes (e.g., juniper encroachment) occurring in the park.

Overall Condition

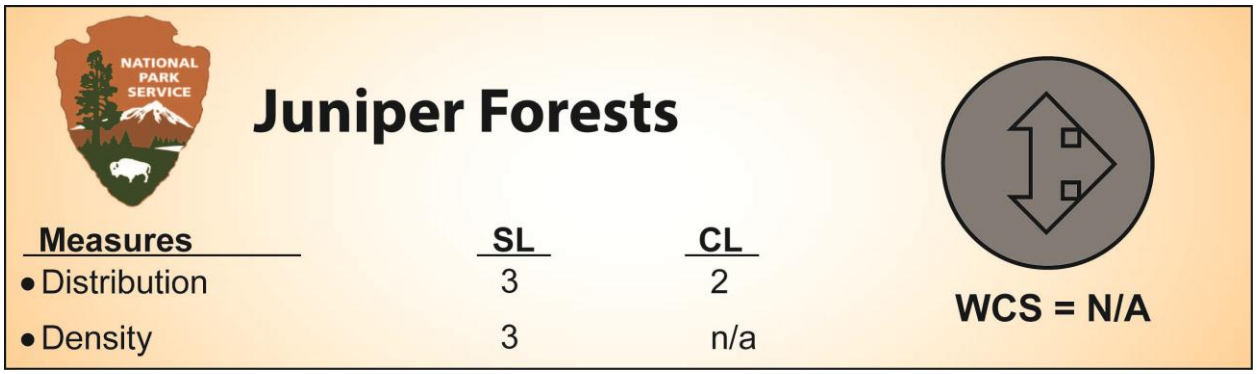
Distribution

A *Significance Level* of 3 was assigned to the measure of juniper forest distribution. Evidence suggests that juniper distribution has expanded in the park over time, perhaps due to a long period of fire suppression. Junipers are encroaching on other native plant communities, which is

a concern for park management. Therefore, this measure is assigned a *Condition Level* of 2, indicating moderate concern.

Density
A *Significance Level* of 3 was assigned to the measure of juniper forest density. Since no recent density information is available for the park, a *Condition Level* could not be assigned.

Weighted Condition Score
A *Weighted Condition Score* (WCS) could not be calculated for the juniper forest community in THRO, since a *Condition Level* was only assigned for one of the two measures. As a result, the condition and trend of juniper forests in the park are considered unknown.



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Laurie Richardson, Botanist, THRO

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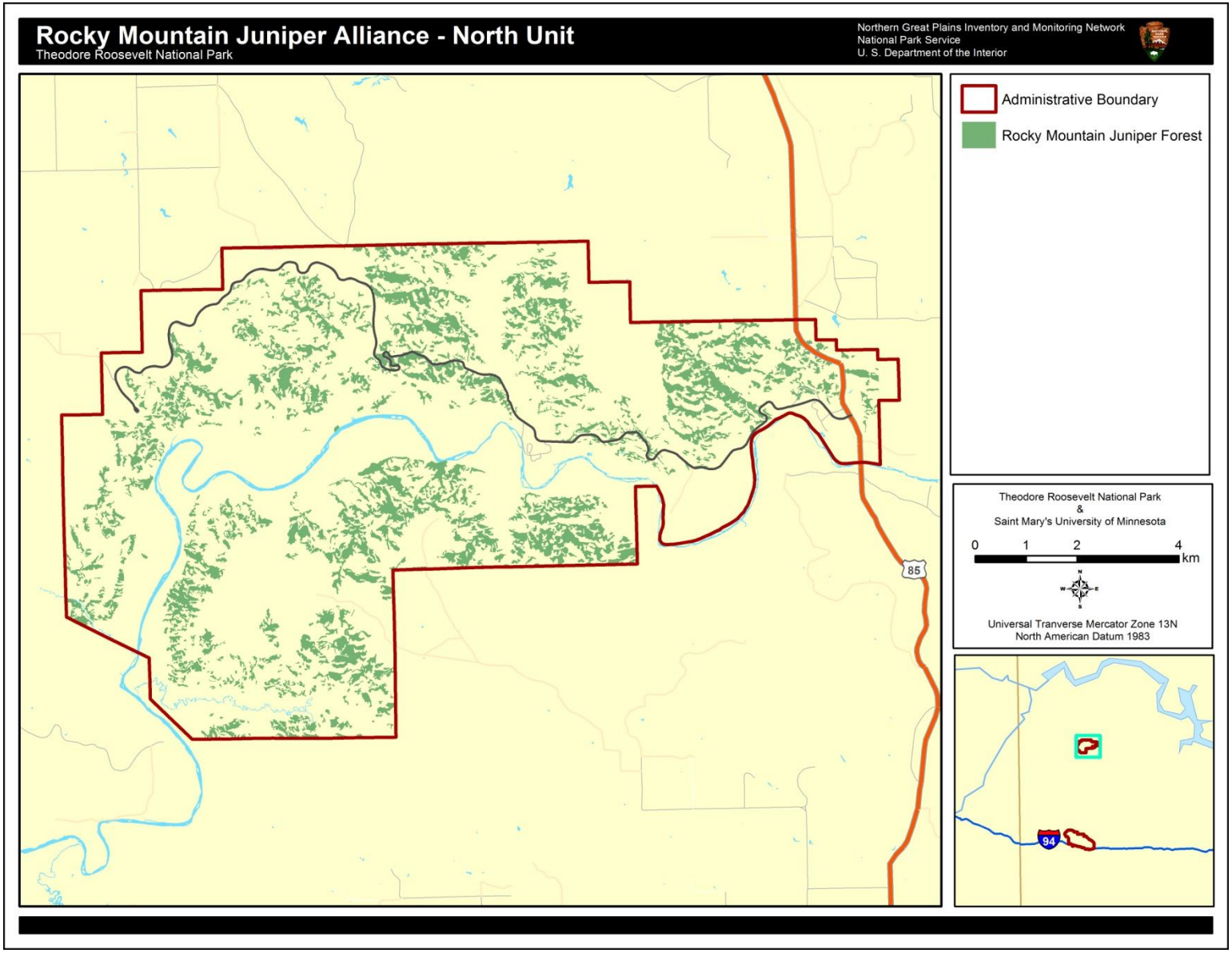


Plate 7. Rocky Mountain Juniper Alliance in the North Unit of THRO.

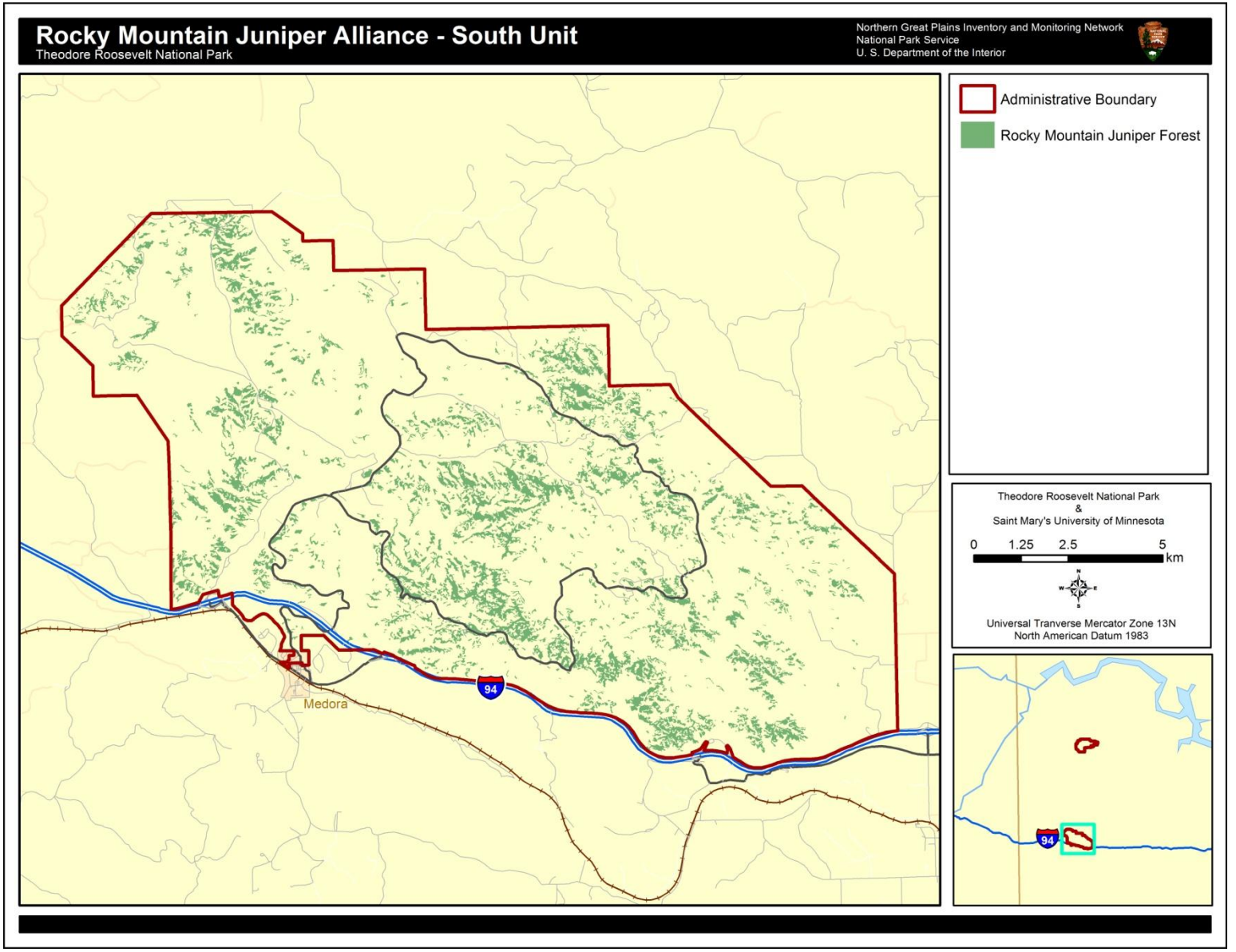


Plate 8. Rocky Mountain Juniper Alliance in the South Unit of THRO.

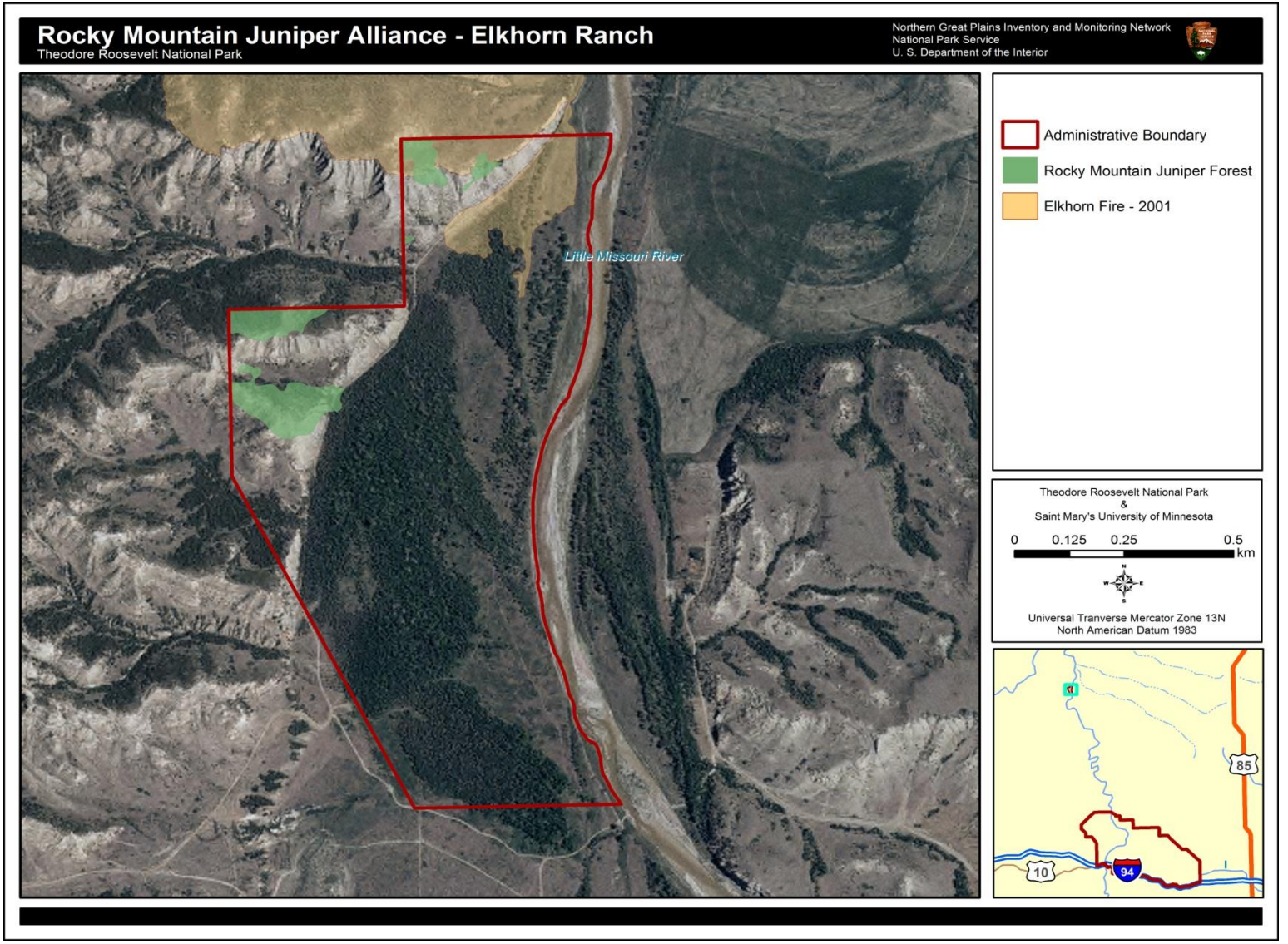


Plate 9. Rocky Mountain Juniper Alliance in the Elkhorn Ranch Unit of THRO (based on 1996 aerial imagery). Juniper stands in the northwestern corner are no longer visible in 2004 aerial photography, as this area burned in the Elkhorn wildfire that occurred in August 2001**.**

4.6 Floodplain Woodlands

4.6.1 Description

Floodplain woodlands are areas dominated by trees with less than 60% canopy cover (Von Loh et al. 2000), occurring along the banks of the Little Missouri River and its major tributaries in THRO (Miller 2005). Sometimes referred to as gallery forests (Norland 1984, Girard et al. 1989), or more broadly as bottomland forests (Nelson 1961), they are primarily characterized by cottonwood-willow (*Populus-Salix* sp.) woodlands (Miller 2005). Floodplain woodlands at THRO are dominated by plains cottonwood (*Populus deltoides* subsp. *Monilifera*).



Photo 13. Floodplain woodlands along the Little Missouri River in the North Unit of THRO (photo by Shannon Amberg, SMUMN GSS 2010).

Native woodlands represent less than 5% of the southwestern North Dakota vegetation (Jakes and Smith 1983); floodplain woodlands along the Little Missouri River represent a subset of these woodlands. The plant communities/alliances related to floodplain woodlands, along with those alliances that may succeed to or from floodplain woodlands, are listed in Table 17. According to GIS data (Von Loh et al. 2000), cottonwood woodlands and other related map units listed in Table 17 make up approximately 55% of the EHR, 7% of the North Unit, and 1% of the South Unit, and 3.4% of the total land area across the three units of THRO. Despite the small proportion on the landscape, these woodlands and associated alliances provide valuable habitat for many wildlife species in THRO including white-tailed deer (*Odocoileus virginianus*) (Nelson 1961), numerous bird species, porcupine (*Erithizon dorsatum*), and beaver (*Castor canadensis*) (NPS 2009).

Reproduction and age structure of cottonwood woodlands are controlled by river flooding and channel migration. Survival of woodland species during drought depends upon a water subsidy from the river. Reproduction and survival of these woodlands has been impaired globally by construction of dams and channel stabilization that limit flooding and channel migration, and by summer water withdrawals that cause drought mortality. The Little Missouri River in THRO is a rare example of a large river with minimal flow regulation, channel stabilization, or land clearing. As a result this forest includes the oldest known plains cottonwood trees in the world (up to 371 years, Friedman pers. comm., 2012), and the age structure and spatial patterns of cottonwood trees serve as a reference example of the natural condition for this plant community.

Table 17 Reproduction and age structure of cottonwood woodlands are controlled by river flooding and channel migration. Survival of woodland species during drought depends upon a water subsidy from the river. Reproduction and survival of these woodlands has been impaired globally by construction of dams and channel stabilization that limit flooding and channel migration, and by summer water withdrawals that cause drought mortality. The Little Missouri River in THRO is a rare example of a large river with minimal flow regulation, channel stabilization, or land clearing. As a result this forest includes the oldest known plains cottonwood trees in the world (up to 371 years, Friedman pers. comm., 2012), and the age structure and spatial patterns of cottonwood trees serve as a reference example of the natural condition for this plant community.

Table 17. Map unit descriptions and NVCS associations related to floodplain woodlands in THRO (Von Loh et al. 2000).

Map unit description	NVCS Association or Complex
Sandbar Willow Temporarily-Flooded Shrubland Alliance [a]	*Salix exigua* temporarily flooded shrubland
Cottonwood – Peachleaf Willow Floodplain Woodland	*Populus deltoides* – (*Salix amygdaloides*) / *Salix exigua* woodland
Cottonwood Temporarily Flooded Woodland Alliance	*Populus deltoides* temporarily flooded woodland
Cottonwood – Rocky Mtn. Juniper Floodplain Woodland	*Populus deltoides* / *Juniperus scopulorum* woodland
Green Ash – American Elm Temporarily-Flooded Woodland Alliance [b]	*Fraxinus pennsylvanica* / *Ulmus americana* temporarily flooded woodland alliance

[a] An early successional stage of cottonwood woodlands, as it contains some young cottonwoods.

[b] A late successional stage of cottonwood woodlands.

4.6.2 Measures

- Species composition and abundance
- Changes in species distribution
- Cottonwood woodland area-age distribution
- Non-native species abundance

4.6.3 Reference Conditions/Values

The ideal reference condition for this component would be the composition and distribution of floodplain woodlands prior to European settlement. Successional processes in these forest types are described in detatil in Johnson et al. (1976). Generally the authors conclude that river meandering patterns are an important determinant of horizontal and vertical distribution of the cottonwood forests, and that the rate of river meandering is a major factor in determing the composition of foodplain woodland stages (e.g., pioneer, transitional, and terminal



Photo 14. Understory view of a cottonwood woodland in the North Unit of THRO (photo by Shannon Amberg, SMUMN GSS, 2010).

forest types). However, no map information is available from this period. Everitt (1968) provides some of the oldest observations of cottonwood stand ages in a 2.4 km (1.5 mi) section of the Little Missouri River in THRO. Norland (1984) also provides some older map information regarding floodplain woodlands; however, the data and specifically map classes are not comparable to recent map data developed by Von Loh et al. (2000). Everitt (1968) described the cottonwood floodplain forests as a living record of past river channel migrations. Cottonwood establishment and survival relies on widening of the river channel after floods and narrowing during low flow periods (Everitt 1968, Johnson 1994, Friedman and Lee 2002).

Cottonwood woodlands dominate the floodplain forest of the Little Missouri River. Girard et al. (1989) found two specific community types common in the floodplain, *P. deltoides/Juniperus scopulurum* (eastern cottonwood/ Rocky Mountain juniper) and *P. deltoides/F. pennsylvanica* (eastern cottonwood/green ash). *P. deltoides/Juniperus scopulurum* occurs on more recently deposited alluvial sites and *P. deltoides/F. pennsylvanica* on more mature sites (Girard et al. 1989). Girard et al. (1989) suggest that under certain conditions (e.g., absence of disturbance), these communities will likely succeed to *F. pennyslvanica*/*S. occidentalis* (green ash/western snowberry). It is unclear if the Green Ash – American Elm Temporarily-Flooded Woodland Alliance identified by Von Loh et al. (2000) represents a transitional gradient of the green ash/ western snowberry community mentioned by Girard et al. (1989). According to the Von Loh et al. (2000) GIS data, the Green Ash – American Elm Temporarily Flooded Woodland Alliance is a climax community of floodplain woodlands and shrublands. The species composition, distribution, and status of cottonwood regeneration in floodplain woodlands may vary over time, depending on disturbance regimes. However, cottonwood stand ages can provide an indication of what the near future may hold for the previously mentioned measures.

The presence of non-native species, especially those considered invasive, is undesirable for the biological integrity of the floodplain woodlands, or any native vegetation community in the park. The ideal reference condition for non-native plant species, particularly those considered invasive, would be no presence in the park. However, this is an unrealistic goal, given the current density and vectors of spread.

4.6.4 Data and Methods

Two GIS datasets characterize the vegetation communities of THRO, one published in 1984 and the other in 2000. The 1984 vegetation dataset is a product of aerial-photo interpretation in Norland (1984) (a bison habitat mapping thesis), using 1:12,000 scale color-infrared photos. Map units relevant to floodplain woodlands include:

- River bottoms mapping unit: areas mapped by the author and simply defined as areas subject to frequent flooding;
- Willows mapping unit: areas dominated by densely growing willow (*Salix* spp.), with little other plant growth;
- Grassed sand floodplain habitat type, or a sandy range (bison) site;
- *Populus deltoides – Juniperus scopulorum* habitat type: identified in the thesis by Michele Girard of North Dakota State University.

The other GIS vegetation dataset in THRO is from the USGS-NPS Vegetation Mapping Program (Von Loh et al. 2000). These data are classified using the Standardized National Vegetation Classification System (NVCS), contain additional plant community types, and also combined some land use classes (e.g., transportation, communications, and utilities; mixed urban or built-up land; croplands and pasture). The map product used 1996, 1:24,000 scale aerial photography from the USFS. The overall initial accuracy was 74.3% for all mapped vegetation classes (Von Loh et al. 2000).

The Von Loh et al. (2000) data contain more detailed information than GIS data derived from the earlier study (Norland 1984). Von Loh et al. (2000) identify 39 unique map classes or map units (27 natural and semi-natural alliances and associations, two complexes, and 10 Anderson et al. [1976] land use classes). However, the two datasets are not quantitatively comparable and cannot be used to examine changes in species composition and abundance, changes in species distribution, or shifts in cottonwood area-age distribution. Von Loh et al. (2000) is used below to report current conditions of floodplain woodlands in THRO.

4.6.5 Current Condition and Trend

Species Composition and Abundance

Von Loh et al. (2000) describe five plant community associations relevant to THRO's floodplain woodlands (Table 17). However, the authors warn that many of the plant associations' compositions are variable and some confusion between associated floodplain shrublands and woodlands were revealed during map accuracy assessments. The sandbar willow temporarily flooded shrubland alliance (cottonwood seedlings are often present in this alliance) may succeed to cottonwood woodlands over time, therefore it is included in the floodplain woodland assessment. Cottonwood woodlands also succeed to cottonwood-Rocky Mountain juniper, and finally to green ash – American elm temporarily flooded woodland alliance. This alliance is the climax vegetation community of the floodplain woodlands, given enough time without flooding (Von Loh et al. 2000). The most common species by stratum in each of the map units is displayed in Table 18.

Table 18. Abundant species in floodplain shrubland and woodlands of THRO (Von Loh et al. 2000).

Common Name / Stratum	Most abundant species
Sandbar Willow Temporarily-Flooded Shrubland Alliance (map unit no. 38)	
Tree Canopy	*Populus deltoides*
Short Shrub	*Salix exigua*
Herbaceous	*Melilotus alba, Xanthium strumarium, Spartina pectinata*
Cottonwood – Peachleaf Willow Floodplain Woodland (map unit no. 41)	
Tree Canopy	*Populus deltoides, Salix amygdaloides*
Short Shrub	*Salix exigua, Symphoricarpos occidentalis*
Herbaceous	*Glycyrrhiza lepidota, Melilotus alba, M. officinalis*
Cottonwood Temporarily-Flooded Woodland (map unit no. 43)	
Tree Canopy	*Populus deltoides, Juniperus scopulorum, Fraxinus pennsylvanica*
Short Shrub	*Symphoricarpos occidentalis, Prunus virginiana*
Herbaceous	*Poa pratensis, Bromus inermis*
Cottonwood – Rocky Mountain Juniper Floodplain Woodland (map unit no. 42)	

Common Name / Stratum	Most abundant species
Tree Canopy	*Populus deltoides, Juniperus scopulorum,*
Short Shrub	*Symphoricarpos occidentalis, Prunus virginiana*
Herbaceous	*Poa pratensis, Bromus inermis*
Green Ash – American Elm Woodland Floodplain (map unit no. 45)	
Tree Canopy	*Fraxinus pennsylvanica, Ulmus pumila*
Short Shrub	*Symphoricarpos occidentalis, Artemisia cana*
Herbaceous	*Poa pratensis, Bromus inermis*

The following paragraphs describing the general species composition of the five different floodplain woodland/shrubland associations are adapted from Von Loh et al. (2000).

Sandbar willow, usually forming dense cover in the tall shrub layer, is the dominant species in the Sandbar Willow Temporarily Flooded Shrubland Alliance. Young, shrub-sized cottonwoods are also found in this alliance. Non-native white sweetclover (*Melilotus alba*), yellow sweetclover, and native Canada cocklebur (*Xanthium strumarium*) and prairie cordgrass are the most common herbaceous species.

The Cottonwood–Peachleaf Willow Floodplain Woodlands are nearly equally dominated by eastern cottonwood and peachleaf willow. These woodlands also contain other woody vegetation, including *Salix amygdaloides*, box elder (*Acer negundo*), green ash, and Rocky Mountain juniper. On dryer sites (river terraces), other shrub species are more common, such as redosier dogwood (*Cornus sericea*), golden currant (*Ribes aureum* var. *villosum*), honeysuckle (*Lonicera* spp.), western snowberry, Woods' rose (*Rosa woodsii*), skunkbush sumac (*Rhus trilobata*), and the vines western white clematis (*Clematis ligusticifolia*) and Virginia creeper (*Parthenocissus quinquefolia*) (Von Loh et al. 2000). Native herbaceous species present in this type include Canada wildrye (*Elymus canadensis*), western wheatgrass, wild licorice (*Glycyrrhiza lepidota*), northern bedstraw (*Galium boreale*), meadow-rue (*Thalictrum dasycarpum*), and smooth scouring-rush (*Equisetum laevigatum*), but many non-native herbaceous plants are also present, namely leafy spurge, Kentucky bluegrass, white sweetclover, yellow sweetclover, Canada thistle, smooth brome, and yellow salsify (Von Loh et al. 2000). This community is likely successional between the Sandbar Willow Temporarily Flooded Shrubland Alliance and the Cottonwood–Rocky Mountain Juniper Woodland (Von Loh et al. 2000).

Large and mature eastern cottonwood trees that form a distinctive tree canopy characterize the Cottonwood Temporarily Flooded Woodlands (Von Loh et al. 2000). Small cottonwood trees and secondary tree species such as green ash and Rocky Mountain juniper are sparse or sometimes absent. The alliance contains a high diversity of short shrub species, though most common are western snowberry. Yellow sweetclover and leafy spurge are very common non-native understory species in South Unit cottonwood stands. This alliance is closely associated with the Silver Sagebrush / Western Wheatgrass Shrubland Alliance, Cottonwood – Rocky Mountain Juniper Woodland, and the Cottonwood–Peachleaf Willow Woodlands (Von Loh et al. 2000).

The Cottonwood – Rocky Mountain Juniper Floodplain Woodlands are stands of old eastern cottonwood, where Rocky Mountain juniper and some green ash begin to fill in gaps.

Cottonwood trees remain the dominate species with Rocky Mountain juniper subordinate. Rocky Mountain juniper and green ash dominate the tree, tall shrub, and short shrub layers. The understory is fairly sparse and similar to the Cottonwood Temporarily Flooded Woodland Alliance (Von Loh et al. 2000).

The Green Ash – American Elm Temporarily-Flooded Woodland Alliance is the climax community of the floodplain woodlands. They exist on the oldest areas of the floodplain woodlands, areas such as meander scars and depressions or along tributaries (Von Loh et al. 2000). They are dominated by green ash and American elm trees, but many species of shrubs establish in the understory of older eastern cottonwood stands. The non-native Siberian elm (*Ulmus pumila*) is a secondary tree species in this alliance. Green ash and western snowberry are common small shrub species, along with some Rocky Mountain juniper. The most abundant herbaceous species is non-native Kentucky bluegrass (Von Loh et al. 2000).

Table 19. Floodplain shrubland and woodland area and percent composition for each THRO unit. GIS data from Von Loh et. al. (2000).

Description	no. of polygons	area (ha)	area (ac)	% composition*
Elkhorn Ranch Unit (EHR)				
Sandbar Willow Temporarily Flooded Shrubland Alliance	13	8.4	20.7	9.1
Cottonwood-Peachleaf Willow Floodplain Woodland	5	3.9	9.5	4.2
Cottonwood Temporarily Flooded Woodland Alliance	1	17.2	42.6	18.7
Cottonwood-Rocky Mountain Juniper Floodplain Woodland	1	0.1	0.3	0.1
Green Ash-American Elm Temporarily Flooded Woodland Alliance	5	21.3	52.6	23.0
North Unit (NU)				
Sandbar Willow Temporarily Flooded Shrubland Alliance	137	410.3	1013.8	4.2
Cottonwood-Peachleaf Willow Floodplain Woodland	7	9.4	23.3	0.1
Cottonwood Temporarily Flooded Woodland Alliance	0	0	0	0.0
Cottonwood-Rocky Mountain Juniper Floodplain Woodland	34	184.2	74.5	0.3
Green Ash-American Elm Temporarily Flooded Woodland Alliance	56	167.8	414.5	1.7
South Unit (SU)				
Sandbar Willow Temporarily Flooded Shrubland Alliance	192	92.9	229.6	0.5
Cottonwood-Peachleaf Willow Floodplain Woodland	30	29.1	72	0.2
Cottonwood Temporarily Flooded Woodland Alliance	28	70.4	174	0.4
Cottonwood-Rocky Mountain Juniper Floodplain Woodland	24	18.2	45.1	0.1
Green Ash-American Elm Temporarily Flooded Woodland Alliance	70	55.1	136.2	0.3
Park-wide (all units combined)				
Sandbar Willow Temporarily Flooded Shrubland Alliance	342	511.6	1264.1	1.8
Cottonwood-Peachleaf Willow Floodplain Woodland	42	42.4	104.8	0.2
Cottonwood Temporarily Flooded Woodland Alliance	29	87.6	216.6	0.3
Cottonwood-Rocky Mountain Juniper Floodplain Woodland	63	223.7	172.2	0.2
Green Ash-American Elm Temporarily Flooded Woodland Alliance	126	222.9	550.7	0.8

*calculated as a percent of total area in unit, EHR = 95.3 ha (228.2 ac), NU = 9,751.7.3 ha (24,096.9), SU = 18,635.2 ha (45,048.6 ac), total area all units = 28,479.2 ha (69,373.7 ac).

Changes in Species Distribution

Floodplain woodlands are found on alluvial soils adjacent to the Little Missouri River and along its major tributaries across southwest North Dakota (Godfread 1994). In THRO, most cottonwood woodlands are restricted to the floodplain of the Little Missouri River, though some stands exist along Box Elder, Beaver, Cherry, Paddock and Corral Creeks. Cottonwood woodlands typically are distributed along the Little Missouri River as bow-shaped stands of even-aged trees, with older stands farther away from the river channel (Miller 2005).

Changes in the distribution of cottonwood woodlands are expected over time, with channel migration and the deposition of new alluvium. However, Miller (2005) found that the high instantaneous peak flows typically occurring during spring snowmelt have decreased in magnitude over time (1939 to 2003), causing a decrease in the active channel area and an increase in the floodplain area. High flows allow for the continued establishment of cottonwood forests, as high peak discharges tend to cause more "floodplain turnover" (Miller 2005). The spring 2011 high peak flows and stage heights may have caused significant changes in successional trajectories of floodplain woodlands. In a study related to water rights issues on the Little Missouri River, Miller (2005) recommended that high flows should be protected and that reductions in summer flows should be avoided to limit drought mortality of floodplain trees.

Von Loh et al.'s (2000) GIS data provide the most current distribution and extent of cottonwood forests in THRO, based on 1996 aerial photography. All three units contain stands of cottonwood woodland types. The North Unit did not contain any Cottonwood-Rocky Mountain juniper floodplain woodlands (Plate 10), whereas the South Unit contains a significant portion of this community type (Plate 11). A mix of the various cottonwood woodlands and some Sandbar

Willow Temporarily-Flooded Shrubland Alliance areas are present in the EHR Unit (

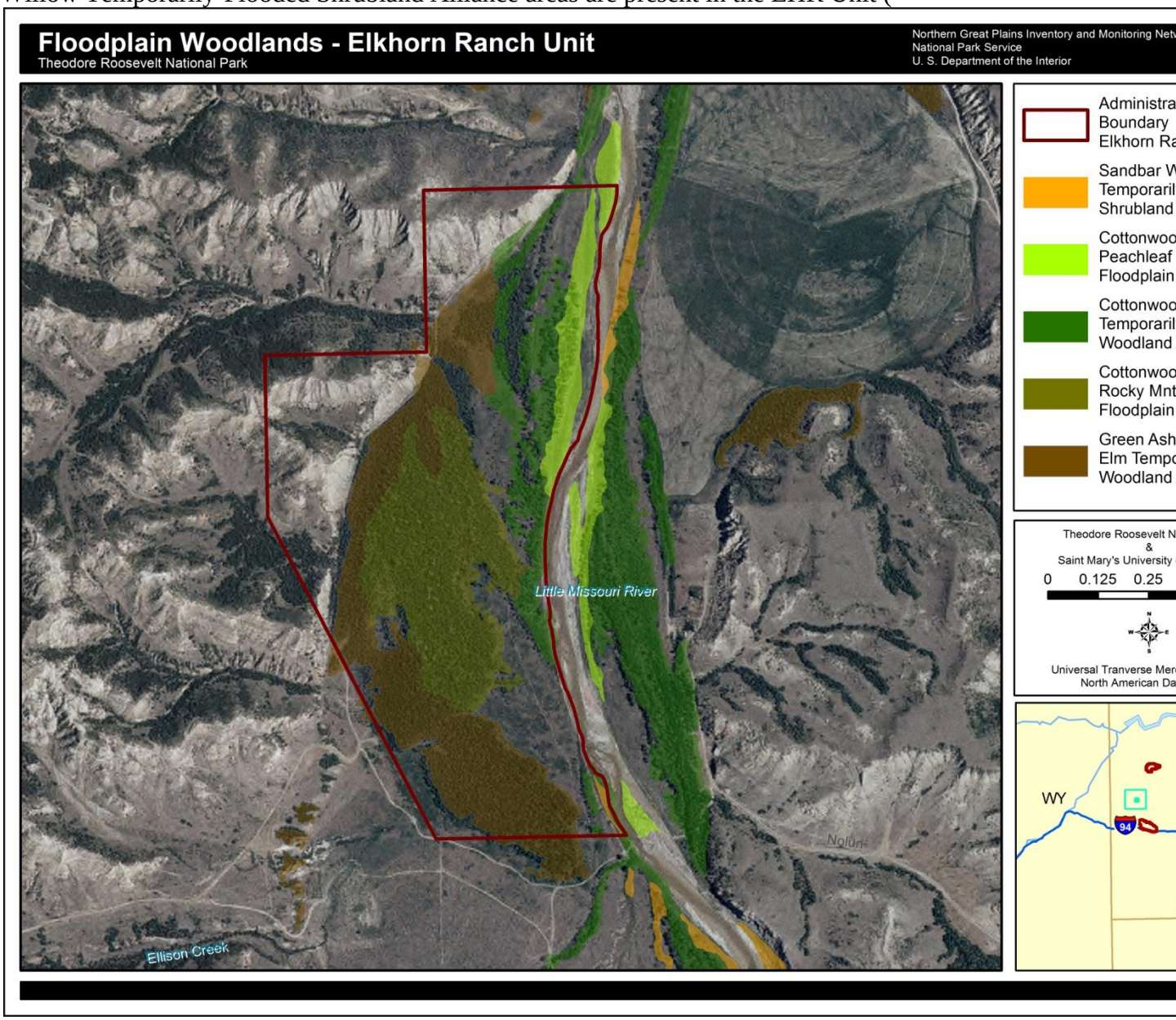


Plate 12).

Cottonwood Woodland Area-Age Distribution

The last specific assessment of cottonwood stand ages in THRO was the dendrologic work by Everitt (1968) in a small section the Little Missouri River in the North Unit of the park (Figure 9).

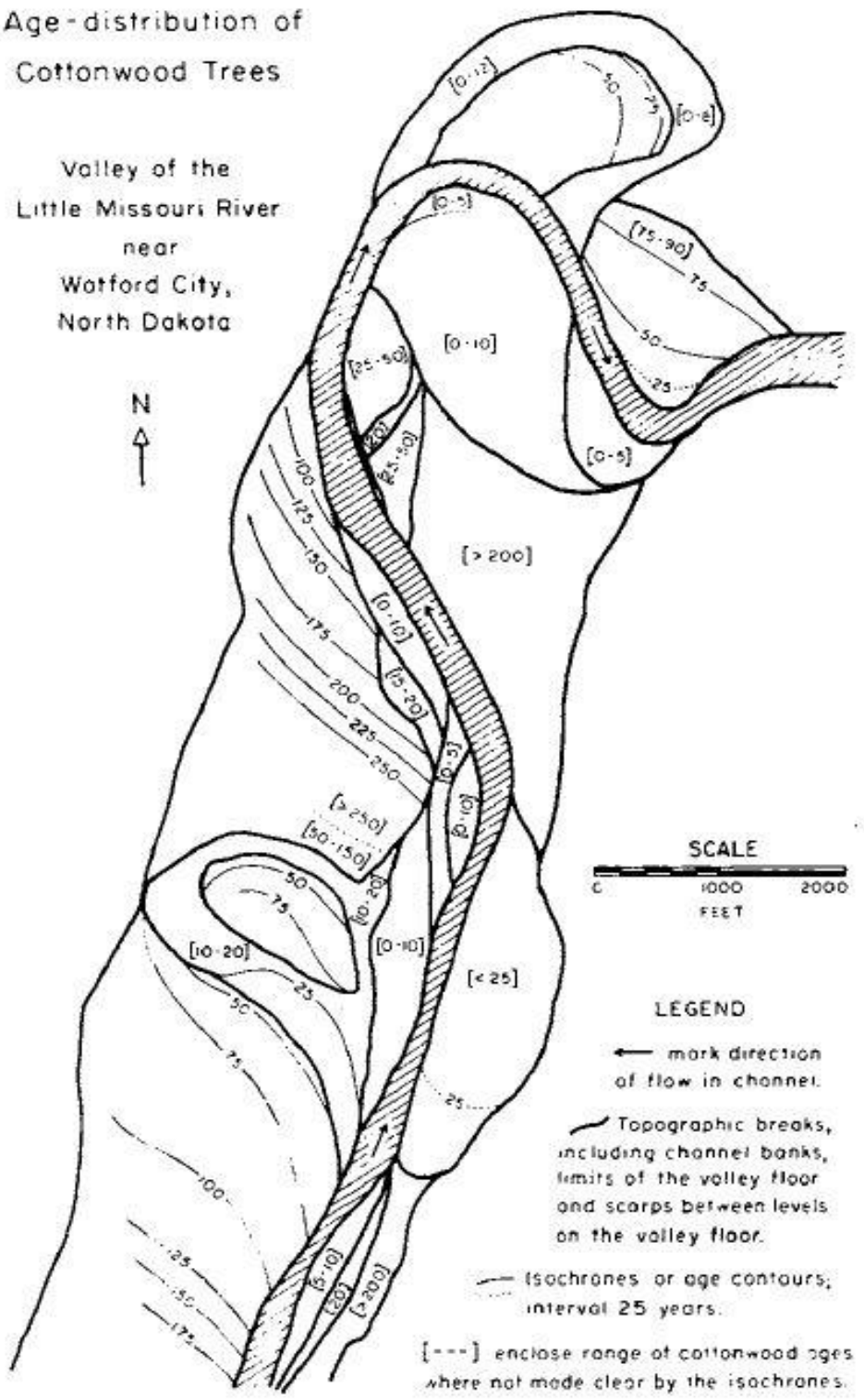


Figure 9. Age map of valley floor. Reproduced from Everitt (1968).

Floodplain riparian forest (woodland) ages are determined by the spatial and temporal variation in historic flood events (Miller 2005). This is because cottonwood seedlings require freshly deposited alluvium for establishment, as older established cottonwood woodlands do not reseed themselves in their under-stories (Everitt 1968). Cottonwood seedling survival depends on these sites being relatively safe from future flooding disturbance, which are typically rare in the riparian landscape (Scott et al. 1996). The creation of new alluvium requires transport and deposition of sediment, mainly through high river discharges, important for the establishment of new cottonwood seedlings (Miller 2005). The seedlings initially form dense stands of cottonwoods or willows on point bars in the Little Missouri River; then, as the channel migrates, narrow bands of cottonwoods mature along older abandoned channels and show an orderly increase in age moving up-valley away from the channel (Everitt 1968, Godfread 1994). Cottonwood trees along the Little Missouri typically reach approximately 90 years of age before their health begins to decline (Wali et al. 1980), after which cottonwood forests will eventually succeed to green ash-American elm woodlands in the absence of flooding (Von Loh et al. 2000).

Everitt (1968) found cottonwood stands to exhibit an age distribution similar to a steady-state exponential relation described in Merigliano et al. (2012). However, research that is more recent found instantaneous high flows have decreased on the Little Missouri, resulting in a larger floodplain area and smaller active river channel area (Miller 2005, Miller and Friedman 2009). The authors suggest the age distribution of the Little Missouri River floodplain is now far from a steady state. However, high peak flows occurring in late-May 2011 may have since reset succession of riparian vegetation in some areas with increased channel migration.

According to GIS data developed by Von Loh et al. (2000), the three aforementioned cottonwood communities, the Sandbar Willow Temporarily Flooded Shrubland Alliance, and the Green Ash-American Elm Temporarily Flooded Alliance community cover approximately 3.4% of the total park area (all units combined). Most of the floodplain woodlands were classified as Cottonwood Temporarily Flooded Woodland Alliance and a relatively large proportion of Green Ash-American Elm Temporarily Flooded Alliance. Smaller proportions were early successional floodplain vegetation stages (Sandbar Willow and Cottonwood-Peachleaf Willow) (Figure 10). This is consistent with Miller and Friedman's (2009) conclusion that old floodplain forest is more abundant than young floodplain areas. Again, this may have changed since 1996 (date of aerial photography used to create GIS data), and given the large magnitude flooding that occurred in spring 2011.

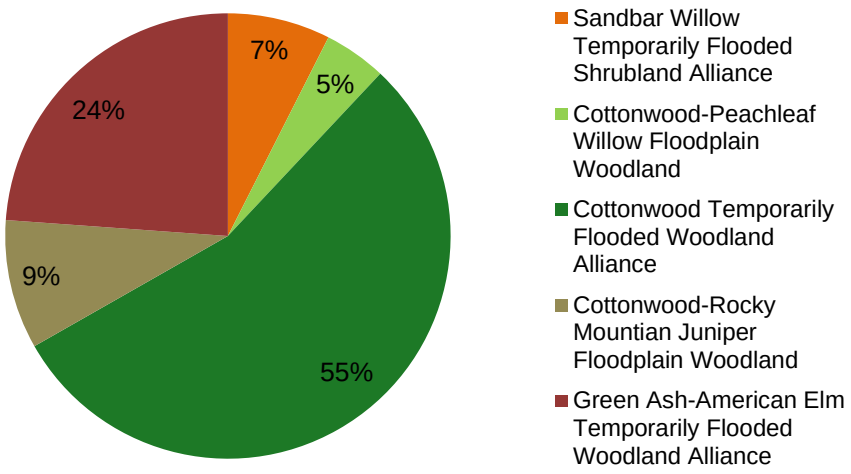


Figure 10. Relative composition of woodland and shrubland floodplain area in THRO. GIS data from Von Loh et. al. (2000).

A floodplain with very few cottonwood seedlings or young cottonwood trees could cause concern for the future of this community type in THRO. However, Friedman (pers. comm., 2012) suggests that using the relative area of young vegetation classes by itself as an index of establishment rate of floodplain woodlands is problematic since cottonwood and willow reproduction are closely linked to channel migration driven by floods, which are uncommon and unevenly distributed in time. That is, the Little Missouri River is dominated by lasting effects of infrequent flooding events (Merigiliano et al. 2012). Instead, Friedman (pers. comm., 2012) suggests that in using aerial photography or satellite imagery to detect channel migration rates along with monitoring the areas of different vegetation types, the NPS can gauge forest reproduction and survival rates. It is important to note that these measures are most valuable when used together, repeatedly, and over a long time-period.

Friedman (pers. comm., 2012) recommends protecting factors that promote channel migration, because riparian vegetation depends so heavily upon this channel migration. Examples of this type of protection include limiting construction activities on the floodplain in or near the park, limiting upstream water withdrawals, and monitoring annual variation in peak flows at the USGS gages in Watford City and Medora, North Dakota. Riparian vegetation is also dependent upon a water subsidy provided by the river. Therefore, summer low flows should be monitored at the USGS gages, upstream water withdrawals should be monitored, and instream flows should be protected during drought.

Non-Native Species Abundance

According to Ashton et al. (2012), non-native species are more abundant in riparian forests than the surrounding upland areas of THRO. Russian olive trees are a specific non-native woody species representing a threat to Sandbar Willow Shrublands, Cottonwood-Peachleaf Willow, and Cottonwood Woodlands in THRO. Once located by NPS invasive plant survey efforts, Russian olive seedlings are immediately removed (L. Richardson, pers. comm., 2012). Another woody species that could threaten floodplain woodlands is saltcedar.

Other abundant non-native invasive species are herbaceous. The Cottonwood–Peachleaf Willow Floodplain Woodlands of THRO contain non-native yellow sweetclover and white sweetclover (Von Loh et al. 2000). In the Cottonwood Temporarily-Flooded Woodland Alliance, common invasive plants include yellow sweetclover, leafy spurge, smooth brome, Kentucky bluegrass, and yellow salsify. Cottonwood – Rocky Mountain Juniper Floodplain Woodlands also contain leafy spurge, Kentucky bluegrass, smooth brome, white sweetclover, yellow sweetclover, and alfalfa. In the Green Ash-American Elm alliance, the primary non-native plant species is Kentucky bluegrass (Von Loh et al. 2000).

Leafy spurge, a species long noted as an aggressive invasive (Bowes and Thomas 1978), was first noted to occur in the river floodplain of THRO, followed by its spread to wooded draws and grasslands (Trammell 1994). More recently, leafy spurge and Canada thistle were found to occur at such densities and large areas as to warrant their own map units in Von Loh et al.'s (2000) mapping efforts. The Leafy Spurge Herbaceous Alliance occurs in many areas of the park, including on floodplains, especially in the South Unit. Since 2002, the EPMT and THRO park staff have utilized integrated pest management practices to reduce/eliminate invasive plant species. The primary focus of these efforts has been on species listed on the North Dakota Noxious Weed List (NPS 2010).

According to GIS data collected by the EPMT, leafy spurge and Canada thistle are the primary invasive non-native plant species in terms of treatment effort in or adjacent to the floodplain woodlands in THRO. However, other typical non-native plant species include Kentucky bluegrass and smooth brome, though less targeted by invasive plant management control efforts. In 2009, nearly 500 acres were treated for these species in or near floodplain woodlands of the park. Multiple herbicides and methods (e.g., helicopter, backpack, ATV) are employed by the EPMT and by THRO park staff. According to the NPS THRO Exotic Vegetation Program Geodatabase (GIS data), THRO staff and NGP EPMT also used biological control on Canada thistle and leafy spurge, releasing biological control agents (e.g., beetles) from 1988 to 2005 in hundreds of locations across the park. Since significant invasive plant treatments began, most of the efforts have been focused in the South Unit of the park.

Threats and Stressor Factors

Non-native Species

Non-native species, especially those considered invasive, can alter the composition and structure of native plant communities. They are considered threats in THRO "because they: 1) replace native species, 2) reduce the land's carrying capacity for livestock and grazing wildlife, 3) may be poisonous to livestock or wildlife, 4) decrease plant species diversity and can further reduce/imperil populations of rare plant species, 5) may carry detrimental insects, diseases, or parasites, 6) can alter fire patterns and intensity, 7) can increase soil nitrogen levels to be detrimental to native species, 8) can result in increased soil erosion and runoff, and 9) can generally degrade or destroy wildlife habitat" (Trammell 1994, CNAP 1999; as cited by Von Loh et al. 2000, p. 2-18).

Although it is a native species, Rocky Mountain juniper is encroaching on some of the floodplain forests (at least those on drier river terraces), along with many of the upland grassland communities. Rocky Mountain juniper forms a sub-canopy beneath larger cottonwood trees in

the riparian areas along the Little Missouri River (Von Loh et al. 2000). Juniper encroachment into the floodplain forest community can replace both green ash and cottonwood trees as terraces dry (Godfread 1994, Von Loh et al. 2000). While its encroachment into floodplain woodlands is part of natural succession occurring as floodplain areas age, the increasing prevalence of this species across the park and its potential influence on other floodplain species is concerning to park staff.

Changes in Flooding Regime

In a study examining the influence of flow variability on the formation and destruction of the Little Missouri River floodplain, discharge of the highest one or two flow events of a decade were correlated most strongly with floodplain destruction (Miller and Friedman 2009). In addition, half of the suspended sand was transported via discharges that occur on average only one day per year (Miller and Friedman 2009). This suggests the geomorphological importance of peak flows in determining the amount of floodplain destruction (i.e., creation of new alluvial surfaces). This is especially true in more arid and smaller watersheds (Merigliano et al. 2012). Miller and Friedman's (2009) time sequence mapping of floodplain ages were similar to stand age maps created through dendrologic examinations (Everitt 1968), and they suggest that this confirms the concept that riparian tree establishment occurs mainly on recent channel locations in the Little Missouri River. Miller and Friedman (2009) found that, from 1939 to 2003, the magnitude of these influential instantaneous peak flows decreased, and suggested that this was primarily due to climatic conditions (i.e., precipitation and temperature patterns). This decrease generally reduced channel migration and erosion rates, thereby reducing the amount of new alluvial surfaces for the establishment of early successional shrubs (willows) and cottonwood trees.

Miller and Friedman (2009) suggest that, "the age distribution of the floodplain is far from steady state" (Miller and Friedman 2009, p. 758). However, this was found to be influenced by an uncommon increase in tree establishment from a large flood in 1947 (Merigliano et al. 2012). Miller (2005) recommended that the NPS should protect high instantaneous peak flows along the Little Missouri to support new cottonwood habitat formation. In addition, during July and August, near Watford City, North Dakota, the Little Missouri River flow can be greatly reduced and has even been known to cease (Everitt 1968). Therefore, Miller (2005) also recommended avoiding reductions in summer low flows because of the potential for drought-caused mortality of trees.

Since the Miller and Friedman (2009) study, a high spring discharge occurred on the Little Missouri in May 2011. This represented a large magnitude flood due to large snowpack in the upper reaches of the watershed. The peak discharge of 36,200 cfs on this day represented the fifth highest flow on record at the USGS gage in Medora, ND (Figure 11) and the second highest recorded gage height, at 6.21 m (20.39 ft) (Figure 12). This likely caused geomorphological changes to the river channel and the riparian vegetation. Refer to Section 4.3 for more information regarding Little Missouri River flooding.

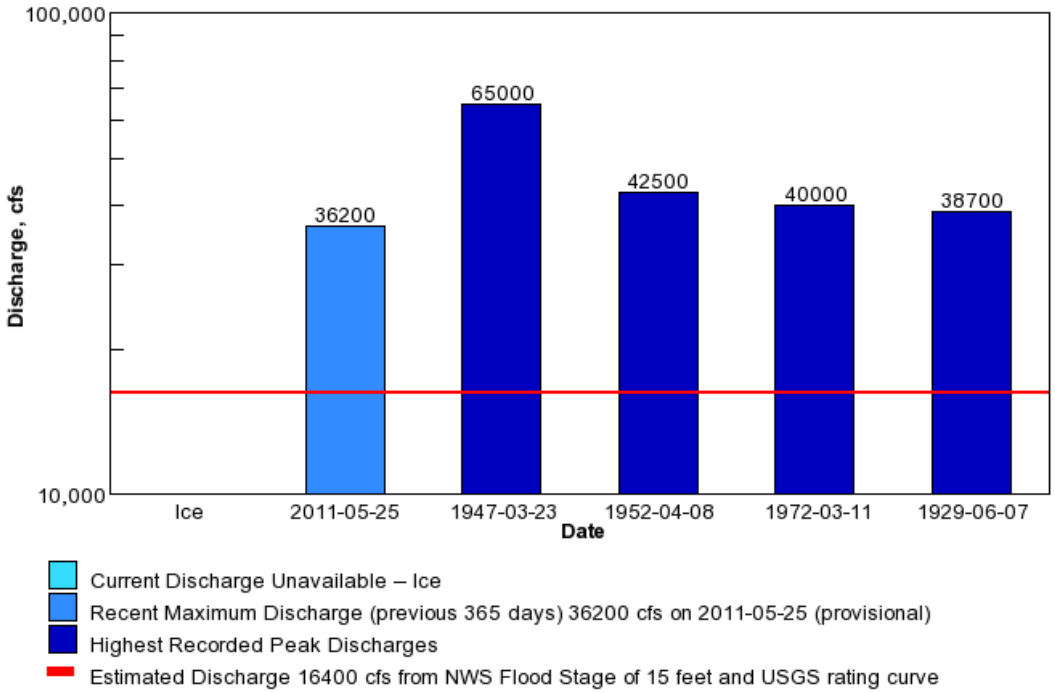


Figure 11. Highest recorded peak discharges and recent (2011) peak discharge from the USGS gage (06336000) at Medora, ND.

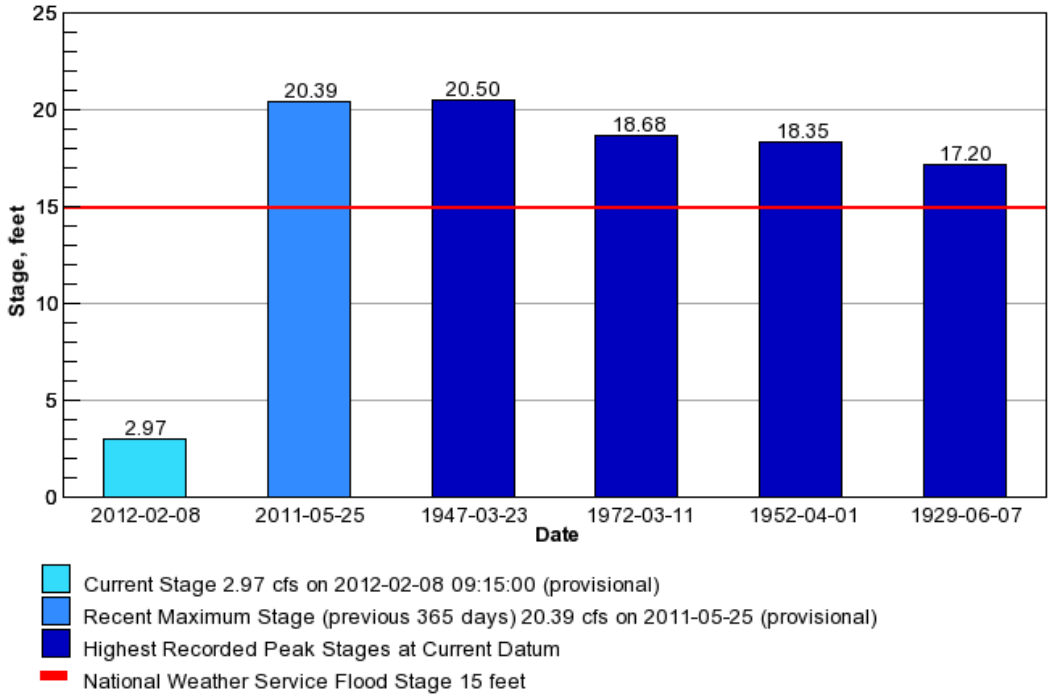


Figure 12. Highest recorded peak stage heights and recent (2011) gage height at the USGS gage (06336000) at Medora, ND.

Ice Jams
Ice jams have been witnessed by park staff in the winter months, leading to flooding that can impact streambanks (Berkeley et al. 1998). This is more typical during the spring snowmelt season (Miller 2005). Spring ice-jams are natural events that cause damage (abrasion) to cottonwood trees. They leave scars on tree trunks for years which act as references for the approximate stage height of past ice-jam floods (Miller 2005). A concern regarding ice-jam floods is the potential for climate/weather changes to alter the hydrologic regime (including the magnitude and frequency of ice-jam flooding events) of the Little Missouri, thereby possibly altering the composition and abundance of floodplain vegetation over time.

Data Needs/Gaps
No specific information is available that examines the species composition and abundance of each floodplain woodland alliance. A NGPN plant community monitoring will help address this gap. However, only five riparian plots have been sampled to date (Ashton et al. 2012). In 2015, the NGPN plant community monitoring program plans to implement a large survey of riparian forests in the park that will examine stand structure and forest health (Symstad et al. 2012).

An assessment of cottonwood woodland stand ages in THRO would give park managers a better understanding of the age composition of these woodlands in order to provide insight for the future of cottonwood forests (e.g., if regeneration is keeping pace with vegetation succession and tree mortality). This research is ongoing in both the North and South Units of the park.

The Von Loh et al. (2000) GIS data describing the extent and distribution of various floodplain woodlands across the three park units was developed using 1996 aerial photography (now nearly 16 years old). An update would provide park management a contemporary understanding of the extent and distribution of floodplain woodlands and would allow for an assessment of changes in community distribution and composition in the park. The 2011 spring flooding likely caused significant alterations to the river channel and riparian vegetation along the Little Missouri River in THRO. These interactions of the river's hydrologic regime and changes in the relative composition of floodplain vegetation classes are important to examine in order to understand the current status of the floodplain woodlands and potential trajectories.

Overall Condition

Species Composition and Abundance
The project team defined the *Significance Level* of frequency as a 3. No specific information examining species-level composition and abundance is currently available, outside of broad categorizations of dominant species for each plant community association in Von Loh et al. (2000); therefore, a *Condition Level* is not assigned. The main issue affecting native species composition and abundance is the influx and expansion of invasive plant species. In the future, data from NGPN plant community monitoring can be used to assess this measure.

Changes in Species Distribution
The project team defined the *Significance Level* of changes in species distribution as a 3. No species-level distribution information is currently available for THRO, only relatively recent community distribution information from Von Loh et al.'s (2000) GIS data. The *Condition Level*

is not assigned. Data from NGPN plant community monitoring may also be useful in assessing this measure in the future.

Cottonwood Area-Age Distribution

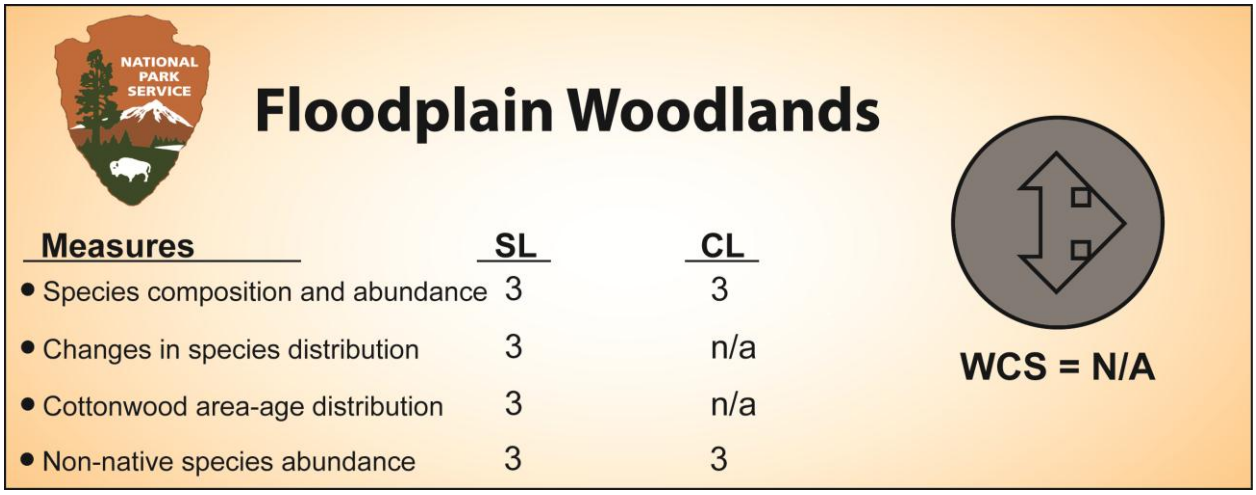
The project team defined the *Significance Level* of cottonwood area-age distribution as a 3. Unlike Everitt's (1968) assessment of stand ages in the North Unit of the park where floodplain ages more closely matched a steady-state exponential relationship, Miller and Friedman (2009) found that floodplain ages were far from a steady state, and that floodplain destruction decreased from 1939 to 2003 on the Little Missouri River. Miller and Friedman (2009) also found that the proportion of older woodlands was higher than younger woodlands. This proportion also was illustrated in examining the relative composition of various successional stages of the floodplain shrubland and woodlands in the Von Loh et al. (2000) GIS data. Merigliano et al. (2012) suggest that there is too much variability in annual peak flows because of local conditions affecting ice jams to detect climate-induced changes in peak flows. Recently, the distribution of cottonwood area-ages has likely changed following the May 2011 flooding. However, given a low level of flow regulation and land clearing, the absence of channel stabilization, the existence of record tree ages, and the natural age structure characteristics of these woodlands, the level of concern for this measure is low (J Hughs, pers. comm., 2012). A *Condition Level* for cottonwood area-age distribution is assigned a value of one, indicating low concern.

Non-native Species Abundance

The project team defined the *Significance Level* of non-native species abundance as a 3. Specific data defining the abundance of non-native species in each of the floodplain woodlands are lacking. However, a few non-native invasive plant species are abundant in many of these woodlands. Despite not having data that specifically estimate abundances, yellow and white sweetclovers, leafy spurge, and Kentucky bluegrass contribute a significant proportion of the species composition in many of the floodplain woodlands. Therefore, this measure is assigned a *Condition Level* of 3, signifying a significant concern for the biological integrity of these floodplain woodlands. Although they currently exist in very low numbers, invasive Russian olive trees present a looming threat to floodplain vegetation of the park.

Weighted Condition Score

Given the lack of information for most of the measures, a *Weighted Condition Score* is not appropriate for this component. However, Friedman (pers. comm., 2012) suggests if, for example, young woodlands decreased in area during and after a period of high river flows, it would be cause for concern especially if channel migration rates were shown to decrease during the same time-period. As another example, if large areas of mature floodplain woodlands were to die-off at a time when upstream withdrawals increased and summer low flows became more extreme, it would also be a cause for concern.



4.6.6 Sources of Expertise

Jonathan Friedman, Hydrologist, USGS, Fort Collins, Colorado
Laurie Richardson, Botanist, THRO

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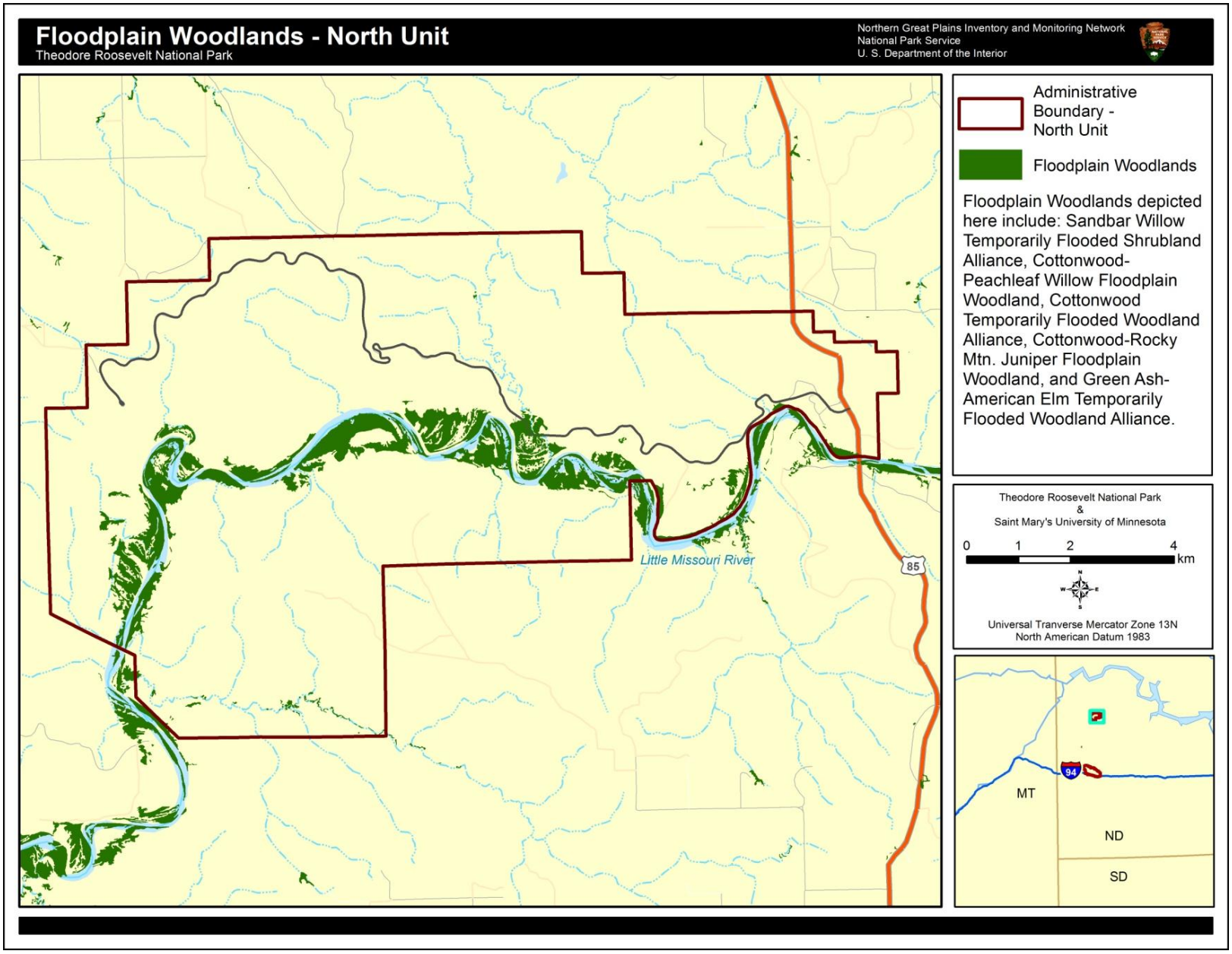


Plate 10. Floodplain woodlands in the North Unit of THRO (Von Loh et al. 2000).

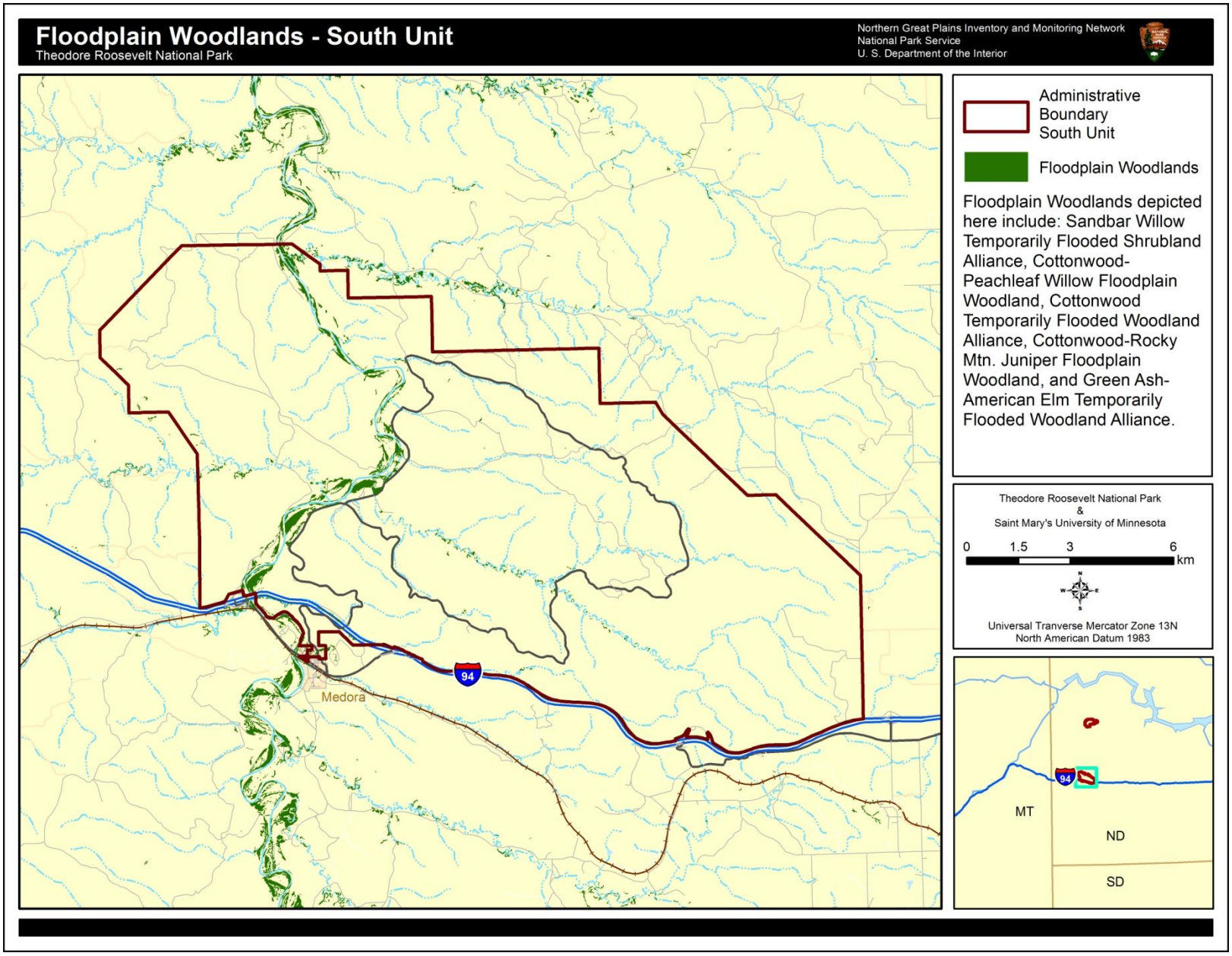


Plate 11. Floodplain woodlands in the South Unit of THRO (Von Loh et al. 2000).

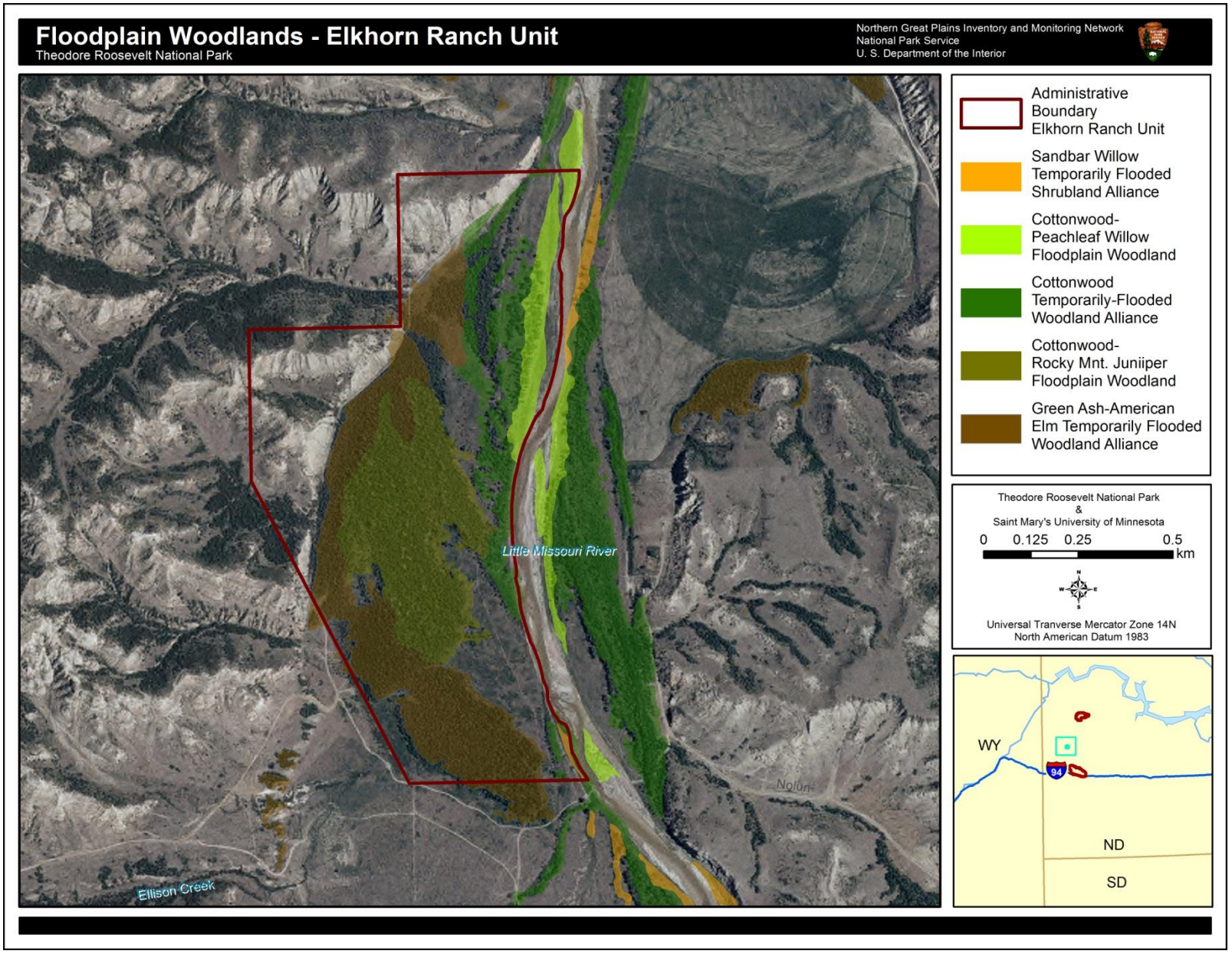


Plate 12. Floodplain woodlands in the Elkhorn Ranch Unit of THRO (Von Loh et al. 2000). Shown with 2004 USDA National Agriculture Imagery Program (NAIP) imagery.

4.7 Woody Draws

4.7.1 Description

Woody draws are small, forested areas that occur in ravines or drainage areas within the badlands landscape (Hull Sieg 1997). The hardwood communities are a small portion of the overall landscape in the northern Great Plains, but provide an important structural contrast to the surrounding grasslands and shrublands (Sullivan et al. 1989). Woody draws provide food and cover for a variety of wildlife species in THRO, including white-tailed deer, mule deer (*Odocoileus hemionus*), porcupine, and forest-dwelling birds. This plant community is dominated by green ash, and support American elm and box elder to a lesser extent (Von Loh et al. 2000).



Photo 15. Woody draw in THRO dominated by green ash with some juniper encroachment (photo by Shannon Amberg, SMUMN GSS, 2010).

4.7.2 Measures

- Species composition and abundance
- Distribution
- Prevalence of non-natives

4.7.3 Reference Conditions/Values

The ideal reference condition for this component would be the composition and distribution of woody draws prior to European settlement. However, no information is available from this historical period. The earliest description of THRO's woody draws comes from Hansen et al.'s (1984) habitat type classification of the park's vegetation. Their characterization of the *Fraxinus pennsylvanica*/*Prunus virginiana* habitat type will be used as the reference condition for species composition in this assessment.

4.7.4 Data and Methods

Irby (2000) monitored 12 green ash draws in the South Unit of THRO between 1985 and 1996 for changes in plant species composition. North Dakota green ash draws were also studied previously by Butler (1983).

Von Loh et al. (2000) used remote sensing to map vegetation in THRO and provided information regarding the composition and distribution of woody draws in the park.

Trammel (1994) surveyed the distribution and extent of exotic species throughout THRO, including in woody draws.

4.7.5 Current Condition and Trend

Species Composition and Abundance

Green ash is one of the dominant tree species found in hardwood draws of the northern Great Plains (Sullivan et al. 1989). Other tree species found in the hardwood draws of THRO include American elm and box elder (Butler 1983, Von Loh et al. 2000). Woody draws sampled by Von Loh et al. (2000) in THRO exhibited 30% mean foliar cover by green ash, followed by 12% mean foliar cover for American elm and 3% for box elder. The shrub layer is typically dominated by chokecherry but can also include Saskatoon serviceberry *(Amelanchier alnifolia*), common snowberry (*Symphoricarpos albus*), western snowberry, currants (*Ribes* spp.), skunkbush sumac, and American plum (*Prunus americana*) (Irby et al. 2000, Von Loh et al. 2000). Northern bedstraw, wild bergamot, and early meadow rue (*Thalictrum venulosum*) are forb species commonly found in these communities (Hansen et al. 1984, Godfread 1994). Common graminoids include Virginia wild-rye (*Elymus virginicus*), Sprengel sedge (*Carex sprengelii*), and Kentucky bluegrass (Butler 1983, Von Loh et al. 2000). The herbaceous layer (forbs and graminoids) in THRO woody draws averaged 45% foliar cover (Von Loh et al. 2000).

Irby et al. (2000) noted that graminoids, forbs, and invasive forbs all showed significant increases in the 12 green ash stands monitored during their 1985-1996 study. The study found a few directional changes in these communities, including a decrease in mature chokecherry and Saskatoon serviceberry and an increase in ground cover plants. These changes did not appear to be due to overuse by ungulates and may be part of natural stand succession. Green ash canopy cover showed little change over the study period (Irby et al. 2000).

Distribution

Woody species are primarily found in draws in THRO, which have greater soil moisture (Hull Sieg 1997). Woody draws rarely comprise more than 2% of the plains landscape due to a lack of moisture (Boldt et al. 1978 and Girard et al. 1989, as cited by Sullivan et al. 1989). The Green Ash-American Elm Woodland Alliance is the dominant woody plant community in THRO draws, in which green ash is the dominant species (Von Loh et al. 2000). Von Loh et al. (2000) states that green ash-American elm draws generally occur in north facing mesic draws or drainages and on moderately steep slopes, but occasionally on east-west oriented sites where moisture requirements are met.

Plate 13, Plate 14, and Plate 15 display the distribution of Green Ash-American Elm Woodland draws in the North, South, and Elkhorn Ranch Units of THRO, respectively.

Prevalence of Non-Natives

Trammel (1994) found 14 non-native plant species present in the hardwood draw vegetational class in a survey of the park. Kentucky bluegrass was the most widespread in the park, with leafy spurge occuring in many of the South Unit draws (Trammel 1994). In recent years Canada thistle has become more common in woody draws as well (L. Richardson, pers. comm., 2012). Table 20 displays non-native plant species documented in THRO hardwood draws in a 1992-1993 survey, along with their mean percent cover and quadrat frequency.

Table 20. Non-native plants documented in THRO woody draws in 1992-1993, with mean percent cover and quadrat frequencies (Trammel 1994). Nine hundred thirty-five quadrats were sampled in 1992 with 150 different quadrats sampled in 1993.

Scientific Name	Common Name	% Cover - 1992 plots	Quadrat freq. - 1992 plots	% Cover - 1993 plots	Quadrat freq. - 1993 plots
Agropyron cristatum	crested wheat grass	T*	0.7		
Bromus inermis	smooth brome	0.9	3.1	0.4	2.6
Bromus arvensis	field brome	T	0.1	0.2	2.6
Bromus tectorum	cheat grass	T	0.7		
Chenopodium album	lambsquarters			T	0.6
Convolvulus arvensis	field bindweed			0.1	4.0
Euphorbia esula	leafy spurge	8.8	29.7		
Lactuca serriola	prickly lettuce	T	0.5		
Lappula echinata	stickseed			T	0.6
Melilotus officinalis	yellow sweetclover	0.1	1.3		
Poa compressa	Canada bluegrass	T	0.5		
Poa pratensis	Kentucky bluegrass	4.8	25.2	6.0	66.6
Taraxacum officinale	dandelion	0.6	5.6	T	2.0
Tragopogon dubius	yellow salsify	0.1	1.5		

* T= Trace (cover < 0.1%)

Irby et al. (2000) found that non-native grasses increased over the 12-year study period but remained low in comparison to natives. Invasive forbs increased more than palatable forbs during this period, although invasive species were a small percentage of total ground cover. Von Loh et al. (2000) noted that Kentucky bluegrass, leafy spurge, burdock (*Arctium minus*), yellow sweetclover, and smooth brome were prevalent in THRO hardwood draws.

Threats and Stressor Factors

Non-native species are a significant threat to the native woody draw communities in THRO. Leafy spurge is a particularly aggressive non-native, which is problematic at the park. The species has proven difficult to control by conventional means (Butler and Trammell 1995), can displace native species (Trammell 1994), and is toxic or unpalatable to some wildlife (Selleck et al. 1962, as cited by Butler and Trammell 1995). Observations suggest that heavily infested areas are sometimes avoided by bison, elk, and deer (Butler and Trammell 1995); however, this has not been validated with an experimental research design. Despite an increase in non-native grasses in the 12-year Irby et al. (2000) study, invasive species remained a small percentage of ground cover in the woody draws that were sampled.

Ungulate foraging is a potential threat to woody draws in THRO if populations grow too large; however, Irby et al. (2000) found no evidence of overgrazing of the green ash woodlands sampled in the South Unit of the park. Elk and mule deer are the two most common ungulates that use woody draws for browse (Irby et al. 2000). Godfread (1994) noted that disturbance by cattle in woody draws allowed non-native plants such as burdock and dandelion (*Taraxacum officinale*) to invade; it is possible that heavy native ungulate activity in THRO could cause similar disturbances (although likely to a lesser degree) in these communities.

Several tree diseases pose a potential threat to woody draws in THRO. A variety of diseases can impact the *Fraxinus* genus, including anthracnose, scorch, ash rust, several heart rots, leafspots, and ash yellows (NDSU 1995). The *Prunus* genus is affected by black knot, plum pockets, and X disease, the latter of which has wiped out many chokecherry stands in the northern Great Plains (NDSU 1995). During a brief visit to THRO in August 2010 to investigate ash die back in several South Unit stands, NDSU researchers found evidence of several ash pathogens, including the fungus *Perenniporia fraxinophila*, wood borers, and bark beetles (Walla and Zeleznik 2010). Ash yellows damage was also observed in one tree. However, this survey was limited to just five green ash stands in the South Unit and does not necessarily reflect conditions throughout the park. Further research is needed to determine if these pathogens are impacting woody draws as a whole.

The emerald ash borer (EAB) (*Agrilus planipennis*) is an invasive insect recently introduced to North America, which has quickly spread across much of the eastern United States and Canada and is now present as far west as Minnesota (USFS et al. 2011). Emerald ash borer larvae kill ash trees by feeding on the inner bark, disrupting the tree's ability to transport water and nutrients (USFS et al. 2011). Emerald ash borer has already decimated large populations of ash trees, and could be devastating to ash trees in the woody draws of THRO if it becomes introduced to the area. The U.S. Department of Agriculture monitors for EAB in the park each summer (L. Richardson, pers. comm., 2012).

Data Needs/Gaps

Green ash draw sites measured by Irby (2000) could be revisited to examine changes in the plant community over time. However, it may be difficult with such a small sample size to determine if any differences represent actual changes or simply natural variation. There is no information currently available regarding the prevalence of diseases in woody draws. Non-native species abundance has not been closely examined specifically in woody draws for a number of years. Research into how these non-natives impact woody draw composition and structure would be helpful in understanding the condition of this plant community in the park.

Overall Condition

Species Composition and Abundance

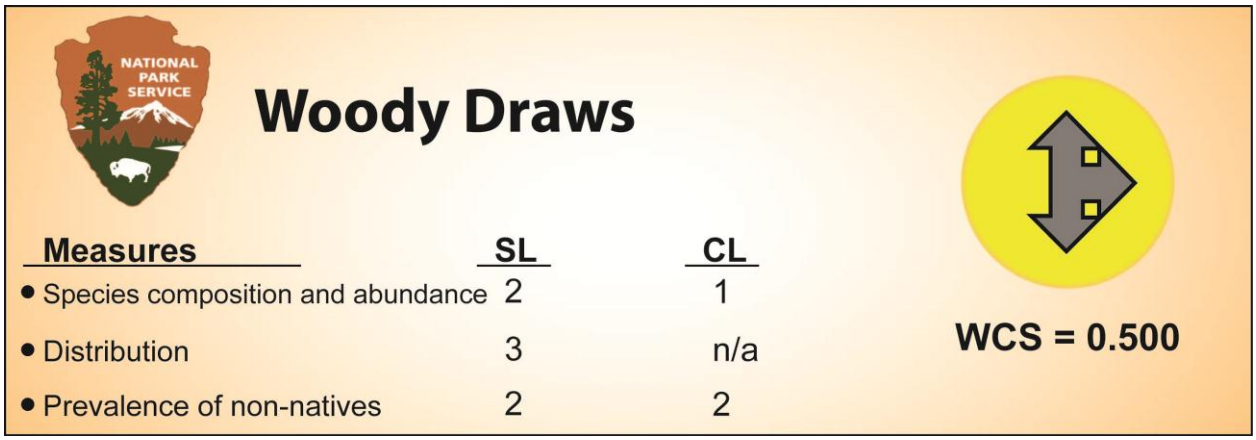
The THRO project team assigned a *Significance Level* of 2 for species composition and abundance. The most recent description of THRO woody draw composition (Von Loh et al. 2000) is very similar to earlier reports by Butler (1983) and Hansen et al. (1984). Since there is currently no evidence of change in the composition or abundance of woody draws, this measure was assigned a *Condition Level* of 1.

Distribution

A *Significance Level* of 3 was assigned to the measure of distribution. Unfortunately, there is only one source of information addressing the distribution of woody draws in THRO (Von Loh et al. 2000). Since there is no historic or more recent distribution information for comparison, a *Condition Level* cannot be assigned for this measure.

Prevalence of Non-natives
A *Significance Level* of 2 was assigned to the measure of prevalence of non-natives. While non-native species comprised a small percentage of the ground cover in woody draws when they were last surveyed, the presence of aggressive invasives such as leafy spurge and Canada thistle makes this measure of moderate concern (*Condition Level* = 2).

Weighted Condition Score
The *Weighted Condition Score* (WCS) for woody draws in THRO is 0.500, which is of moderate concern. Since woody draws have not been surveyed in any detail over the past decade, the trend in their condition is unknown.



4.7.6 Sources of Expertise
Laurie Richardson, Botanist, THRO

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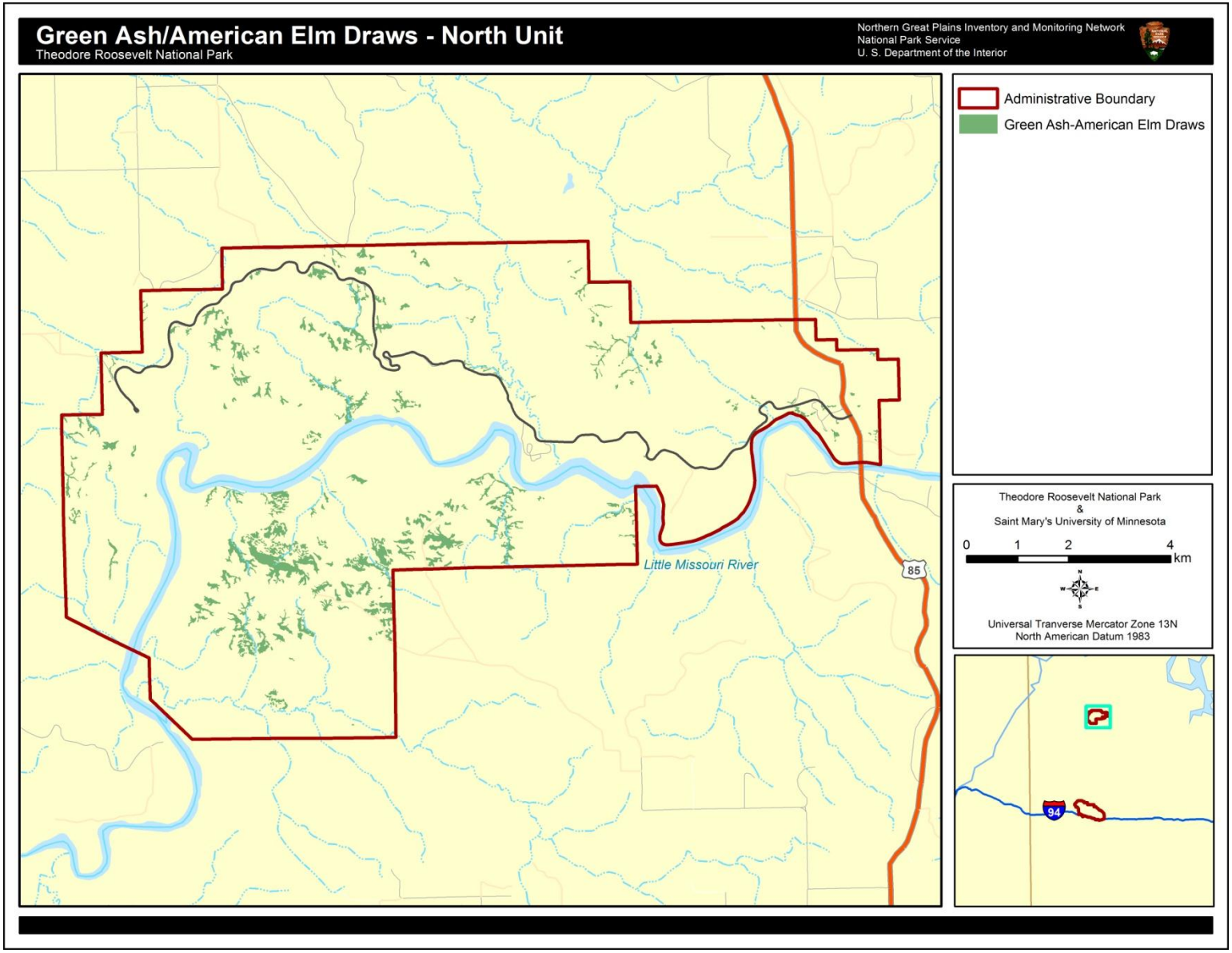


Plate 13. Green Ash-American Elm Woodland Alliance distribution in the North Unit of THRO (mapped in 2000).

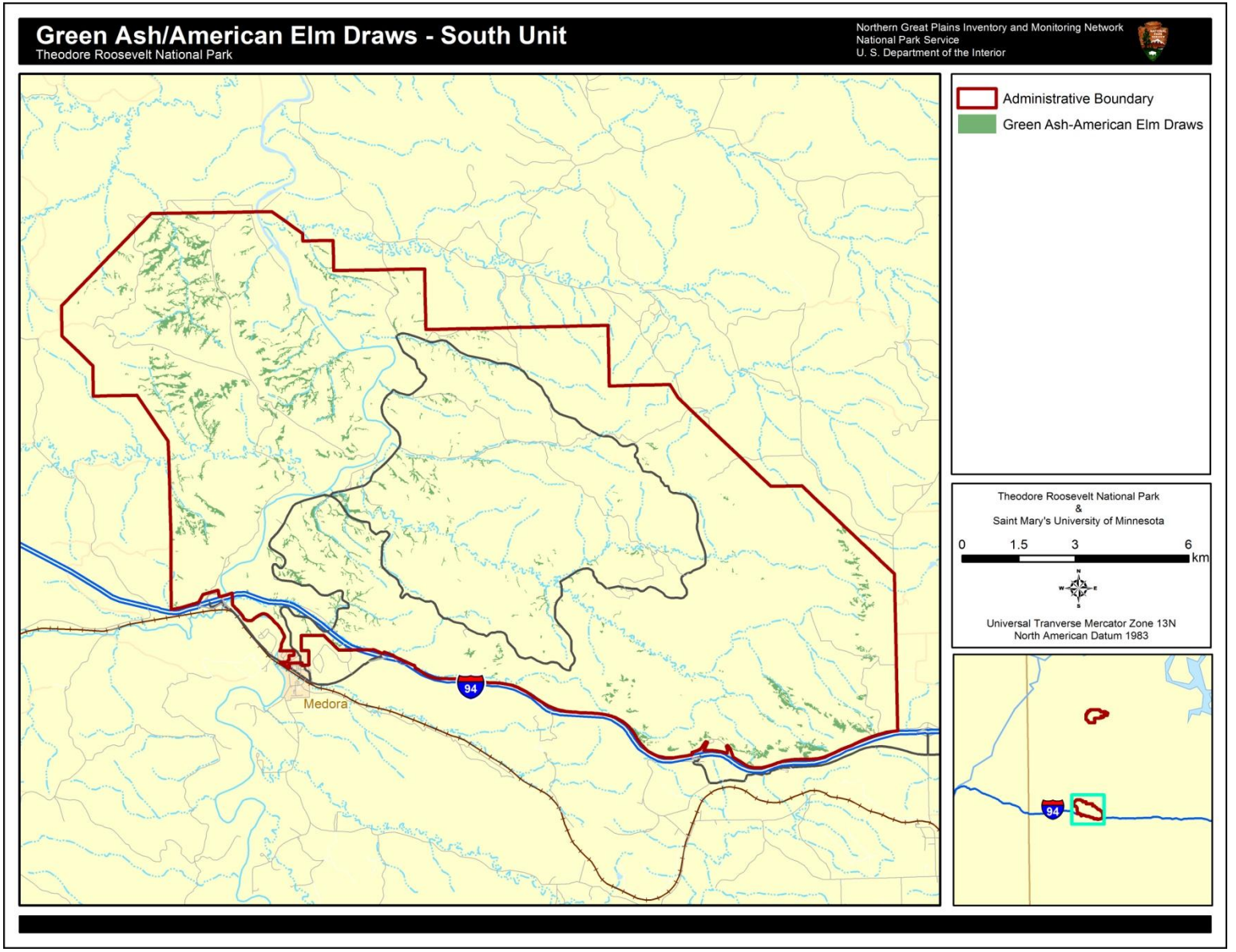


Plate 14. Green Ash-American Elm Woodland Alliance distribution in the South Unit of THRO (mapped in 2000).

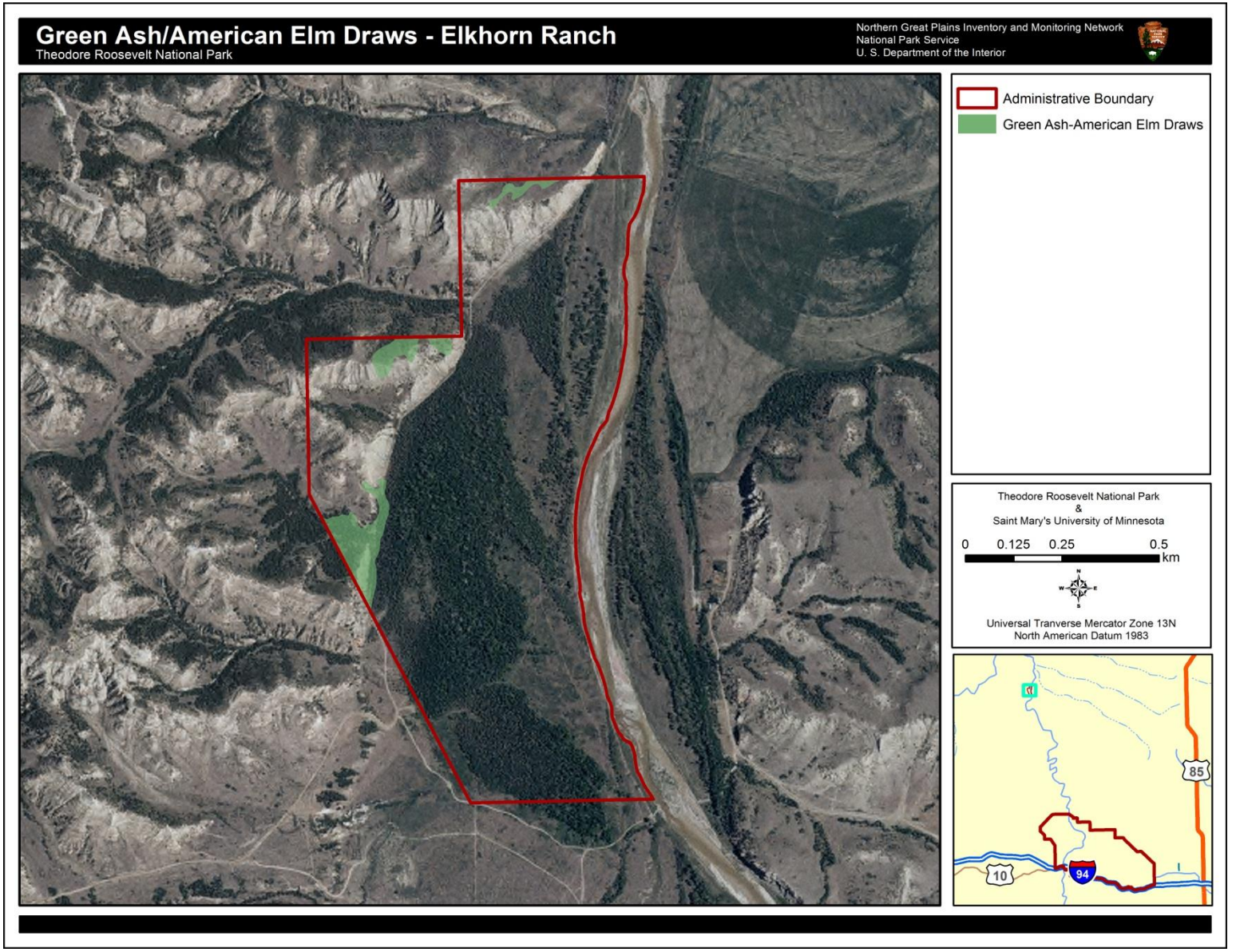


Plate 15. Green Ash-American Elm Woodland Alliance distribution in the Elkhorn Ranch Unit of THRO (mapped in 2000).

4.8 Upland Shrubland Communities

4.8.1 Description

Shrubland communities are found on a wide variety of landform types in THRO, including floodplains, flats, slopes, slumps, draws, hills, and ridges (Von Loh et al. 2000). This assessment focuses on shrubland communities found in upland habitats of the park. These areas provide important resources for wildlife, including elk and North Dakota conservation priority species such as the lark bunting (*Calamospiza melanocorys*) and black-billed cuckoo (*Coccyzus erythropthalmus*) (NPS 2010). Von Loh et al. (2000) identified nine shrubland community types that occur in the park's upland areas. These are listed in Table 21.

Table 21. Upland shrubland communities of THRO (Von Loh et al. 2000).

Common Name	NVCS Association or Complex
Silver Sagebrush / Western Wheatgrass Shrub Prairie	*Artemisia cana* / *Pascopyrum smithii* Shrubland
Wyoming Big Sagebrush - Spiny Saltbush Shrubland	*Artemisia tridentata* - *Atriplex confertifolia* Shrubland
Wyoming Big Sagebrush / Western Wheatgrass Shrubland	*Artemisia tridentata* ssp. *wyomingensis* / *Pascopyrum smithii* Shrubland
Rubber Rabbitbrush / Bluebunch Wheatgrass Shrub Prairie	*Ericameria nauseosa*/ *Pseudoroegneria spicata* Shrubland
Creeping Juniper / Little Bluestem Dwarf-shrubland	*Juniperus horizontalis* / *Schizachyrium scoparium* Dwarf-shrubland
Silver Buffaloberry Shrubland	*Shepherdia argentea* Shrubland
Western Snowberry (Buckbrush) Shrubland	*Symphoricarpos occidentalis* Shrubland
Skunkbush Sumac / Thread-leaved Sedge Shrub Prairie	*Rhus trilobata* / *Carex filifolia* Shrub Herbaceous Vegetation
Greasewood / Western Wheatgrass Shrub Prairie	*Sarcobatus vermiculatus* / *Pascopyrum smithii* - (*Elymus lanceolatus*) Shrub Herbaceous Vegetation

4.8.2 Measures

- Species composition
- Distribution (including changes)
- Prevalence of non-natives



Photo 16. Sagebrush on an upland slope in THRO (Photo by Shannon Amberg, SMUMN GSS 2010).

4.8.3 Reference Conditions/Values

The ideal reference condition for this component would be the composition and distribution of these communities prior to European settlement. However, no information is available from this historical period. The earliest description of THRO's shrubland communities comes from Hansen et al.'s (1984) habitat type classification of vegetation in the park. This report identified four shrubland community types in the park: *Artemisia tridentata/Pascopyrum smithii*, *Artemisia cana/Pascopyrum smithii*, *Juniperus horizontalis/ Schizachyrium scoparium*, and

Symphoricarpos occidentalis. These descriptions are used as the reference condition for species composition within those communities in this assessment. No reference condition could be found for the other shrublands in the park.

4.8.4 Data and Methods

In 1997-98, the USGS and NPS collaborated on a vegetation mapping program of THRO to classify the major plant community types (Von Loh et al. 2000). This report provides the majority of information on the upland shrub communities in the park. Trammel (1994) surveyed the distribution and extent of exotic species throughout THRO, including in several shrubland community types.

4.8.5 Current Condition and Trend



Photo 17. Bison grazing in an upland shrubland habitat dominated by sagebrush (Photo by Shannon Amberg, SMUMN GSS 2010).

<u>Species Composition</u>

One of the first scientific records of western North Dakota shrublands comes from Hanson and Whitman (1938), who described the sagebrush flat type community, in which silver sagebrush is the primary shrub species. Silver sagebrush generally occurs on floodplain terraces, but is also found on some upland flats and slopes. It is often associated with western wheatgrass and is sometimes co-dominant with or dominated by western snowberry (Von Loh et al. 2000).

Western snowberry, also known as buckbrush, is widespread throughout the park, occupying upland depressions, mesic swales and heads of mesic draws, and is an understory of all woodland types in THRO. Western snowberry forms dense thickets, typically 75-90% aerial cover. The species most commonly associated with western snowberry is the non-native Kentucky bluegrass (Von Loh et al. 2000).

Silver buffaloberry (*Shepherdia argentea*) forms very dense stands in lowland areas, but also occurs at the top of mesic draws. Major stands of buffaloberry are found near the turn-around at the west end of Scenic Drive in the North Unit and along the Wind Canyon Trail in the South Unit (Von Loh et al. 2000).

Skunkbush or three-leaved sumac stands are found on ridges, hills, and slopes that consist mostly of scoria outcrops or soils derived from scoria. This species is often associated with silver sagebrush and chokecherry, as well as a variety of herbaceous species in the understory (Von Loh et al. 2000).

Rabbitbrush (*Ericameria nauseosa*) is a dominant shrub on slumps, which are soils disturbed by sliding down steep slopes (Von Loh et al. 2000). This is an uncommon shrub in THRO; the main examples are found on the slump-slope below the Painted Canyon Overlook, the Interstate 94

right-of-way near Medora, and the slump-slope south of the Long X Trail Pullout. Rabbitbrush is often associated with silver sagebrush and western snowberry on these slump locations (Von Loh et al. 2000).

On the higher hillslopes of the park, horizontal or creeping juniper is commonly found in dense patches, sharing habitat with the silver buffaloberry and skunkbush sumac shrubland alliances, as well as the little bluestem - sideoats grama herbaceous alliance (Von Loh et al. 2000). Nelson (1961) noted that horizontal juniper was commonly found on scoria knobs and in the open prairies, and in lesser amounts in the juniper slope forests in his survey of the western North Dakota Badlands.

Wyoming big sagebrush - saltbush shrubland occurs on slopes and ridges in the park, often mixed with sparse badlands vegetation (Von Loh et al. 2000). Plants are typically short and relatively sparse, with total cover ranging from 20-40%. Spiny saltbush (*Atriplex confertifolia*) and broom snakeweed (*Gutierrezia sarothrae*) are common secondary shrubs (Von Loh et al. 2000). Wyoming big sagebrush also occurs in a shrubland community with western wheatgrass. In this community, shrubs are widely spaced with approximately 25% cover (Von Loh et al. 2000). In addition to western wheatgrass, the understory includes needle-and-thread and blue grama.

Greasewood (*Sarcobatus vermiculatus*) stands are the rarest shrub type in THRO, dominating in only two locations in the South Unit (Von Loh et al. 2000). However, the species is also found in sparse vegetation alliances or mixed with other shrubs. Greasewood forms open stands with prairie sagewort, western wheatgrass, field brome, and Canada bluegrass (*Poa compressa*). Individual greasewood shrubs are interspersed with sagebrush and saltbush shrubs on badlands formations (Von Loh et al. 2000).

Table **22** summarizes the most abundant shrub and herbaceous species in each of these shrub communities.

Table 22. The upland shrub communities of THRO and the most abundant species in each community, as surveyed by Von Loh et al. (2000).

Shrub community	Most Abundant Species	
	Shrubs	**Herbaceous**
Silver sagebrush/Western wheatgrass (*Artemisia cana / Pascopyrum smithii*)	*Artemisia cana, Symphoricarpos occidentalis, Prunus virginiana*	*Pascopyrum smithii, Bromus inermis, Euphorbia esula*
Wyoming big sagebrush - Spiny saltbush (*Artemisia tridentata - Atriplex confertifolia*)	*Artemisia tridentata, Atriplex confertifolia, Gutierrezia sarothrae*	*Pascopyrum smithii, Bouteloua gracilis, Muhlenbergia cuspidata*
Wyoming big sagebrush /Western wheatgrass (*Artemisia tridentata - Pascopyrum smithii*)	*Artemisia tridentata, Atriplex confertifolia, Ericameria nauseosa*	*Pascopyrum smithii, Hesperostipa comata, Bouteloua gracilis*
Rubber rabbitbrush / Bluebunch wheatgrass (*Ericameria nauseosa / Pseudoroegneria spicata*)	*Ericameria nauseosa, Prunus virginiana, Symphoricarpos occidentalis*	*Pascopyrum smithii, Elymus trachycaulus, Melilotus officinalis*
Creeping juniper / Little bluestem (*Juniperus horizontalis / Schizachyrium scoparium*)	*Juniperus horizontalis, Prunus virginiana, Dasiphora fruticosa, Rhus trilobata*	*Schizachyrium scoparium, Calamovilfa longifolia*
Silver buffaloberry (*Shepherdia argentea*)	*Shepherdia argentea, Symphoricarpos occidentalis, Prunus virginiana*	*Poa pratensis, Pascopyrum smithii*
Western snowberry (*Symphoricarpos occidentalis*)	*Symphoricarpos occidentalis, Prunus virginiana*	*Pascopyrum smithii, Poa pratensis, Nassella viridula*
Skunkbush sumac / Threadleaf sedge (*Rhus trilobata / Carex filifolia*)	*Rhus trilobata, Prunus virginiana*	*Muhlenbergia cuspidata, Melilotus officinalis*
Greasewood / Western wheatgrass (*Sarcobatus vermiculatus / Pascopyrum smithii*)	*Sarcobatus vermiculatus*	*Pascopyrum smithii*

Distribution

The distribution of shrub communities in the North and South Units of THRO are displayed in Plate 16 and Plate 17 respectively. Elkhorn Ranch Unit (EHR) shrublands are shown in Plate 18. Sandbar willow communities were excluded from these maps since they do not occur in the park's uplands (they are included in the floodplain woodland section of this report). The Wyoming big sagebrush shrublands also are not shown, as they were combined with the sparse vegetation mapping units rather than being mapped separately.

Western snowberry is the most widespread shrub species in THRO, followed by silver sagebrush and skunkbush sumac (Von Loh et al. 2000). The area covered by each mapped shrub community type in the park is shown in Table 23. Note that these areas include shrublands in both floodplains and upland locations, as these were not separated in the Von Loh et al. (2000) mapping project.

Table 23. Area (in hectares) covered by shrublands in THRO. GIS data from Von Loh et. al. (2000).

Common Name	North Unit	South Unit	EHR	Total
Western Snowberry (Buckbrush) Shrubland	735.0	846.0	11.7	1,592.7
Silver Sagebrush / Western Wheatgrass Shrub Prairie	601.8	586.8	8.7	1,197.3
Skunkbush Sumac / Thread-leaved Sedge Shrub Prairie	161.2	816.5	1.4	979.1
Creeping Juniper / Little Bluestem Dwarf-shrubland	1.7	82.4	0.5	84.6
Rubber Rabbitbrush / Bluebunch Wheatgrass Shrub Prairie	5.2	34.0	--	39.2
Silver Buffaloberry Shrubland	9.9	14.2	--	24.1
Greasewood / Western Wheatgrass Shrub Prairie	0.8	0.4	--	1.2
Total	1,515.6	2,380.3	22.3	3,918.2

Prevalence of Non-Natives

Non-native species occur in all plant communities in THRO, including upland shrubland habitats. These plants can impact native species composition and alter natural processes such as fire, nutrient cycling, and erosion (Von Loh et al. 2000). Silver sagebrush communities have been heavily invaded by leafy spurge in the South Unit of THRO, particularly along the Little Missouri River, and Knutson and Paddock Creeks (Von Loh et al. 2000). Leafy spurge has also been found in creeping juniper shrublands, where it has caused a decrease in species richness (Butler and Cogan 2004). Yellow sweetclover is often associated with the skunkbush sumac shrubland alliance on south-facing ridges. Western snowberry stands are most frequently invaded by Kentucky bluegrass (Von Loh et al. 2000). Other non-native species documented in park shrublands include field brome, field bindweed (*Convolvulus arvensis*), dandelion, yellow salsify, smooth brome, and Canada thistle (Trammel 1994, Von Loh et al. 2000). A full list of non-native plants confirmed in THRO, some of which may also be found in shrublands, is included in Appendix C.

Threats and Stressor Factors

Ungulate browsing and grazing impacts the park's upland shrub communities, as well as the distribution of non-native plants such as leafy spurge (Vitousek et al. 1996). Heavy grazing and the associated soil disturbance have been known to promote exotic grass invasion (Knight 1994). Some shrub communities may be replaced by shortgrass species in areas where grazing occurs. In the North Unit of the park, western snowberry shrublands "literally stop at the fenceline and are replaced by shortgrasses on annually grazed areas on the non-park side of the fenceline" (Von Loh et al. 2000). In big sagebrush shrublands, grazers may trample sagebrush seedlings, inhibiting reproduction. However, grazing can also reduce competition from grasses, increasing shrub density and sagebrush establishment (Beck and Mitchell 2000).

Data Needs/Gaps

THRO's shrubland communities have not been surveyed in depth since the Von Loh et al. (2000) study in 1997-98. The NGPN began a long-term monitoring program in 2011 to examine plant composition and structure in THRO. While the focus is not on shrublands in particular, all of the 21 plots visited in 2011 had a substantial shrub component (Ashton et al. 2012). These and future data should provide information on the species composition and exotic cover in shrublands. Updated information is needed on plant species composition, particularly regarding the prevalence and impact of non-native species specifically within these shrubland communities.

More recent distribution information would also help managers determine if the extent of these communities is changing.

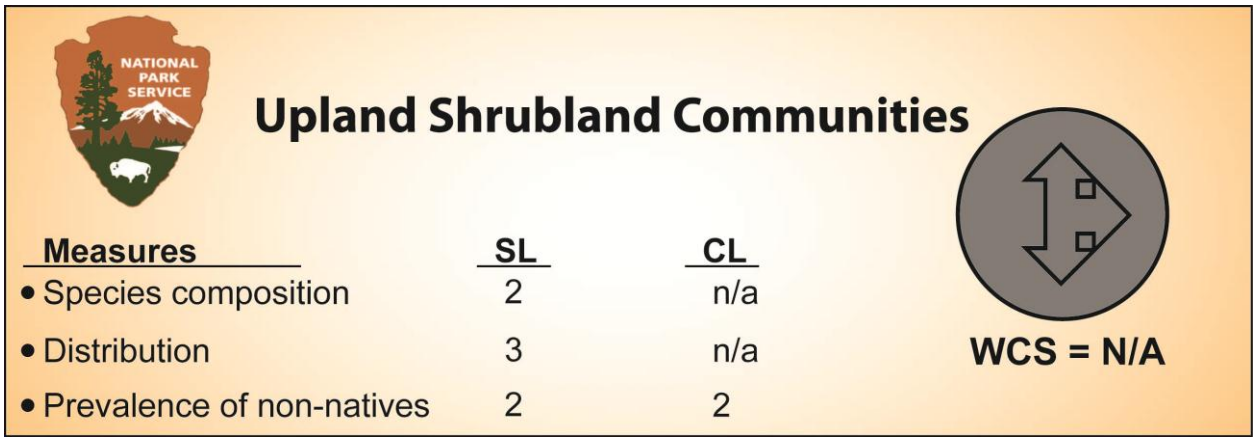
Overall Condition

Species Composition
During initial scoping meetings, THRO staff assigned the measure of species composition a *Significance Level* of 2. The species composition of the four shrubland habitat types surveyed by Hansen et al. (1984) was similar to that found by Von Loh et al. in 2000, with the exception of a few additional non-native species. No reference condition could be established for the remaining upland shrublands, so no comparisons could be made for these communities. Therefore, a *Condition Level* could not be assigned at this time for the upland shrub communities as a whole. In future assessments, data from NGPN plant community monitoring will likely be useful in evaluating this measure.

Distribution
A *Significance Level* of 3 was assigned to the measure of distribution. However, there is only one source of information addressing the distribution of all the shrubland communities in THRO (Von Loh et al. 2000). Since neither a historic or more recent distribution map is unavailable for comparison, *Condition Level* is unknown. Data from NGPN plant community monitoring may also be useful in assessing this measure in the future.

Prevalence of Non-natives
A *Significance Level* of 2 was assigned to the measure of prevalence of non-native species. Leafy spurge has severely infested several shrublands in the park, causing an apparent decrease in plant species richness (Butler and Cogan 2004). In the early 1980s, Hansen et al. (1984) found a small amount of this species in only one of their shrubland sampling plots. Numerous other non-native species have been documented in the park's upland shrublands. As a result, the *Condition Level* for this measure is a 2, signifying moderate concern.

Weighted Condition Score
Since *Condition Levels* for two of the three upland shrubland communities are unknown, a *Weighted Condition Score* (WCS) was not calculated for this component.



4.8.6 Sources of Expertise
Laurie Richardson, THRO Botanist

4.8.7 Literature Cited

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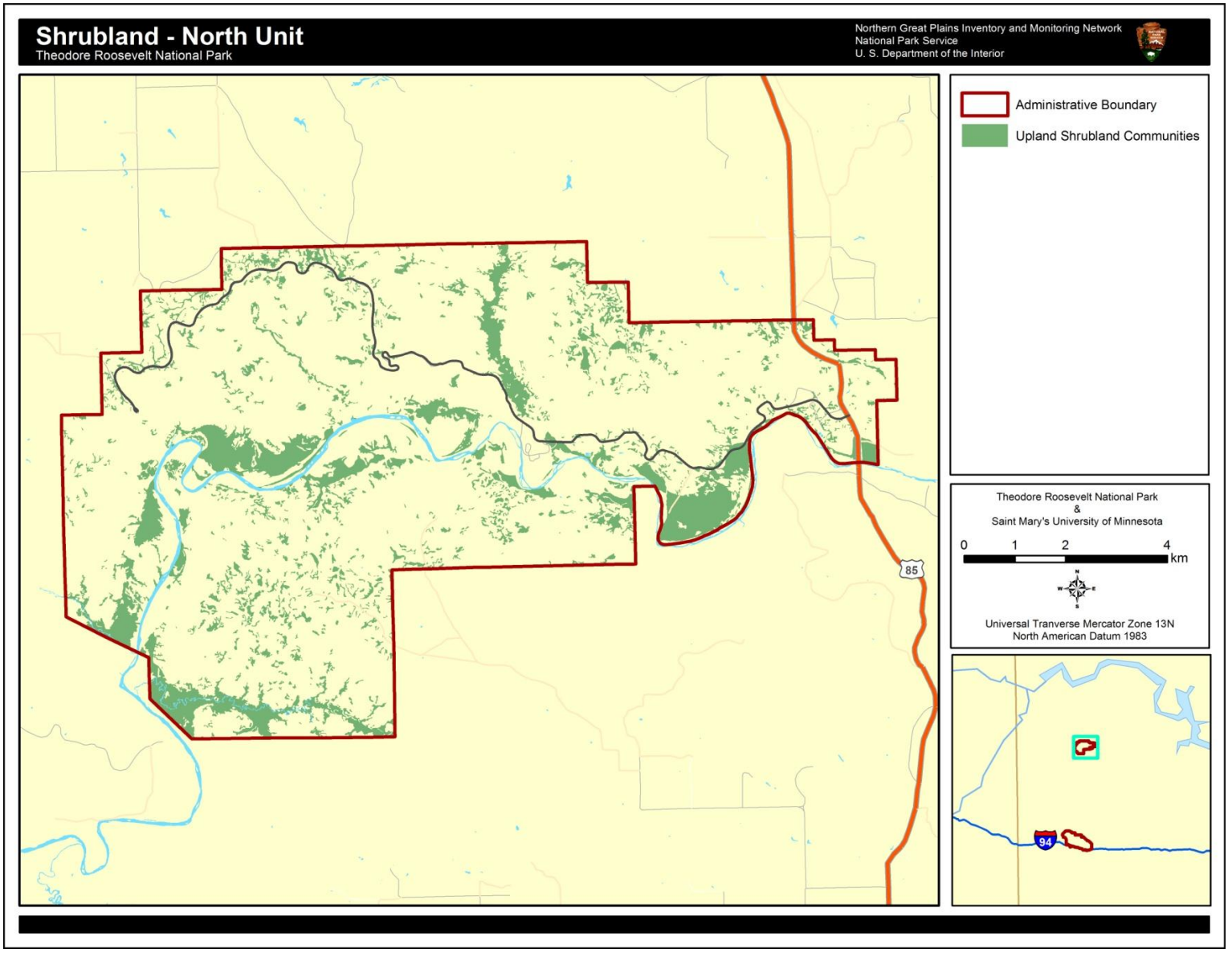


Plate 16. Shrubland alliances in the North Unit of THRO.

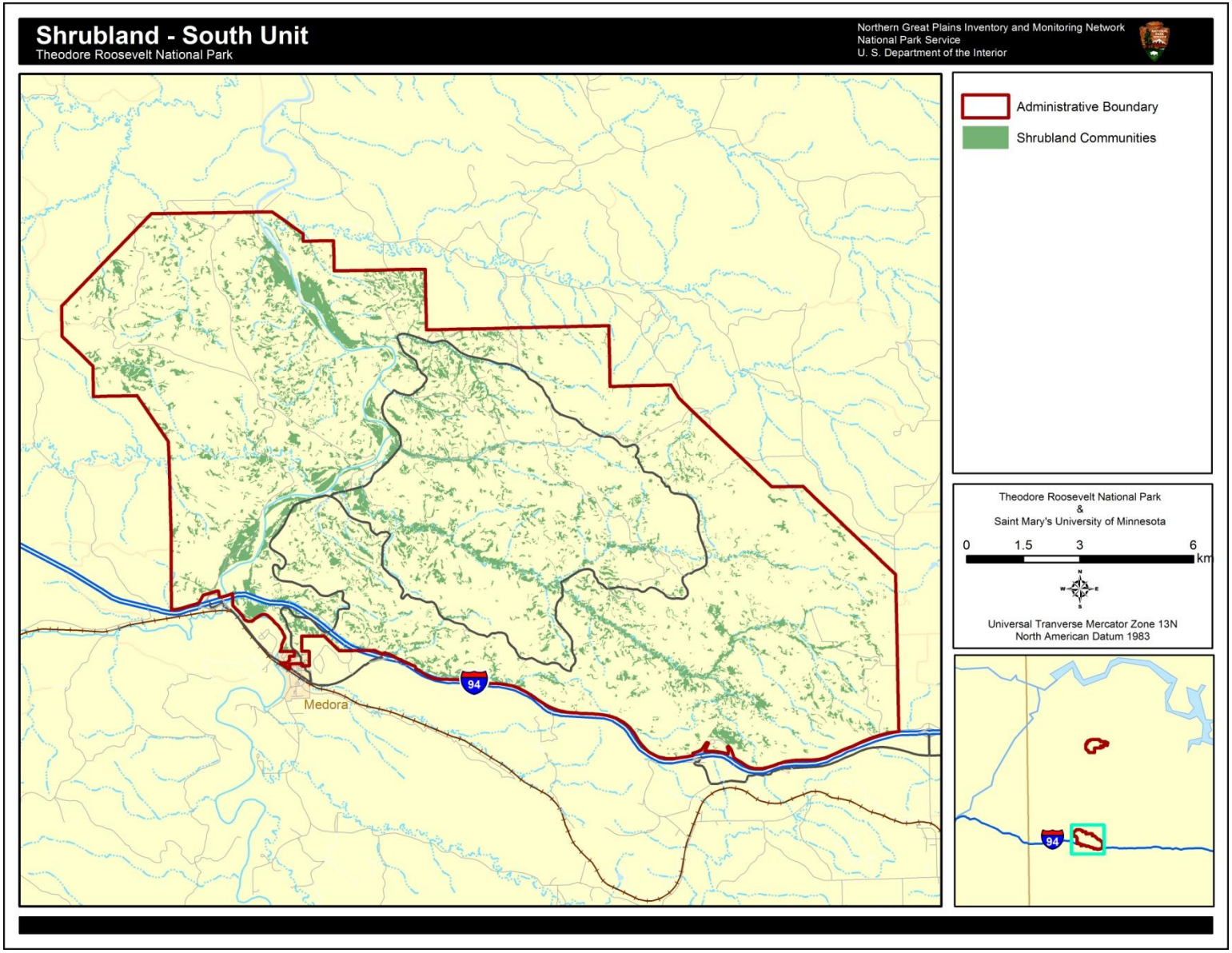


Plate 17. Shrubland alliances in the South Unit of THRO.

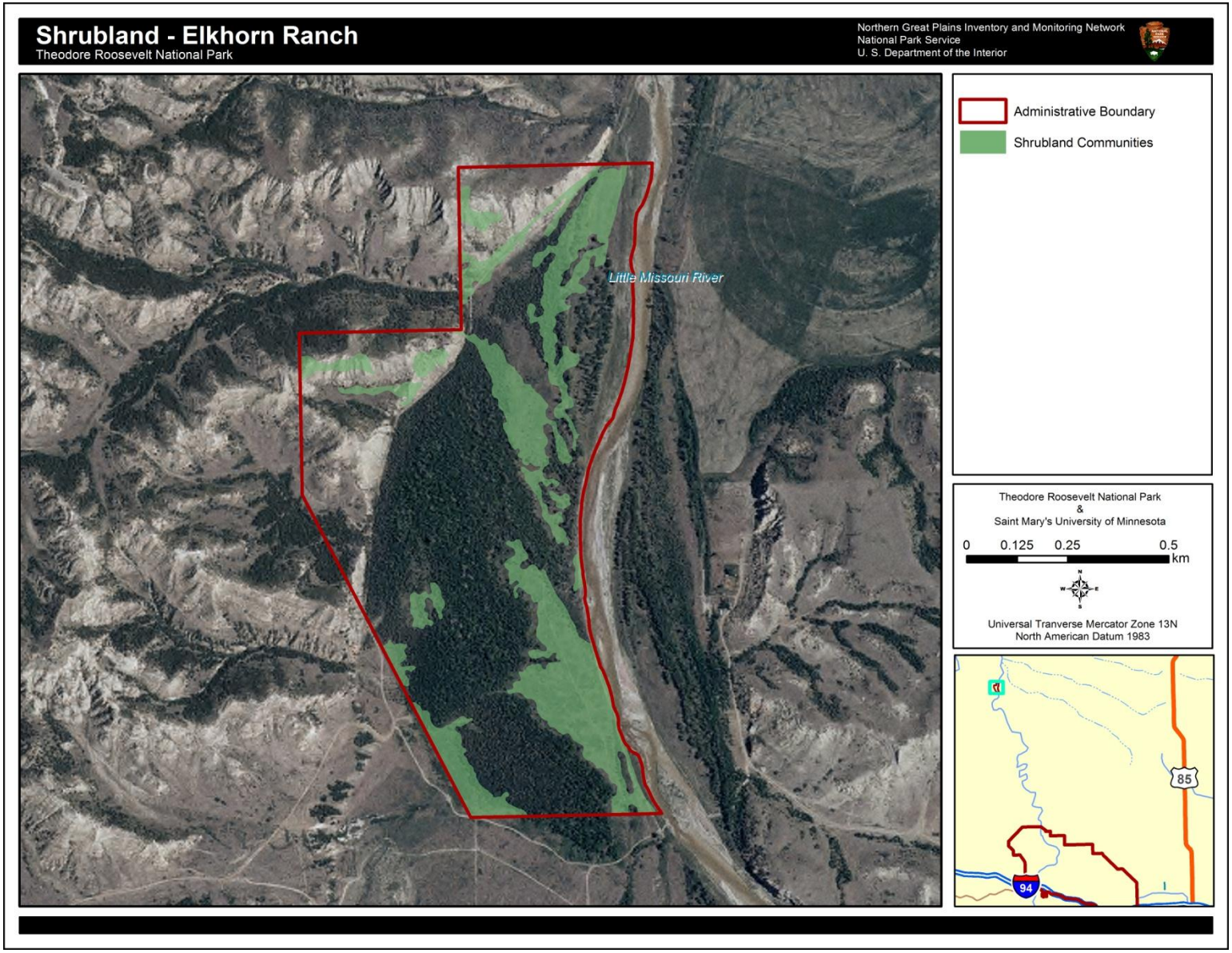


Plate 18. Shrubland alliances in the Elkhorn Ranch Unit of THRO.

4.9 Aquatic Communities

4.9.1 Description

Water is a scarce and highly valuable resource in the semi-arid landscape of THRO. While wetland and riparian areas are important habitats for some aquatic species in the park (Berkeley et al. 1998), the aquatic communities of THRO are mainly limited to the Little Missouri River, which connects all three units of the park, and tributary streams that feed into the river. The Little Missouri River is the only water body that supports a fish community in the park (NPS 2010). The river is primarily suited for small, non-game fish species; game species are more productive during wet years with high water levels (Duerre 1986, as cited in Berkley et al. 1998). There are 29 species of fish present in the Little Missouri River (NPS 2011). Little is known about the macroinvertebrate community in the Little Missouri River and other park water bodies, although limited research suggests that species diversity and abundance appear to be low in some stretches of the river (Rust 2006).



Photo 18. Longnose dace (*Rhinichthys cataractae*) (NPS photo).

4.9.2 Measures

- Native fish species composition and abundance
- Macroinvertebrate composition and abundance

4.9.3 Reference Conditions/Values

The reference condition for aquatic communities is the range of abundance and diversity of native fish and macroinvertebrate species over the duration of available survey and monitoring data. Historic fish species lists are cross-referenced to identify potential changes or shifts in abundance and diversity.

4.9.4 Data and Methods

Kelsch (1994) conducted a fish survey of the Little Missouri River at 24 sample sites between the towns of Marmarth and Medora in North Dakota in 1993.

USFWS (1999) also conducted a fish survey of the Little Missouri River in 1998 as part of the sturgeon chub (*Macrhybopsis gelida*) reintroduction project.

Rust (2006) collected water quality samples for several parameters on the Little Missouri River in THRO in 2004-2005. The objective of the research was to provide baseline descriptions of macroinvertebrate communities in the aquatic systems of national parks in the NGPN (including THRO), as well as select optimal metrics for use in future monitoring efforts by park resource managers. Chemical, physical, and habitat parameters were assessed for streams, rivers, and springs during the 2004 and 2005 summer seasons. The diversity and abundance of macroinvertebrate species was sampled at three locations on the Little Missouri River during this time.

4.9.5 Current Condition and Trend

Native Fish Species Composition and Abundance

Minnows (Cyprinidae), perches (Percidae), suckers (Catostomidae), and catfishes (Ictaluridae) make up 70% of the native fish fauna of the northern Great Plains region (Berkley et al. 1998). Hankinson (1929) was the first to survey fish species in the Little Missouri River, describing 17 species. Personius and Eddy (1955) reportedly identified 13 species during a survey from the headwaters in Wyoming to the junction with the Missouri River in central North Dakota. The list of fish species from Personius and Eddy (1955) is displayed in Table 24. It is important to note that this survey did not focus specifically on the stretch of river passing through THRO, but covered the entire Little Missouri River.

Table 24. Fish species documented in a 1950 survey of the Little Missouri River (Personius and Eddy 1955).

Scientific Name	Common Name
Carpiodes carpio carpio	northern river carpsucker
Catostomus commersoni commersoni	common white sucker
Cyprinus carpio	carp
Hybopsis gracilis communis	plains flathead chub
Hybopsis plumbea	northern chub
Hybopsis meeki	sickelfin chub
Rhinichthys cataclae	longnose dace
Notropis deliciosus missuriensis	plains sand shiner
Hybognathus placita	plains minnow
Pimephales promelas promelas	northern fathead minnow
Ictalurus punctatus	channel catfish
Ameiurus melas melas	northern black bullhead
Stizostedion canadense	sauger

The current NPS Certified Species List for THRO fish expands upon the list developed by Personius and Eddy (1955). Table 25 displays fish species confirmed to be present in THRO. The plains flathead chub (*Platygobio gracilis*, previously *Hybopsis gracilis communis*) was documented by Personius and Eddy (1955) but is not included on the current park species list.

Table 25. Certified species list for fish in THRO (NPS 2011).

Scientific Name	Common Name
Ameiurus melas	black bullhead
Aplodinotus grunniens	freshwater drum
Carpiodes carpio	river carpsucker/carpsucker
Catostomus commersonii	white sucker
Couesius plumbeus	lake chub
Culaea inconstans	brook stickleback
Cyprinus carpio	carp/European carp
Esox lucius	northern pike
Etheostoma exile	Iowa darter
Hiodon alosoides	goldeye
Hybognathus argyritis	western silvery minnow
Hybognathus hankinsoni	brassy minnow
Hybognathus placitus	plains minnow
Ictalurus punctatus	channel catfish
Lepomis cyanellus	green sunfish
Lepomis macrochirus	bluegill
Lota lota	burbot
Moxostoma macrolepidotum	shorthead redhorse
Notemigonus crysoleucas	golden shiner
Notropis atherinoides	emerald shiner
Notropis stramineus	sand shiner
Noturus flavus	stonecat
Phoxinus eos	northern redbelly dace
Pimephales promelas	fathead minnow, flathead minnow
Platygobio gracilis	flathead chub
Rhinichthys cataractae	longnose dace
Sander canadensis	sauger
Sander vitreus	walleye
Semotilus atromaculatus	creek chub

Kelsch (1994) surveyed the Little Missouri River in 1993 and documented 13 fish species. Three species were commonly found during the survey: flathead chub (*Platygobio gracilis*), plains minnow (*Hybognathus placitus*), and the longnose dace (*Rhinichthys cataractae*). These three species comprised 95% of individuals captured during the study; the flathead chub alone represented 72% of individuals captured. Generally, species diversity and abundance were low during the survey; only three sample sites out of 24 yielded more than five fish species (Kelsch 1994). Two species of special concern were captured during the study, the northern redbelly dace (*Phoxinus eos*) and the lake chub (*Couesius plumbeus*). The survey results may not have been representative of normal conditions on the Little Missouri River, as the study was conducted after a drought followed by unusually high flow and velocity (Kelsch 1994).

USFWS (1999) found that fish abundance in the Little Missouri River was dominated by a few species: flathead chubs, *Hybognathus* spp., sandshiners, and longnose dace comprised 90% of fish biomass in the survey. These results are quite similar to the findings of Kelsch (1994).

The sturgeon chub and sicklefin chub (*Macrhybopsis meeki*) are listed as Level I species by the North Dakota Game and Fish Department, meaning they are "species in the greatest need of conservation" within the state (NDGFD 2010). Neither species is federally-listed as threatened or endangered in the United States (Rahel and Thel 2004). The sturgeon chub and sicklefin chub now are considered extirpated from the Little Missouri River, and a sturgeon chub reintroduction effort conducted between 1998 and 2000 was unsuccessful (Rahel and Thel 2004).

Macroinvertebrate Composition and Abundance

Rust (2006) collected invertebrates in the Little Missouri River within THRO and found a low level of species diversity, with 47% of total abundance composed of the order Diptera (true flies). Twenty-four percent of macroinvertebrates in the survey were attributed to EPT (Ephemeroptera, Plecoptera, and Trichoptera) orders. Macroinvertebrate abundance in the Little Missouri River also was considered low by Rust (2006). This was the first and only study to examine the macroinvertebrate community in THRO. The Wyoming Natural Diversity Database sampled the macroinvertebrate community in THRO in 2011 (L. Tronstad, pers. comm., 2012). Data currently are being analyzed and are not yet available for comparison with Rust's (2006) findings.

Threats and Stressor Factors

Non-native species threaten native fish and macroinvertebrate populations in the Little Missouri River, and are present in part due to habitat alterations caused by reservoir construction (Rahel and Thel 2004). Non-native fish species present in the Little Missouri River include the common carp (*Cyprinus carpio*), and piscivorous fish species such as walleye (*Zander vitreum*), striped bass (*Morone saxatilis*), and largemouth bass (*Micropterus salmoides*) that have been stocked in Little Missouri River reservoirs in an attempt to develop sport fisheries (Rahel and Thel 2004).

Habitat alterations to the Little Missouri River, including conversion of riverine habitat to standing water habitat, reduction of turbidity, and fragmentation, have altered the natural water quality (Rahel and Thel 2004). Reduction of turbidity in particular has led to the replacement of fish species tolerant of turbid water with species characteristic of clearer waters. Species such as the sturgeon chub particularly have been affected by these water quality changes, with an increase in clear water fish that often prey on the chub (Rahel and Thel 2004).

Data Needs/Gaps

Kelsch (1994) stated that additional fish surveys during periods of both normal and low flow would be necessary to truly understand diversity and abundance in the Little Missouri River. The few surveys conducted to date have been sporadic and only present a snapshot of the fish community under certain conditions. There have been no published studies on fish populations in or near THRO over the past decade.

There is little data available regarding macroinvertebrate diversity and abundance. Rust (2006) provided some baseline data on the community in the Little Missouri River and the Wyoming Natural Diversity Database recently sampled the macroinvertebrate community in THRO,

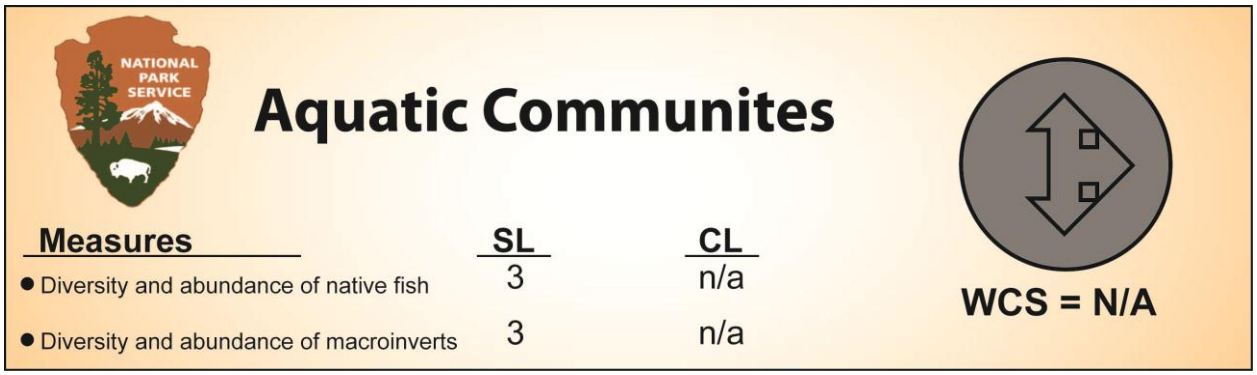
although this data is not yet available. Continued monitoring of macroinvertebrates could help managers identify any changes in the park's aquatic community and possibly water quality.

Overall Condition

Native Fish Species Composition and Abundance
The THRO project team defined the *Significance Level* for native fish species composition and abundance as a 3. Documented fish species diversity has increased over time in THRO, though this is likely due to more intensive sampling. There is not enough historic and current diversity and abundance data to determine a *Condition Level*.

Macroinvertebrate Composition and Abundance
A *Significance Level* of 2 was assigned for the measure of macroinvertebrate composition and abundance. Because there has only been one published study on the macroinvertebrate community in the Little Missouri River to date, there is not enough data to determine a *Condition Level* for this measure.

Weighted Condition Score
A *Weighted Condition Score* (WCS) cannot be assigned at this time due to lack of data on component measures.



4.9.6 Sources of Expertise
Steven Kelsch, Associate Professor of Biology, University of North Dakota

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4.10 Prairie Dogs

4.10.1 Description

Black-tailed prairie dogs (*Cynomys ludovicianus*), hereafter prairie dogs, are stout, burrowing rodents commonly associated with early successional vegetation (NRCS 2012). Grasses comprise a majority of their diet, but forage varies across the species' range. Prairie dogs are gregarious animals; they live in social groups called towns or colonies. Within these towns are multiple burrows connected through underground tunnels. Prairie dogs are a keystone species in their environments as they provide essential food and shelter for other prairie species. At THRO, some of the species that utilize towns include burrowing owls (*Athene cunicularia*), ferruginous hawks (*Buteo regalis*), and mountain plovers (*Charadrius montanus*); these species depend on prairie dogs for food, use of their burrows, and other reasons (Antolin et al. 2002).

4.10.2 Measures

- Extent of prairie dog colonies

4.10.3 Reference Conditions/Values

There is not an established reference condition for this component. Park management actively observes the dog colonies throughout the year to be prepared in case management action is necessary. However, the use of active management techniques by park staff is rare with this species. Future assessments should incorporate the new prairie dog management plan that is currently in development.



Photo 19. Black-tailed prairie dog (Photo by Shannon Amberg, SMUMN GSS, 2010).

4.10.4 Data and Methods

The primary source of data for this component is the THRO Wildlife Program Geodatabase. This database holds polygon feature classes with the extent of prairie dog colonies for 12 years: 1984, 1996, 1997, 1999, 2000-2003, 2005, and 2007-2011. Mike Oehler, THRO Wildlife Biologist, indicated that data gathered after 2000 is of higher quality due to adjusted methods. Attributes from this dataset used in this assessment include colony name, area (acres), and perimeter (meters). Data from the extent feature classes were extracted to an Excel table, where fields were dissolved in order to allow for easy development of tables and graphs.

4.10.5 Current Condition and Trend

<u>Extent of Prairie Dog Colonies</u>

From 1984 to 2008, the total area of prairie dog colonies in THRO increased to a maximum recorded area of 1,879 acres (Figure 13). Then, from 2009 to 2011, prairie dog acreage decreased each year, with total acreage in 2011 being 1,151 acres. In 1984, the total area occupied by prairie dogs in the South Unit was 422 acres, according to a vegetation map produced by Jack Norland of North Dakota State University. In 2008, the acreage in the South Unit was at an all-time high, since recordkeeping began, with 1,742 acres (Figure 14). The earliest date that prairie

dog mapping occurred in the North Unit was 1997. In 1997, the total acreage in the North Unit was 108 acres. Since 1997, the extent of prairie dogs in the North Unit has been stable (mean = 112, range = 31-145), not showing any particular trend (Figure 15). However, the most recent occupied acreage, in 2011, was the second lowest on record at 72 acres.

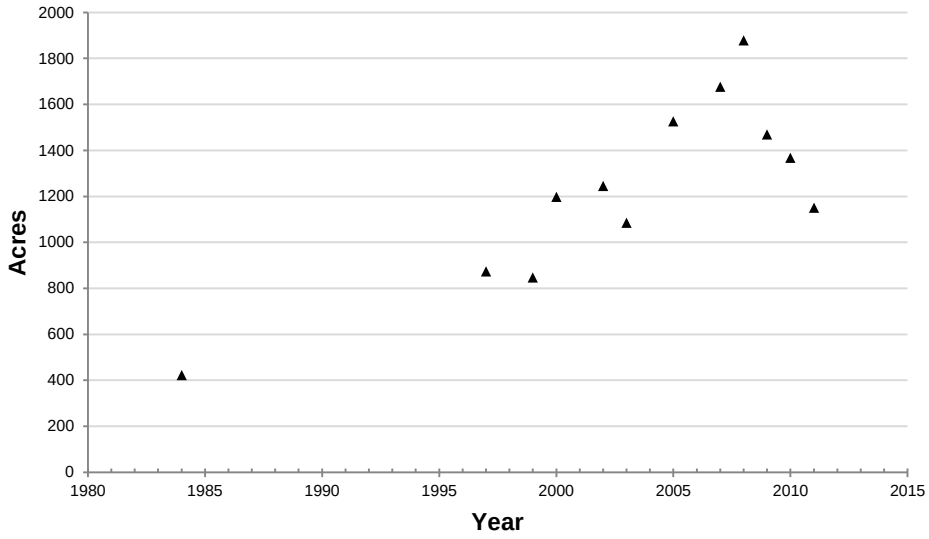


Figure 13. Total acres of prairie dog colonies in THRO, 1984-2011 (THRO 2010).

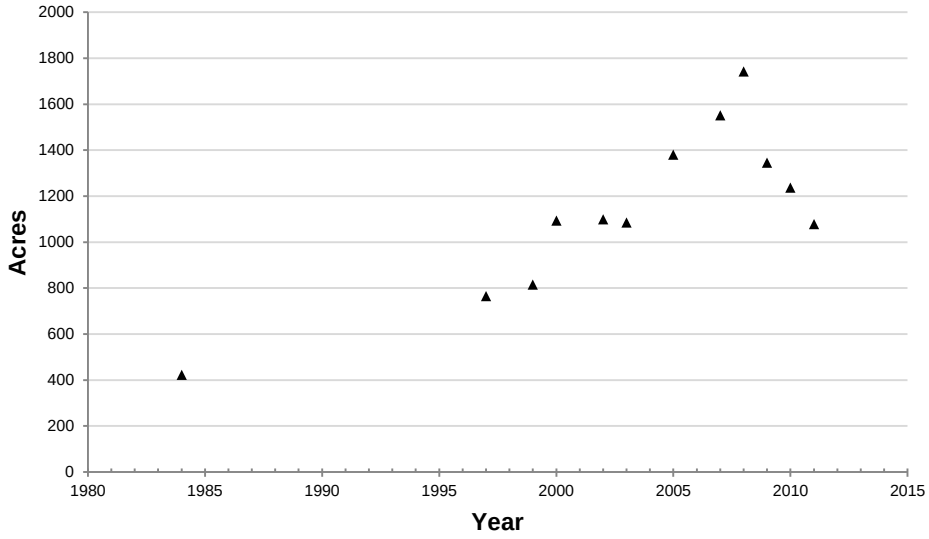


Figure 14. Total acres of prairie dog colonies in the South Unit of THRO, 1997-2011 (THRO 2010).

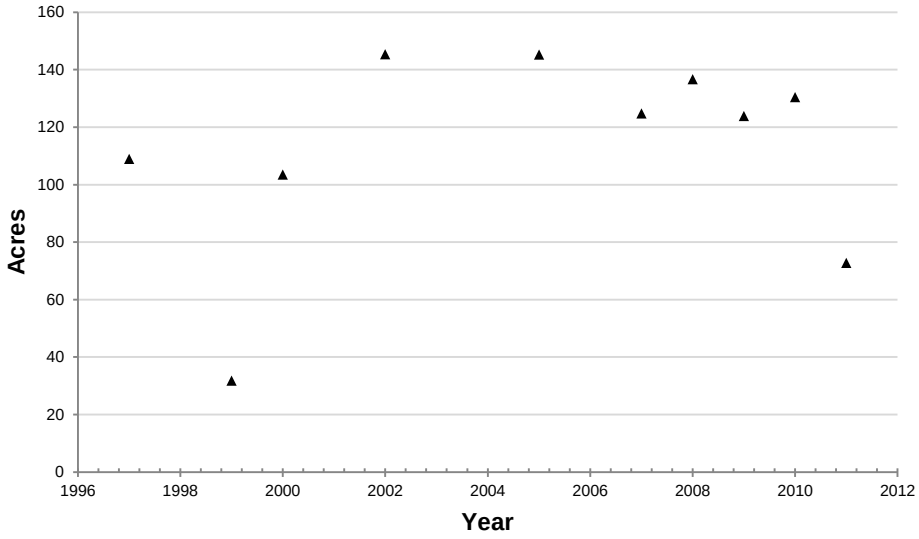


Figure 15. Total acres of prairie dog colonies in the North Unit of THRO, 1997-2011 (THRO 2010).

Increases in prairie dog acreage within the South Unit in the mid-2000s occurred during years of drought, possibly because colonies must expand to access more forage (M. Oehler, pers. comm., 2012). If this is true, even though acreage is expanding, the relative change in total population over that time is still unknown. THRO typically allows colonies to expand and contract according to natural processes. The only exception is when a colony infringes upon park infrastructure. In the North Unit of the park, prairie dog acreage is relatively stable over the duration of the available data; the reason for the stability is not described in the literature, but rough terrain and limited suitable habitat are two possibilities identified by park staff (M. Oehler, C. Sexton, pers. comm., 2012).

Threats and Stressor Factors

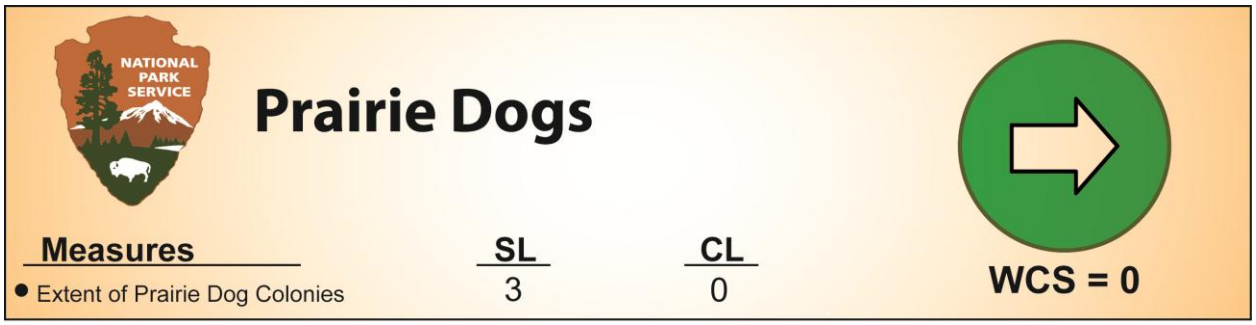
Sylvatic plague, caused by the bacterium *Yersinia pestis,* is the most well-known stressor to prairie dog populations and one of the four primary causes for the rangewide decline in prairie dog distribution and abundance over the past century (Van Putten and Miller 1999, Antolin et al. 2002, Pauli et al. 2006). It is the only major factor that limits prairie dog abundance that is beyond human control (Cully and Williams 2001). Black-tailed prairie dogs are highly susceptible to plague, exhibiting near 100% mortality, compared to approximately 85% mortality in white-tailed prairie dogs (Barnes 1993, Cully and Williams 2001). Additionally, plague results in smaller and more isolated prairie dog colonies, which reduces genetic variability through inbreeding and genetic drift (Trudeau et al. 2004). Sylvatic plague occurred in THRO in 1986, 1993, and on a few later occasions, but data are unpublished (C. Sexton, pers. comm., 2012).

Data Needs/Gaps

There are currently no data gaps for the prairie dog population at THRO. Park staff performs yearly delineations of the prairie dog colonies to inform their management.

Overall Condition

Extent of Prairie Dog Colonies
The *Significance Level* of this measure is a 3 because prairie dog management at the park focuses nearly exclusively on prairie dog acreages. THRO's active management of the prairie dog colonies is minimal; this allows natural processes to govern the size and location of the dog towns. Currently, sylvatic plague is not present in the park and other stressors common to prairie dogs elsewhere are absent in the park. Therefore, the *Condition Level* for this component is 0, indicating minimal concern; because there is only one measure for this component, the *Weighted Condition Score* is also 0.



4.10.6 Sources of Expertise
Mike Oehler, Wildlife Biologist, THRO
Chad Sexton, Geographic Information Systems Analyst, THRO

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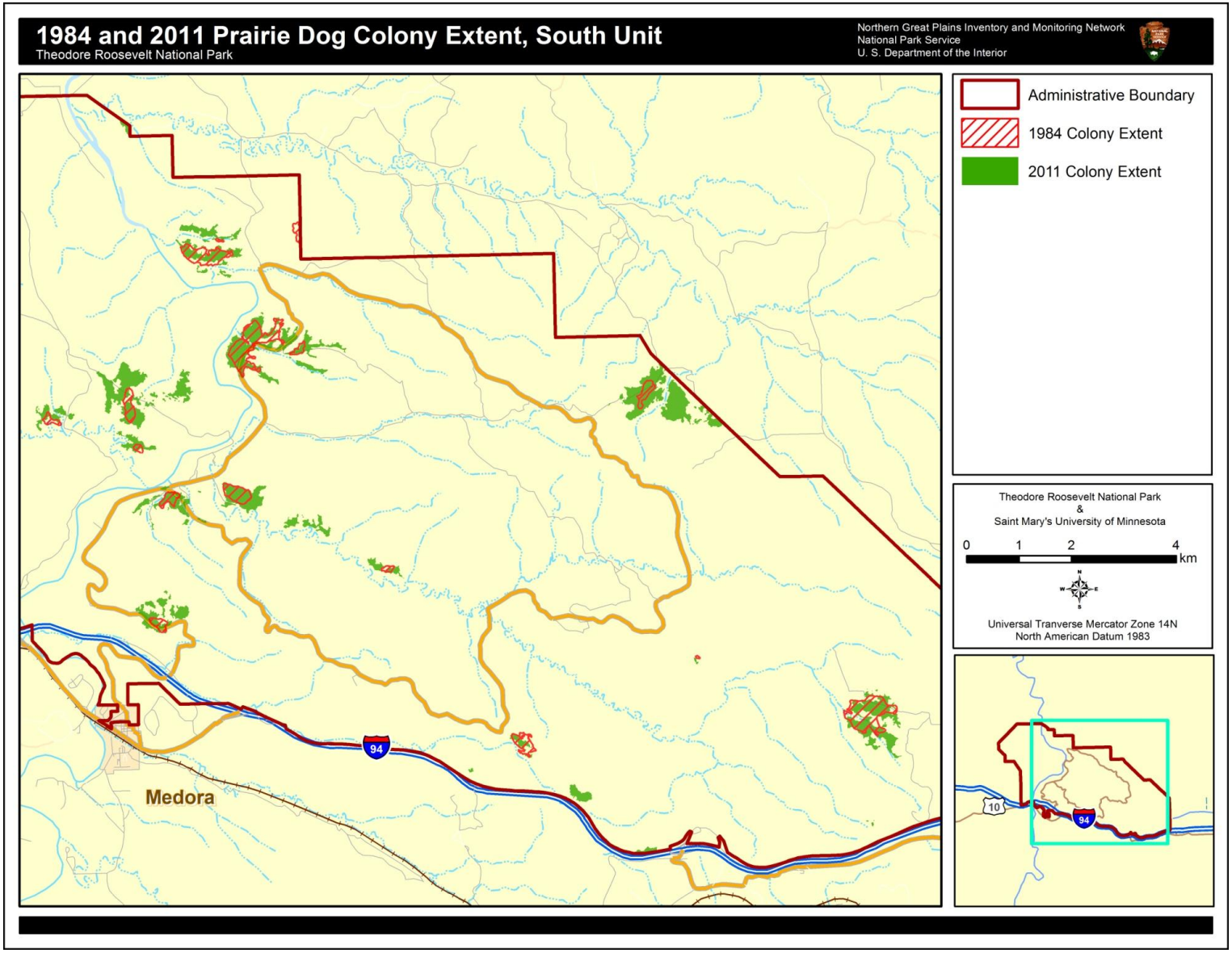


Plate 19. Prairie dog colony extent, South Unit,1984 and 2011.

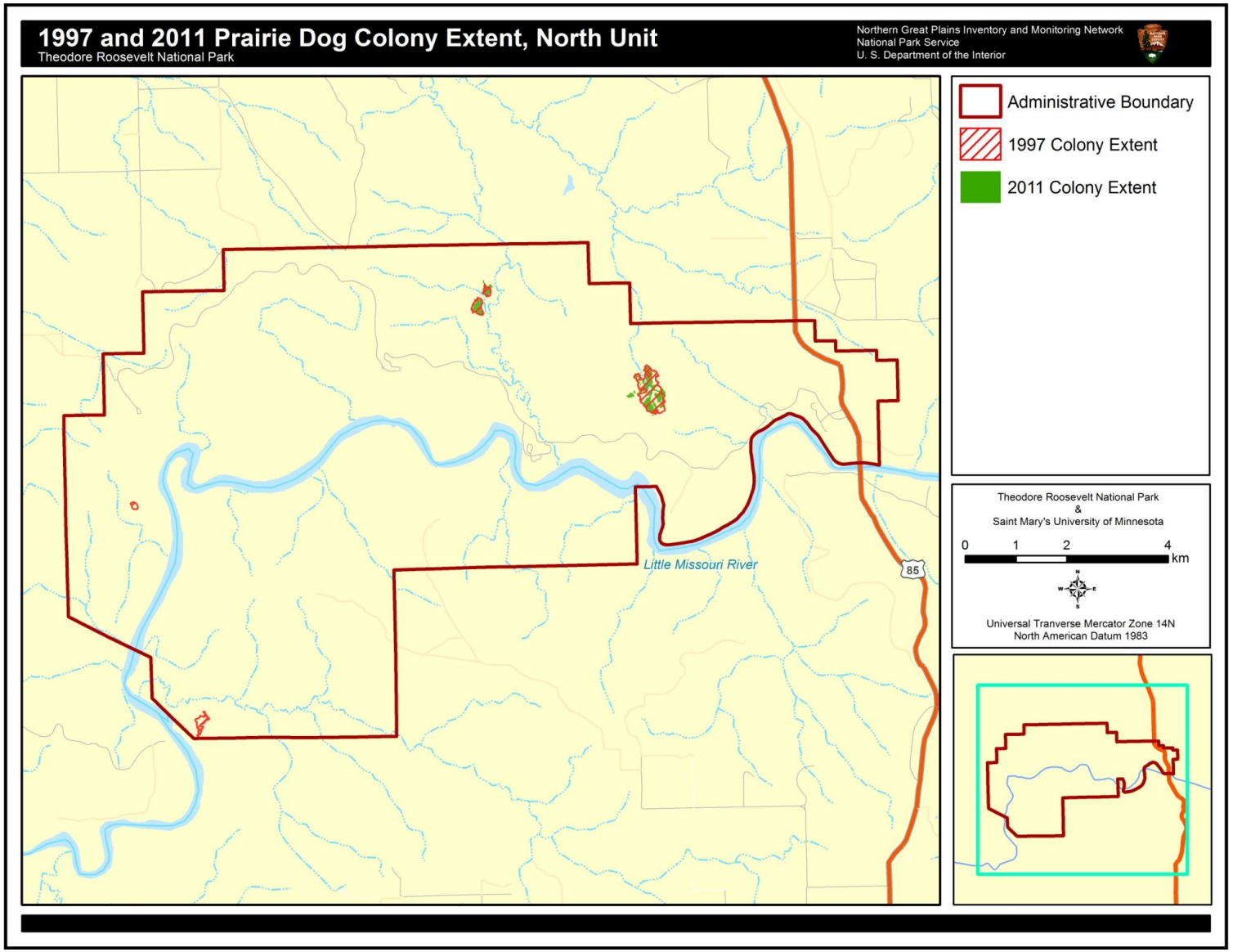


Plate 20. Prairie dog colony extent, North Unit, 1997 and 2011.

4.11 Breeding Birds

4.11.1 Description

Bird populations are excellent indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are typically easy to observe and identify, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010).



Photo 20. Pine siskin (*Carduelis pinus*) (NPS Photo, Nathan King).

THRO is home to a unique diversity of habitats including floodplain forests, native grasslands, and juniper slope forests. These habitats provide the avian species in the park with nesting habitat and food sources. Over 185 bird species have been confirmed in the park (NPS 2011). Monitoring avian population health and diversity in these habitats will be important for detecting ecosystem change.

There has not been a formal effort to classify which species in THRO breed in the area annually. Therefore, this assessment will include all species observed during surveys conducted during the breeding season (e.g., Breeding Bird Surveys [BBS], Integrated Monitoring in Bird Conservation Regions [IMBCR] surveys).

4.11.2 Measures

- Species richness
- Number of species of conservation concern
- Raptor species richness

4.11.3 Reference Conditions/Values

There have been limited bird surveys in THRO, and because of this, the reference condition will be the characteristics of the breeding bird population from the nearby Little Missouri National Grassland (LMNG). This grassland has established IMBCR sampling grids similar to grids recently established in THRO. The LMNG grids serve as a comparison for the THRO grids. If IMBCR grid sampling is continued in THRO, the data from 2009-2012 could serve as a baseline reference condition for this component in the future.

4.11.4 Data and Methods

The NPS Certified Bird Species List (NPS 2011) for THRO was used for this assessment. This list represents all of the confirmed bird species present in the park.

In 1999, Powell (2000) began a breeding bird study at four national park units (Agate Fossil Beds National Monument, Scott's Bluff National Monument, Badlands National Park, and

THRO). The specific objective of this study was to investigate and identify the quantity of grassland-associated species in these Great Plains parks. Powell (2000) utilized fixed-radius point counts to survey breeding birds in THRO. The sample points were located in grassland habitats and were spaced 250 m apart; points were sampled for 5 minutes. All birds seen or heard within a 100 m radius were counted.

Because the objectives of Powell (2000) were specifically concerning grassland birds, the point counts focused only on the grassland habitats in THRO. Thus, these point counts may have missed breeding species that are not dependent upon grassland habitats.

The THRO breeding bird survey route is part of the large-scale North American Breeding Bird Survey (BBS), which began in 1966 and is coordinated by the USGS and the Canadian Wildlife Service (Robbins et al. 1986). The standard BBS route is approximately 40 km (25 mi) long with survey points at every 0.8 km (0.5 mi). The survey begins ½ hour before sunrise, and at each survey point the number of birds seen and heard within a 0.4-km (0.25-mi) radius during a three-minute interval is recorded. Only BBS route 64033 (Roosevelt Park Route) crosses within the park's North Unit boundaries (Plate 21). This route was surveyed annually from 1982-2009 (USGS 2011).

The Rocky Mountain Bird Observatory (RMBO) and its partners monitor land bird populations in several Bird Conservation Regions (BCRs) across North America; THRO lies within Bird Conservation Region 17 (BCR 17: Badlands and Prairies) (Figure 16) and has been monitored by RMBO and its partners since 2009 (White et al. 2011). Land bird monitoring in THRO is part of the IMBCR program, and utilizes a spatially-balanced sampling design during survey efforts (White et al. 2011).

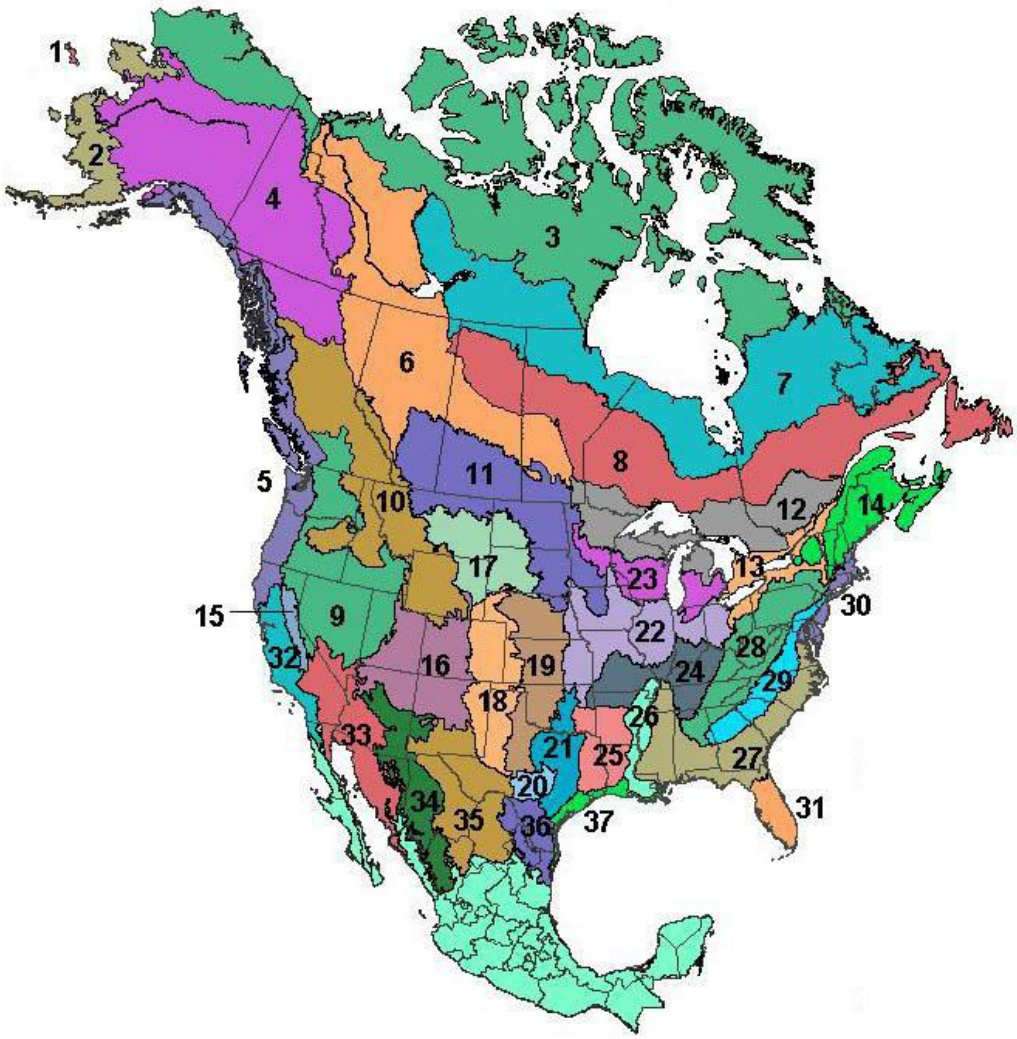


Figure 16. Bird Conservation Regions through North America. THRO lies within BCR 17. Image reproduced from (http://www.nabci-us.org/map.html).

The IMBCR land bird monitoring program established a series of strata and super-strata (White et al. 2011). Within these strata, RMBO and its partners utilized generalized random-tessellation stratification (GRTS) to select sample units (Stevens and Olson 2004, White et al. 2011). According to White et al. (2011, p. 8):

> The IMBCR design defined sampling units as 1-km^2 cells that were used to create a uniform grid over the entire BCR. Within each grid cell we established a 4 x 4 grid of 16 points spaced 250 m apart (Figure 17, Plate 22).

The IMBCR program surveys all land bird species during the typical breeding season. Data and analyses in this document represent the likely breeding landbirds.

Selected transects (Plate 22) were sampled early in the breeding season after all migratory species had returned to their breeding areas. Care was taken not to survey too early in the season, as an early survey could potentially miss migratory breeding species or could sample transient birds that are migrating through the area (Hanni et al. 2011). Each point on a transect was sampled for 6 minutes using methods that allow for estimating detection probability through the principles of distance sampling (Buckland et al. 2001, Thomas et al. 2010), removal modeling (Farnsworth et al. 2002) and occupancy estimation (MacKenzie et al. 2002, MacKenzie 2006). All bird species detected were recorded, along with several variables such as distance from the observer, habitat type, weather, and land ownership (Hanni et al. 2011).

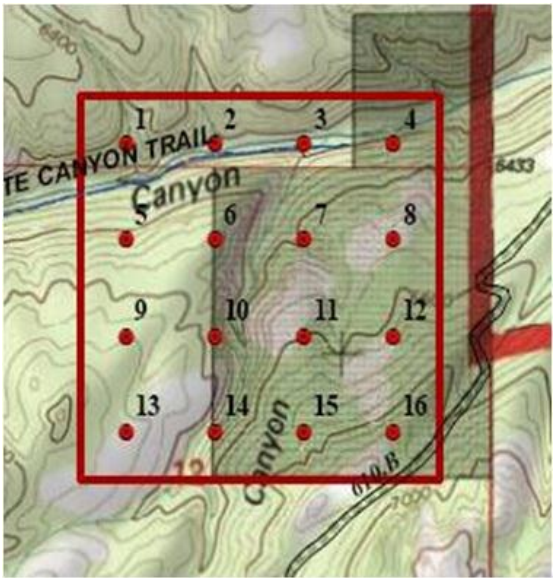


Figure 17. Example of a grid cell created by the RMBO using the IMBCR design. Reproduced from White et al. (2011).

4.11.5 Current Condition and Trend

Species Richness

Breeding Bird Survey

Species counts for each year of the BBS were calculated (Figure 18). The average number of species observed on the THRO BBS from 1982-2009 was 53.4 species. There does not appear to be an increasing or decreasing trend in species richness observed each year (Figure 18). However, there may be undetected changes in species richness of native species compared to non-native species, or in Neotropical migrant species compared to resident species. Such changes would not be apparent in Figure 18. The THRO BBS only surveys the North Unit of the park (Plate 21), and does not survey any part of the South Unit. Thus, species richness values shown here may not be truly indicative of the overall species richness for THRO.

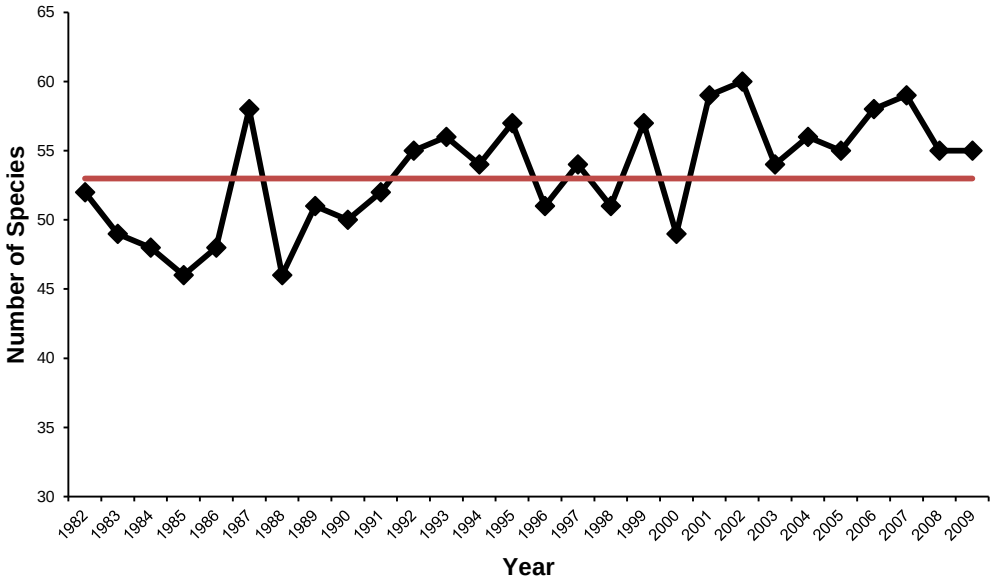


Figure 18. Species richness estimates from the annual BBS route in THRO. The solid red line indicates the 28-year average (53 species) for the survey.

Powell (2000) Grassland Bird Inventory

Powell (2000) conducted a fixed-radius point count of breeding bird species (with emphasis on the grassland species in THRO) at 18 points in the park. During this 1-year survey, Powell (2000) found 650 individuals of 49 species on point counts. When not restricted to the species observed on the point counts, Powell (2000) reported 76 species observed. Approximately 31% of the breeding species recorded were grassland-associated species; the most abundant species observed were spotted towhee (*Pipilo maculatus*), vesper sparrow (*Pooecetes gramineus*), field sparrow (*Spizella pusilla*), and yellow-breasted chat (*Icteria virens*).

IMBCR Land Bird Sampling

RMBO surveyed two grids under the IMBCR design during visits to the South Unit of THRO from 2009-2011 (ND-BCR17-NP1 and ND-BCR17-NP3) (Plate 22). In 2009, 35 bird species were observed on 21 points along both grids, while 37 species were observed at 20 points along both grids in 2010. In 2011, 39 bird species were identified at 22 points along both grids.

The IMBCR grids within THRO have been surveyed for only 3 years, and deciphering any trends from these data is not appropriate at this time. Continued monitoring with increased sampling intensity will allow for long-term species richness trend comparisons and may provide insights into the habitat availability for bird species in the park from year to year.

The IMBCR grids in THRO present an opportunity to compare the park's species richness to that of the nearby LMNG. LMNG is also part of the RMBO's IMBCR program, and has several established transects in the grassland. LMNG is in a similar habitat type as THRO, and serves as an appropriate reference condition for the breeding birds in THRO (J. Birek, pers. comm., 2012). From 2009-2011, LMNG had an average of 77.6 species observed. In 2009, 76 species were observed at 146 points, while 83 species were observed at 123 points in 2010 (Figure 19). In 2011, 74 species were identified at 83 points in LMNG (Figure 19). These estimates of species

richness are higher than those reported for THRO. However, LMNG has 16 established grids while THRO only has two, which may result in some discrepancy when comparing the data.

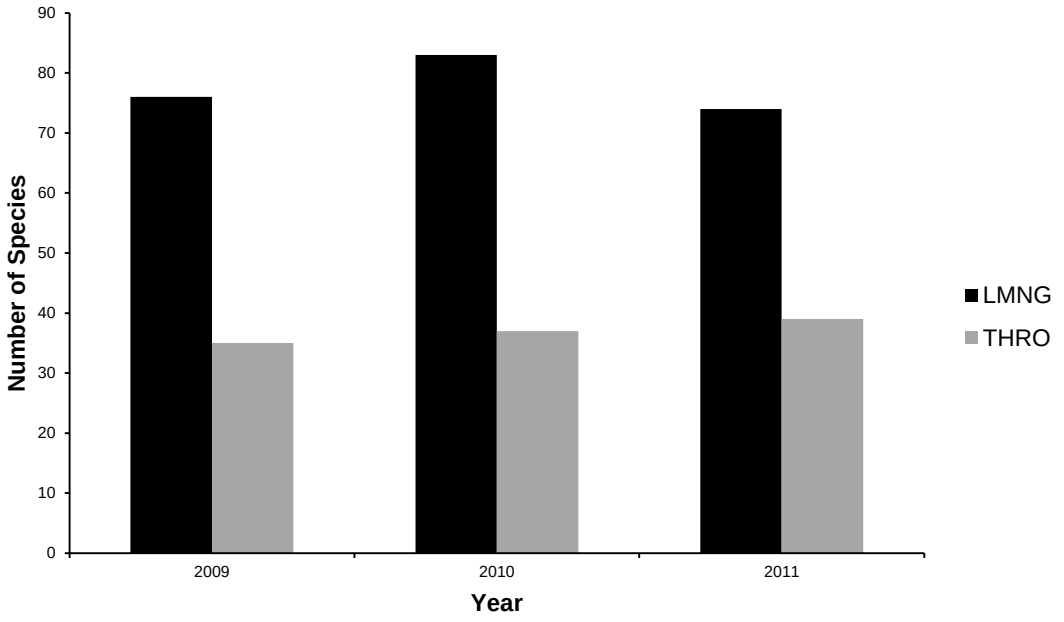


Figure 19. Species richness for IMBCR surveys in both LMNG (16 grids or transects) and THRO (two grids or transects) from 2009-2011.

Number of Species of Conservation Concern

Breeding Bird Survey
Partners in Flight (PIF) compiles a list (RMBO 2005) of species of regional importance for each BCR in North America. Seventeen species identified on this list were observed on the BBS in THRO from 1982-2009

Table 26). Similarly, the U.S. Fish and Wildlife Service (USFWS) compiles a list of birds of conservation concern for all BCRs in North America (USFWS 2008). During the THRO BBS, ten species from this list were identified within the park

Table 26).

Table 26. Species of conservation concern observed during the THRO BBS from 1982-2009.

Species	USFWS (2008)[a]	PIF SRI[b]	NDGFD (2004)[c]
sharp-tailed grouse		X	
American white pelican			X
northern harrier		X	
Swainson's hawk		X	X
golden eagle	X	X	
prairie falcon	X		
upland sandpiper	X		X
black-billed cuckoo	X	X	X
red-headed woodpecker	X	X	
Say's phoebe		X	
loggerhead shrike	X	X	
black-billed magpie		X	
northern rough-winged swallow		X	
mountain bluebird		X	
Sprague's pipit	X	X	X
vesper sparrow		X	
lark bunting		X	X
grasshopper sparrow	X	X	X
Baird's sparrow	X	X	X
chestnut-collared longspur	X	X	X

[a] = USFWS Species of Conservation Concern, 2008
[b] = Partners in Flight Species of Regional Importance for BCR 17 (RMBO 2005)
[c] = North Dakota's 100 Species of Conservation Priority

NDGFD (2004) identifies 100 species of conservation priority in North Dakota. However, the species identified in this report are not limited to only avian species. This report separates the species into three levels: Level-I, Level-II, and Level-III. For this report only avian species identified as Level-I species are considered. A Level-I species is defined by NDGFD (2004, p. 3) as:

> Species having a high level of conservation priority because of declining status either in North Dakota or across their range; or a high rate of occurrence in North Dakota constituting the core of the species' breeding range, but are at-risk range wide, and non-SWG [State Wildlife Grants] funding is not readily available to them.

Within THRO, nine Level-I species were identified on the THRO BBS route from 1982-2009 (

Table **26**).

Powell (2000) Grassland Bird Inventory

During a 1999 breeding bird inventory, Powell (2000) documented 17 species listed as species of conservation concern by USFWS (2008), 23 species of regional importance (RMBO 2005), and 11 Level-I species identified in NDGFD (2004) (Table 27).

Table 27. Species of conservation concern observed during the Powell (2000) bird survey in 1999.

Species	USFWS (2008)[a]	PIF SRI[b]	NDGFD (2004)[c]
northern goshawk		X	
golden eagle	X	X	
ferruginous hawk	X	X	X
Swainson's hawk		X	X
northern harrier		X	
bald eagle	X		
prairie falcon	X		
peregrine falcon	X		
American white pelican			X
upland sandpiper	X		X
long-billed curlew	X		
Wilson's phalarope			X
black-billed cuckoo	X	X	X
sharp-tailed grouse		X	
dickcissel	X	X	
black-billed magpie		X	
Baird's sparrow	X	X	X
grasshopper sparrow	X	X	X
lark bunting		X	X
chestnut-collared longspur	X	X	X
vesper sparrow		X	
northern rough-winged swallow		X	
western meadowlark		X	
loggerhead shrike	X	X	
Sprague's pipit	X	X	X
mountain bluebird		X	
Say's phoebe		X	
red-headed woodpecker	X	X	
short-eared owl	X	X	
burrowing owl	X	X	

[a] = USFWS Species of Conservation Concern, 2008
[b] = Partners in Flight Species of Regional Importance for BCR 17 (RMBO 2005)
[c] = North Dakota's 100 Species of Conservation Priority

IMBCR Land Bird Sampling

On the two IMBCR transects in THRO, three species of conservation concern (USFWS 2008), 10 species of regional importance (RMBO 2005), and three species identified in NDGFD (2004) were observed (Table 28).

Table 28. Species of conservation concern observed during the IMBCR bird monitoring in THRO from 2009-2011.

Species	USFWS (2008)[a]	PIF SRI[b]	NDGFD (2004)[c]
black-billed magpie		X	
golden eagle	X	X	
grasshopper sparrow	X	X	X
lark bunting		X	X
mountain bluebird		X	
northern harrier		X	
Say's phoebe		X	
sharp-tailed grouse		X	
upland sandpiper	X		X
vesper sparrow		X	
western meadowlark		X	

[a] = USFWS Species of Conservation Concern, 2008
[b] = Partners in Flight Species of Regional Importance for BCR 17 (RMBO 2005)
[c] = North Dakota's 100 Species of Conservation Priority

Raptor Species Richness

No raptor-dedicated survey effort currently exists in THRO. The available data for raptors in the area come from the aforementioned surveys and reports.

Breeding Bird Survey

From 1982-2009, 11 raptor species were observed on the annual BBS route in THRO (Table 29). The average raptor species richness on the THRO BBS was three species per year; the highest number of raptor species was observed in 1987 (seven species), while only one species was observed in 1989, 1999, 2002, and 2007 (Figure 20).

Table 29. Raptor species observed on the THRO BBS from 1982-2009.

Common Name	Number of years observed
turkey vulture	12
northern harrier	11
sharp-shinned hawk	4
Cooper's hawk	5
Swainson's hawk	2
red-tailed hawk	9
golden eagle	3
American kestrel	25
prairie falcon	9
eastern screech-owl	1
great horned owl	2

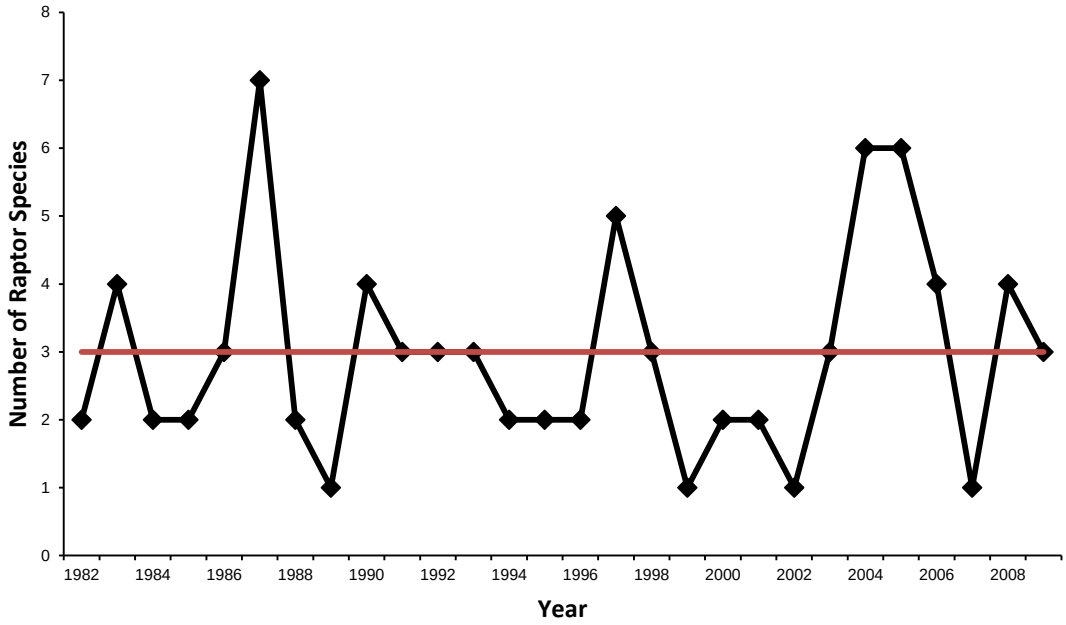


Figure 20. Raptor species richness estimates from the annual BBS route in THRO from 1982-2009. The solid red line indicates the 28-year average (three species) for the survey.

Powell (2000) Grassland Bird Inventory

The Powell (2000) grassland bird inventory only recorded the presence of species, and did not indicate the number of observations of each species. In 1999, seven raptor species were observed: sharp-shinned hawk, golden eagle, Swainson's hawk, northern harrier, turkey vulture, American kestrel, and great horned owl (Powell 2000).

IMBCR Land Bird Sampling

The two IMBCR transects in THRO have been surveyed annually since 2009. During these surveys, five raptor species have been observed. In 2009, two species were observed (northern harrier and turkey vulture), while only one raptor species was observed in 2010 (turkey vulture). 2011 had three raptor species observations (American kestrel, golden eagle, and red-tailed hawk). Table 30 represents the total number of individuals observed during the IMBCR transect surveys.

Table 30. Number of individual raptors observed from 2009-2011 during IMBCR surveys in THRO.

Species	2009	2010	2011
American kestrel			3
golden eagle			1
northern harrier	1		
red-tailed hawk			1
turkey vulture	1	1	

Threats and Stressor Factors

One of the major threats facing bird populations across all habitat types is land cover change (Morrison 1986). Land cover change is not restricted to breeding habitat; many species depend

on specific migratory and wintering habitat types. Altered habitats can compromise the reproductive success or wintering survival rates of species adapted to that habitat. Priority species in THRO, such as Sprague's pipit (*Anthus spraugueii*) and Baird's sparrow (*Ammodramus bairdii*), often require specific vegetative communities (e.g., tall prairie grasses and ample ground cover) for successful nesting to occur. A loss or alteration of these vegetative structures could compromise the nesting success of these species in THRO.

Another threat facing land bird populations is shifts in reproductive phenology. Several bird species depend on temperature ranges or weather cycles to cue their breeding. As global temperatures change, some bird species have adjusted by moving their home range north (Hitch and Leberg 2007). Other species have adjusted their migratory period and have begun returning to their breeding grounds earlier in the spring; American robins (*Turdus migratorius*) in the Colorado Rocky Mountains are now returning to their breeding grounds 14 days earlier compared to 1981 (NABCI 2009). A concern is that this shift in migration may be out of sync with food availability and could ultimately lead to lowered reproductive success.

The North American Bird Phenology Program (BPP) is currently analyzing the migration patterns and distribution of migratory bird species across North America (USGS 2008). Information from this analysis will provide new insights into how bird distribution, migration timing, and migratory flyways have changed since the later part of the 19th century. This information may also be applied to estimate changes in breeding initiation periods in specific habitats.

Data Needs/Gaps

Breeding bird surveys provide snapshots in time of species richness. However, only one survey/visit per year yields little information in terms of population trends. Further observation could help to remedy this data gap and could potentially help the park better understand the status of breeding bird species in the park as well. BBS route 64033 (Roosevelt Park) in the North Unit was surveyed annually from 1982-2009. Resuming this survey, despite its limited coverage of THRO, would be beneficial for future analysis.

Increased sampling under the IMBCR spatially balanced land bird protocol would allow for density and occupancy estimates to be calculated in the future. These estimates could provide baseline values that would serve as sources of comparison for future studies. Expansion of the IMBCR land bird monitoring effort would also provide a more accurate depiction of the breeding bird composition in both the North and South Units of THRO. The spatially-balanced nature of these transects would provide a more reliable assessment of current breeding bird composition. Data and results would also be directly comparable to and combinable withnearby IMBCR strata and super-strata (e.g., LMNG, BCR 17).

With so many priority species lists in existence, it is often difficult for managers to isolate which species in a park are in need of particular attention. The establishment of a priority species population monitoring program, or even just a yearly breeding survey of a few species, could provide park managers with insights into the overall breeding health of these species in THRO. A program such as this could also provide valuable information about habitat use and potentially provide new information about the overall health of high-priority habitats.

Currently, THRO does not conduct in-depth raptor-specific monitoring. The establishment of a raptor monitoring program, or an in-depth analysis of prey species composition of raptors, would not only give managers insights into the health of the THRO raptor population, but could also provide information about the health and abundance of prey species (e.g., small mammals). Although not monitored in detail, THRO staff do observe activity on the few know Golden eagle nests in the park each spring. However, systematic searches for raptor nests are not conducted. With a few modifications, the same sampling frame and sampling grids from the GRTS-based design used in the IMBCR program can be used for monitoring of raptors and other species in THRO.

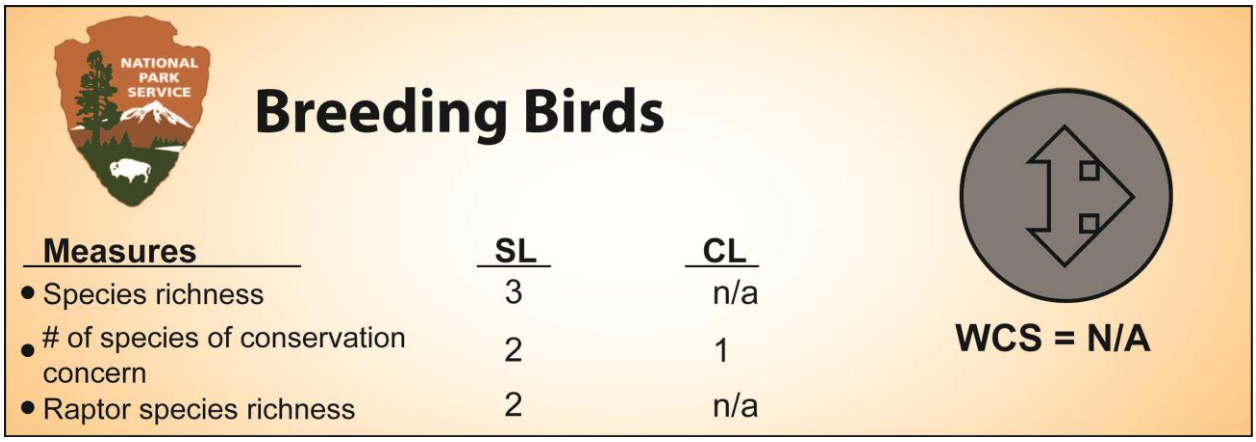
Overall Condition

Species Richness
The measure species richness was assigned a *Significance Level* of 3. Data for this measure are limited to two surveys (IMBCR transects from 2009-2011, and BBS routes from 1982-2009) and one grassland bird inventory in 1999 (Powell 2000). While the data suggest that species richness has not fluctuated much and appears stable, a more comprehensive data source is needed to accurately assess the condition of this measure in THRO. Compared to the reference condition, the THRO IMBCR surveys yielded species richnesses that were just over half those of LMNG. This is likely due to the disparity in sample size and number of transects in the park, but nonetheless it highlights the need for expansion of survey efforts to accurately assess the condition of this measure in THRO. For this reason, a *Condition Level* for species richness was not assigned.

Number of Species of Conservation Concern
The number of species of conservation concern was assigned a *Significance Level* of 2. Data from all available sources indicate that several species designated as species of conservation concern exist in the park. However, no study has investigated the population trends or nesting success of these species. Such trend data would provide for a more accurate assessment of this measure. There does not appear to be particular concern in THRO for this measure, although an investigation of priority species that may be conspicuously absent could benefit managers. This measure was assigned a *Condition Level* of 1.

Raptor Species Richness
A *Significance Level* of 2 was assigned to the raptor species richness measure. There has been no raptor-specific monitoring within THRO. The data that do exist for this measure are from general bird surveys, and the number of raptor observations is sparse. This is largely affected by the large geographic ranges of raptors, the limited temporospatial extent of current sampling and a lack of raptor-specific monitoring efforts in THRO. Because of this data gap, a *Condition Level* for this measure was not assigned.

Weighted Condition Score
A *Weighted Condition Score* for breeding birds in THRO was not assigned because >50% of the measures had unknown *Condition Levels*.



4.11.6 Sources of Expertise
Jeff Birek, Outreach Biologist, Rocky Mountain Bird Observatory

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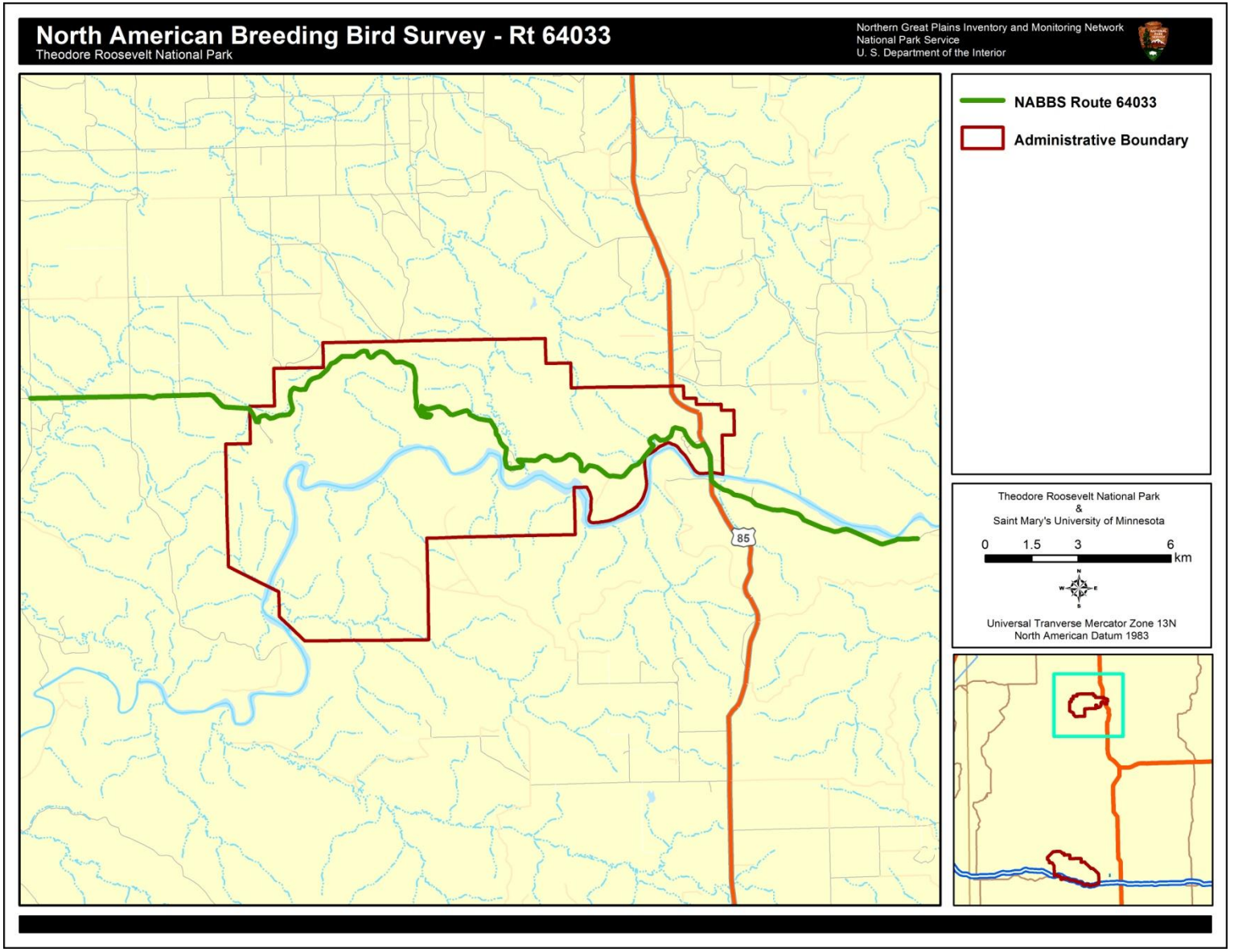


Plate 21. Breeding Bird Survey route 64033 in the North Unit of THRO.

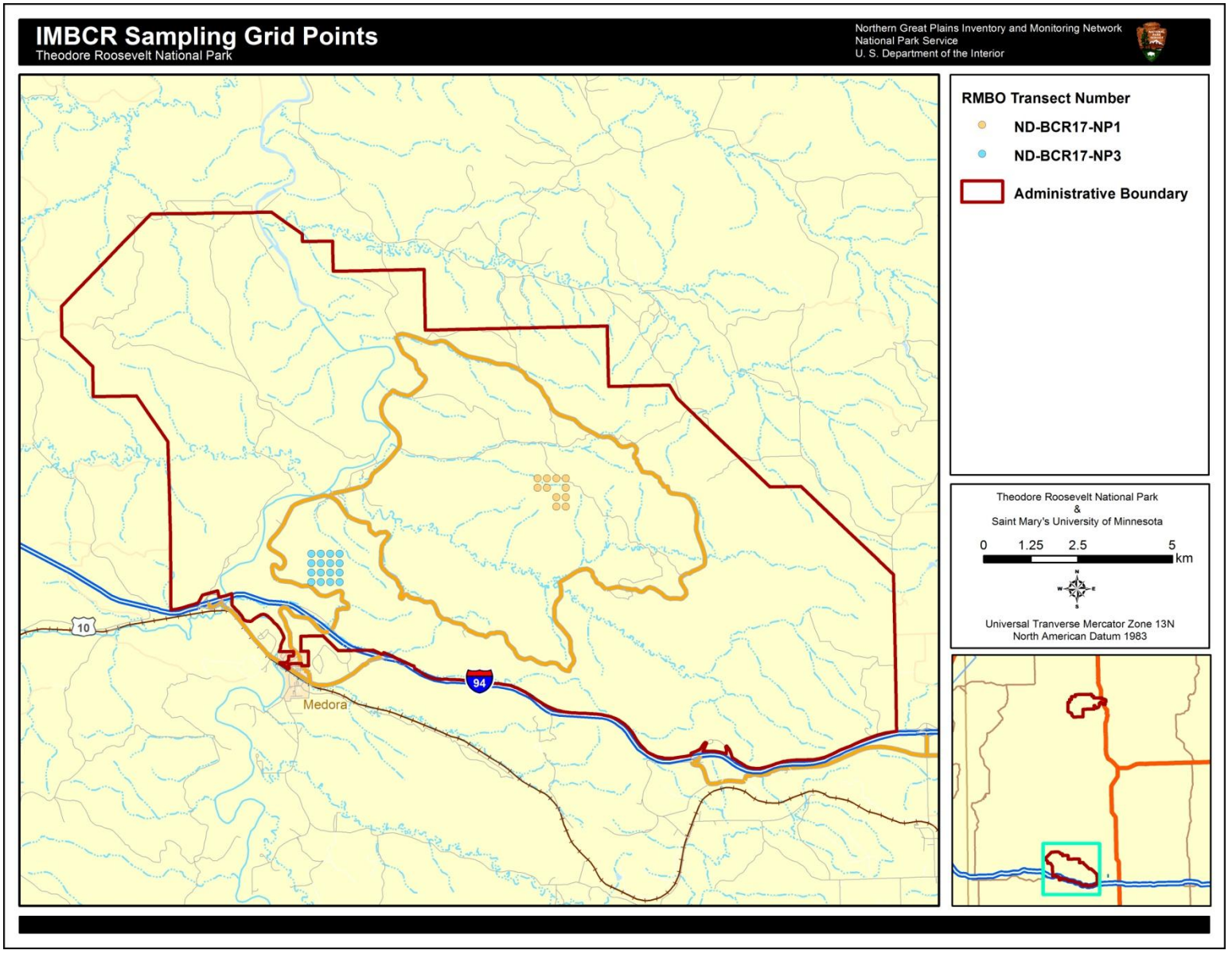


Plate 22. IMBCR points sampled in the South Unit of THRO 2009-2011.

4.12 Air Quality

4.12.1 Description

Air pollution can significantly affect natural resources and their associated ecological processes. Consequently, air quality in parks and wilderness areas is protected and regulated through the 1916 Organic Act and the Clean Air Act of 1977 (CAA) and the CAA's subsequent amendments. The CAA defines two distinct categories of protection for natural areas, Class I and Class II airsheds. Class I airsheds receive the highest level of air quality protection as offered through the CAA; only a small amount of additional air pollution is permitted in the airshed above baseline levels. For Class II airsheds, the increment ceilings for additional air pollution above baseline levels are slightly greater than for Class I areas and allow for moderate development (EPA 2008a). However, new and modified sources of air pollution must be analyzed for potential impacts to ambient air quality and visibility prior to development. THRO is designated as a Class I airshed.

Parks designated as Class I and II airsheds typically use the Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS) for criteria air pollutants as the ceiling standards for allowable levels of air pollution. The EPA believes these standards, if not exceeded, protect human health and the health of natural resources (EPA 2008a). The CAA also establishes that current visibility impairment in these areas must be remedied and future impairment prevented (EPA 2008a). However, the EPA acknowledges that the NAAQS are not necessarily protective of ecosystems and is currently developing secondary NAAQS for ozone, nitrogen, and sulfur compounds to protect sensitive plants, lakes, streams, and soils (EPA 2010a, 2010b). To comply with CAA and NPS Organic Act mandates, the NPS established a monitoring program that measures air quality trends in many park units for key air quality indicators, including atmospheric deposition, ozone, and visibility (NPS 2008).

Although THRO is located in a rural part of the country, several sources of air pollution threaten the park's air quality. The more persistent and permanent sources include oil and gas development in western North Dakota, vehicle emissions, and emissions from the nearby operation and development of coal-fired power plants (Peterson et al. 1998). Smoke from wildland fires, agricultural burning, and prescribed burning can also periodically affect air quality in THRO (Peterson et al. 1998), but these are of short duration compared to more permanent sources.

4.12.2 Measures

- Nitrogen deposition
- Sulfur deposition
- Ozone concentration
- Mercury deposition/concentration
- Concentration of particulate matter (PM 2.5 and 10)
- Visibility

Atmospheric Deposition

Nitrogen and sulfur oxides are emitted into the atmosphere primarily through the burning of fossil fuels, industrial processes, and agricultural activities (EPA 2008b). While in the atmosphere, these emissions form compounds that may be transported long distances and settle out of the atmosphere in the form of pollutants such as particulate matter (e.g., sulfates, nitrates, ammonium) or gases (e.g., nitrogen dioxide, sulfur dioxide, nitric acid, ammonia) (EPA 2008b, NPS 2008). Atmospheric deposition can be in wet (i.e., pollutants dissolved in atmospheric moisture and deposited in rain, snow, low clouds, or fog) or dry (i.e., particles or gases that settle on dry surfaces as with windblown dusts) form (EPA 2008b). Deposition of sulfur and nitrogen can have significant effects on ecosystems including acidification of water and soils, excess fertilization or increased eutrophication, changes in the chemical and physical characteristics of water and soils, and accumulation of toxins in soils, water, and vegetation (NPS 2008, reviewed in Sullivan et al. 2011a and 2011b). Grassland prairie and meadow communities are sensitive to increased levels of nitrogen and may be impacted by excess nitrogen enrichment via deposition (reviewed in Sullivan 2011b); the predominant landcover in THRO is grassland and meadow (NPS 2005, Pohlman and Maniero 2005, Sullivan et al. 2011c). On the other hand, many non-natives, such as the invasive cheatgrass, prefer nitrogen rich environments and may displace native species as nitrogen deposition increases in these sensitive communities (Sullivan et al. 2011a, b, and c).

Ozone

Ozone occurs naturally in the earth's atmosphere where, in the upper atmosphere, it protects the earth's surface against ultraviolet radiation (EPA 2008b). However, it also occurs at the ground level (i.e., ground-level ozone) where it is created by a chemical reaction between nitrogen oxides and volatile organic compounds (VOCs) in the presence of heat and sunlight (NPS 2008). Ozone is also one of the most widespread pollutants affecting vegetation in the U.S. (NPS 2008). Considered phytotoxic, ozone can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems (EPA 2008a, NPS 2008). Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass, and prolonged exposure can increase vulnerability to insects and diseases or other environmental stresses (NPS 2008). At high concentrations, ozone can aggravate respiratory and cardiovascular diseases, reduce lung function, cause acute respiratory problems, and increase susceptibility to respiratory infections (EPA 2008b, 2010c); this would be a concern for visitors and staff engaging in aerobic activities in the park, such as hiking.

Mercury

Sources of atmospheric mercury include fuel combustion and evaporation (especially coal-fired power plants), waste disposal, mining, industrial sources, and natural sources such as volcanoes and evaporation from enriched soils, wetlands, and oceans (EPA 2008b). Mercury deposited into rivers, lakes, and oceans can accumulate in various aquatic species, resulting in exposure to wildlife and humans that consume them (EPA 2008b).

Particulate Matter (PM) and Visibility

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets suspended in the atmosphere. PM is categorized as fine particles ($PM_{2.5}$), which are 2.5 micrometers in diameter or smaller, and inhalable coarse particles (PM_{10}), which are smaller than 10 micrometers (the width of a single human hair) (EPA 2009a). Particulate matter largely

consists of acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA 2008a, 2009a). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2010b). $PM_{2.5}$ can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries, and/or vehicles react with air (EPA 2009a, 2010d). Sources of coarse particles (PM_{10}) include grinding or crushing operations and windblown or stirred up dust from dirt surfaces (e.g., roads, agricultural fields). Particulate matter either absorbs or scatters light. As a result, the clarity, color, and distance seen by humans decreases, especially during humid conditions when additional moisture is present in the air (EPA 2010d). PM_{10} and $PM_{2.5}$ are also a concern for human health as these particles can easily pass through the throat and nose and enter the lungs (EPA 2008b, 2009a, 2010d). Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation (EPA 2008b, 2009a).

4.12.3 Reference Conditions/Values

The NPS Air Resources Division (ARD) developed an approach for rating air quality conditions in national parks, based on the current NAAQS, ecosystem thresholds, and visibility improvement goals (Table 31) (NPS 2010a). Assessment of current condition of nitrogen and sulfur atmospheric deposition is based on wet (rain and snow) deposition. Ozone condition is based on the NAAQS standard of 75 parts per billion (ppb). Visibility conditions are assessed in terms of a Haze Index, a measure of visibility derived from calculated light extinction (NPS 2010a). The NAAQS standard for PM_{10} is 150 $\mu g/m^3$ over a 24-hour period; this level may not be exceeded more than once per year on average over three years (EPA 2010d). The standard for $PM_{2.5}$ is 15.0 $\mu g/m^3$ weighted annual mean or 35 $\mu g/m^3$ in a 24-hour period over an average of three years (EPA 2010d). Currently, there is no standard or threshold established for mercury deposition. Finally, NPS ARD recommends the following values for determining air quality condition (Table 31). The "good condition" metrics may be considered the reference condition for THRO.

Table 31. National Park Service Air Resources Division air quality index values (NPS 2010a).

Condition	Ozone concentration (ppb)	Wet Deposition of N or S (kg/ha/yr)	Visibility (dv)
Significant Concern	≥ 76	> 3	> 8
Moderate	61-75	1-3	2-8
Good	≤ 60	< 1	< 2

4.12.4 Data and Methods

Monitoring in the Park

Substantial monitoring efforts have been ongoing in THRO since the early 1980s and, thus, monitoring data for the period of record may be examined for trends in air quality. Air quality monitoring in the park includes ozone monitoring (NPS Gaseous Pollutant Monitoring Program [GPMP]), wet deposition monitoring of atmospheric pollutants, including nitrogen, sulfur, and ammonium (National Atmospheric Deposition Program [NADP]), dry deposition monitoring of atmospheric pollutants (Clean Air Status and Trends Network [CASTNet]), and visibility monitoring (Interagency Monitoring of Protected Visual Environments Program [IMPROVE]) (Pohlman and Maniero 2005). Data from these on-site monitors are used to evaluate trends in air quality at the park, most recently for the period 1999-2008 (NPS 2010b).

NPS Data Resources

In addition, NPS ARD provides estimates of ozone, wet deposition of nitrogen and sulfur, and visibility that are based on interpolations of data from all air quality monitoring stations operated by NPS, EPA, various states, and other entities, averaged over five years (2005-2009). These estimates are available from the Explore Air website (NPS 2011) and are used to evaluate air quality conditions. Note that on-site or nearby data are needed for a statistically valid trends analysis, while a five-year average interpolated estimate is preferred for the condition assessment. NPS ARD (2010b) reports on air quality conditions and trends in an annual report for over 200 park units, including THRO.

Other Air Quality Data Resources

The National Atmospheric Deposition Program–National Trends Network (NADP) database provides access to annual average summary data for nitrogen and sulfur concentration and deposition in THRO (monitoring site ND00) (NADP 2011).

The Clean Air Status and Trends Network (CASTNet) provides access to summaries of the composition of nitrogen and sulfur deposition in THRO (site number THR422) (EPA 2012a).

The EPA Air Trends database provides access to annual average summary data for ozone concentrations in the North and South Units of THRO (North Unit monitoring site = 380530002; South Unit monitoring site = 380070002) (EPA 2012b).

The Visibility Information Exchange Web System (VIEWS) database provided average annual visibility monitoring data (in deciviews [dv]) for THRO from 2001 through 2004 (VIEWS 2010). The IMPROVE Program provided access to annual summary data for particulate matter concentrations and average visibility (in dv) in the park (IMPROVE 2011).

Special Air Quality Studies

Pohlman and Maniero (2005) reports on the estimated risk of foliar injury from ozone on native vegetation in national parks in the NGPN. Information on ozone sensitive plant species present in the parks, levels of ozone exposure, and relationships between exposure and soil moisture are synthesized into a risk assessment of foliar injury for each park, including THRO.

Sullivan et al. (2011a) assessed the relative sensitivity of national parks to the potential effects of acidification caused by acidic atmospheric deposition from nitrogen and sulfur compounds. The relative risk for each park was assessed by examining three variables: the level of exposure to emissions and deposition of nitrogen and sulfur; inherent sensitivity of park ecosystems to acidifying compounds (N and/or S) from deposition; and level of mandated park protection against air pollution degradation (i.e., Wilderness and Class I). The outcome was an overall risk assessment that estimates the relative risk of acidification impacts to park resources from atmospheric deposition of nitrogen and sulfur (Sullivan et al. 2011a). Using the same approach, Sullivan et al. (2011b) assessed the sensitivity of national parks to the effects of nutrient enrichment by atmospheric deposition of nitrogen. The outcome was an overall risk assessment that estimates the relative risk to park resources of nutrient enrichment from increased nitrogen deposition.

4.12.5 Current Condition and Trend

Atmospheric Deposition

Five-year interpolated averages are used to estimate the condition of most air quality parameters; this offsets annual variations in meteorological conditions, such as heavy precipitation one year versus drought conditions in another. The current 5-year average (2005-2009) estimates total wet deposition of nitrogen in THRO to be 2.26 kg/ha/yr, while the wet deposition of sulfur is 0.93 kg/ha/yr (NPS 2011). Overall, deposition of nitrogen and sulfur appears to be stable. Based on NPS ratings for air quality conditions, the current estimates for nitrogen deposition fall into the *Moderate Concern* category, while the current estimates for sulfur deposition fall into the *Good Condition* category (see Table 31 for ratings values). However, several factors are considered when rating the condition of atmospheric deposition, including effects of deposition on different ecosystems (NPS 2010a). Based on the NPS process for rating air quality conditions, ratings for parks with ecosystems considered potentially sensitive to nitrogen or sulfur deposition are typically adjusted up one condition category. In general, native grassland and meadow ecosystems can be sensitive to increased levels of nitrogen, as acidification and nutrient enrichment can cause shifts in native species composition and encourage encroachment of exotic species and grasses (reviewed in Sullivan et al. 2011a and 2011b). THRO comprises native grassland/prairie vegetation communities, which may be at risk from increased nitrogen deposition. Thus, the condition in THRO typically would be considered of *Significant Concern* for nitrogen deposition and *Moderate Concern* for sulfur deposition, based on natural background and current average nitrogen deposition rates. However, trend analysis of wet deposition data collected in THRO from 1999-2008 indicates nitrogen deposition is of moderate concern with a stable trend, while sulfur deposition is in good condition with a stable trend (NPS 2010b).

Concentrations (mg/L) of nitrogen, sulfur, and ammonium compounds in wet deposition can be used to evaluate trends in deposition of total nitrogen and sulfur. Since atmospheric wet deposition can vary greatly depending on the amount of precipitation that falls in any given year, it can be useful to examine concentrations of pollutants, which factor out the variation introduced by precipitation. Figure 21 shows the annual average concentrations of sulfate, nitrate, and ammonium recorded in THRO from 2000-2010. Despite a slight increase in concentrations in 2002 and 2006, annual averages indicate that sulfate and nitrate concentrations in the park have been decreasing overall, while ammonium deposition appears stable (NADP 2011).



Figure 21. Annual average precipitation-weighted concentrations of nitrate (NO_3), sulfate (SO_4), and ammonium (NH_4) (mg/L) in THRO, 2000-2010 (NADP monitoring site ND00) (Source: NADP 2011).

Dry deposition (dust, particles, and aerosols) also contributes significantly to total deposition in the region around THRO. CASTNet data indicate that dry forms contribute about one-fourth (26%) to total deposition of nitrogen, and about 30% to total sulfur deposition (EPA 2012a) (see Figure 22 and Figure 23). Figure 26 indicates that reduced forms of nitrogen (i.e., ammonium [NH_4]) contribute approximately 50% of total nitrogen deposition; this is likely an underestimate because ammonia gas is not included in the measurements.

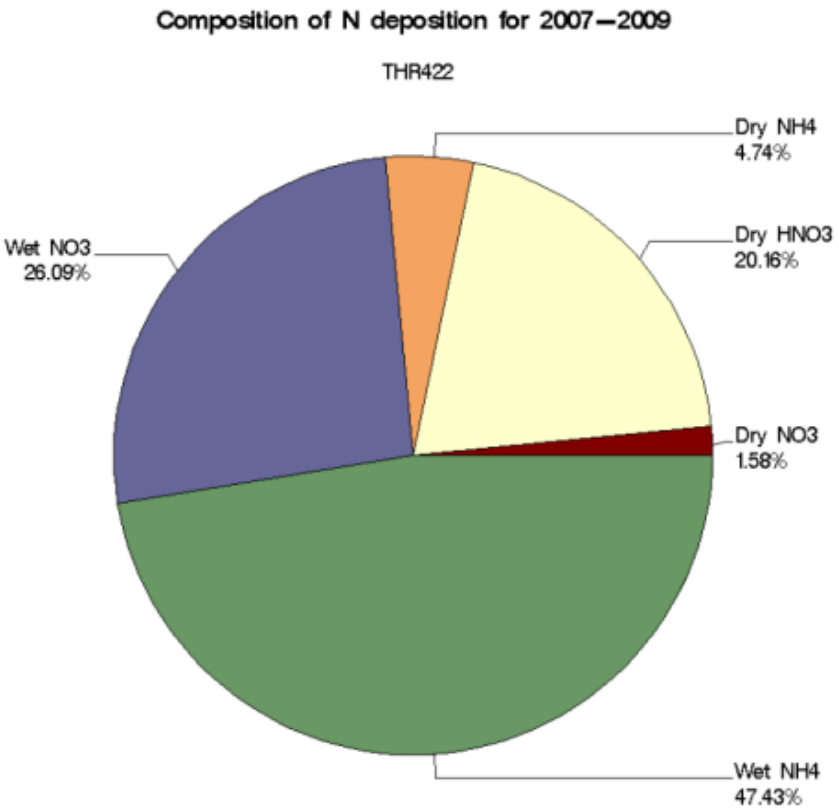


Figure 22. Composition of nitrogen deposition in THRO, 2007-2009 (Monitoring station THRO422) (EPA 2012a).

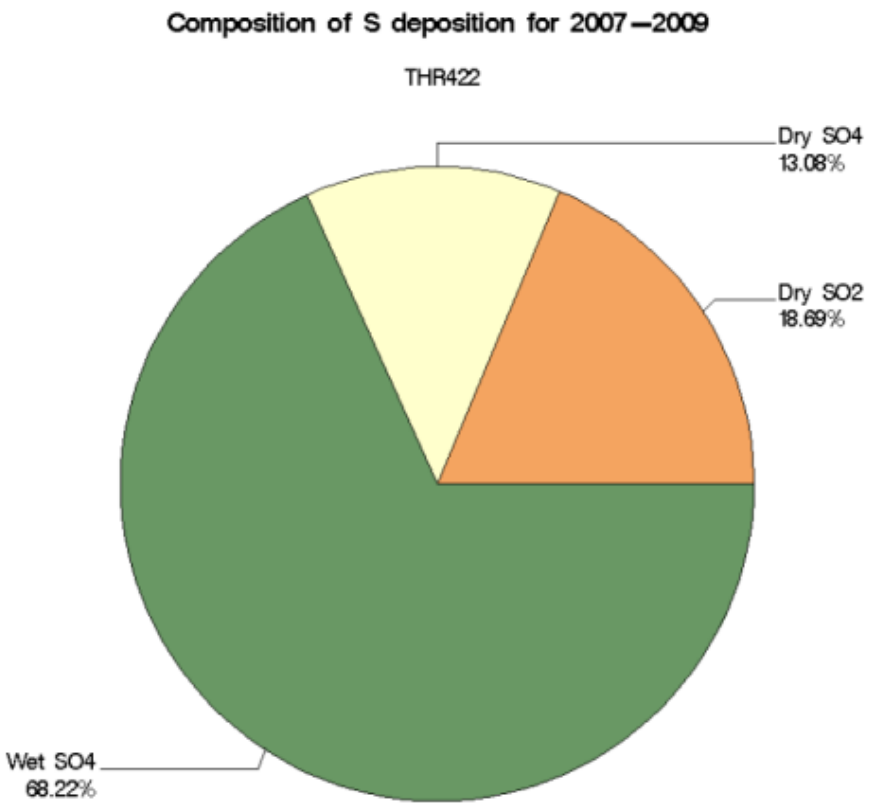


Figure 23. Composition of sulfur deposition in THRO, 2007-2009 (Monitoring station THRO422) (EPA 2012a).

Sullivan et al. (2011a) ranked THRO as having moderate acidifying (nitrogen and sulfur) pollutant exposure, moderate ecosystem sensitivity to acidification in its grassland ecosystem, and very high park protection (Class I airshed) against air pollution. The relative ranking of overall risk from acidification due to acid deposition is high relative to other parks (Sullivan et al. 2011a). In a separate examination, Sullivan et al. (2011b) used the same approach to assess the sensitivity of national parks to nutrient enrichment effects from atmospheric nitrogen deposition relative to other parks. Risk relative to other parks was assessed by examining exposure to nitrogen deposition, inherent sensitivity of park ecosystems, and mandates for park protection. THRO was ranked as being at low risk for nitrogen pollutant exposure, very high ecosystem sensitivity of grasslands and meadows, and very high park protection mandates (Class I airshed). The ranking of overall risk of effects from nutrient enrichment due to atmospheric nitrogen deposition was determined to be very high relative to other parks (Sullivan et al. 2011b).

Ozone Concentration

The NAAQS standard for ground-level ozone is the benchmark for rating current ozone conditions within park units. The condition of ozone in NPS park units is determined by calculating the 5-year average of the fourth-highest daily maximum of 8-hour average ozone concentrations measured at each monitor within an area over each year (NPS 2010a). The current 5-year average (from 2005-2009) for THRO indicates an average ground-level ozone concentration of 60.0 ppb (NPS 2011), which falls under the *Good Condition* category based on

NPS guidelines. Based on trend analysis of annual average data from 1999-2008, ozone concentrations in THRO are in good condition with a stable trend (NPS 2010b). Figure 24 and Figure 25 show the trends for average annual ozone concentrations in the South and North Units of THRO (Note: concentrations are in ppm, while NPS thresholds are in ppb) from 1991 to 2010 with respect to the national standard (EPA 2012b). Data suggest ozone concentrations vary slightly, but overall, concentrations appear to be stable and within the EPA national standard.

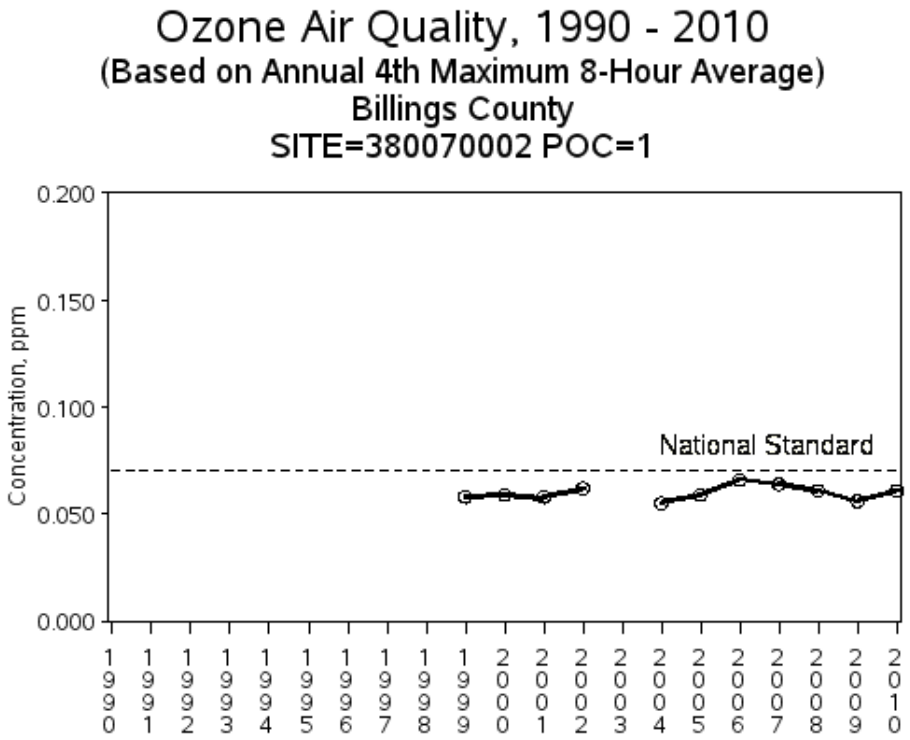


Figure 24. Average annual ozone (O_3) concentration (ppm) for the South Unit of THRO, 1999-2010 (Source: EPA 2012b).

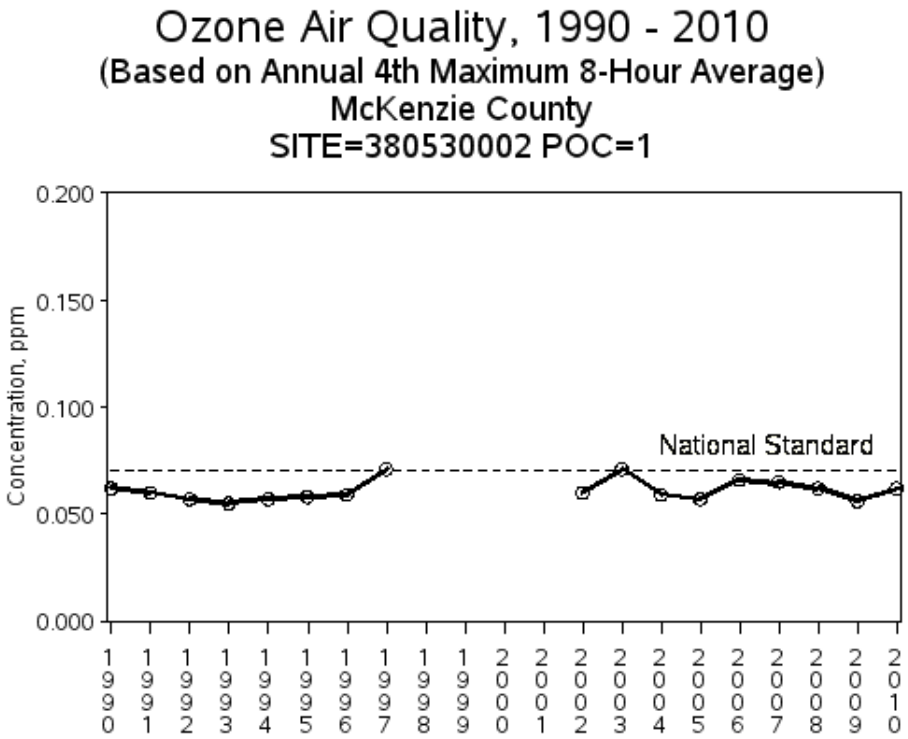


Figure 25. Average annual ozone (O_3) concentration (ppm) for the North Unit of THRO, 1990-2010 (Source: EPA 2012b).

Pohlman and Maniero (2005) assessed ozone concentrations in the NPGN and the risk of injury to plant species that are sensitive to sustained ozone exposure. Data from 1995-1999 indicate ozone concentrations in THRO during this time frequently exceeded 60 ppb for a few hours each year, but only exceeded 80 ppb a few times in one year out of the five; ozone concentrations never exceeded 100 ppb. Sensitive plant species begin to experience foliar injury when exposed to ozone concentrations of 80-120 ppb/hour for extended periods of time (8 hours or more) (Pohlman and Maniero 2005). Thus, the risk of foliar injury to plants was determined to be low (Pohlman and Maniero 2005). However, if ozone concentrations should increase in the future, an on-site monitoring program that assesses foliar injury and growth progress may be necessary (Pohlman and Maniero 2005).

Various plant and tree species are monitored to track air pollution impacts. THRO has 18 plant species known to be sensitive to excessive or extended concentrations of ozone, including a number of species that are highly sensitive. Highly sensitive species include Ponderosa pine (*Pinus ponderosa*), chokecherry, quaking aspen (*Populus tremuloides*), spreading dogbane (*Apocynum androsaemifolium*), paper birch (*Betula papyrifera*), Virginia strawberry (*Fragaria virginiana*), common snowberry, and green ash (Peterson et al. 1998, NPS 2006).



Photo 21. Chokecherry (NPS photo).

Mercury Concentration

THRO does not have a monitoring station that records mercury deposition. The nearest monitoring station is located in Eagle Butte, South Dakota. However, it is approximately 322 km (200 mi) southeast of THRO and, thus, it is inappropriate to estimate deposition rates in the park from this monitor. For locations in the U.S. that do not have mercury monitoring stations, deposition is interpolated from the nearest sites in areas with sufficient numbers of samplers; this data can be used to estimate conditions in a particular area, but should be used with caution in considering current condition or in determining trends. Figure 26 shows the most recent interpolated average mercury wet deposition for monitoring sites across the U.S. (the approximate location of THRO is marked with a yellow star). Recent average deposition data indicate wet deposition of mercury in the region of the park is approximately 4-6 µg/m^2 (NADP 2012).

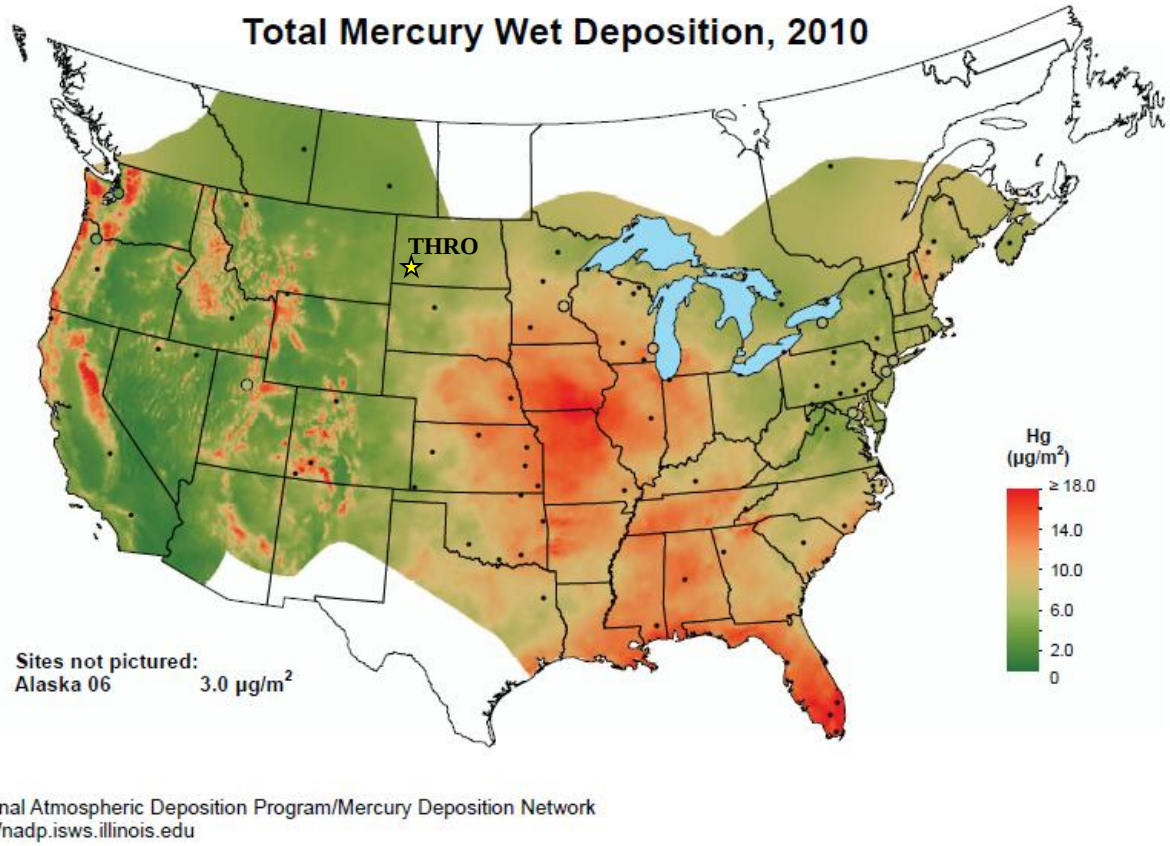


Figure 26. Total mercury deposition near THRO, 2010 (Source: NADP 2012). Yellow star indicates the approximate location of THRO.

Wet deposition of mercury can vary greatly depending on variations in the amount of precipitation that has fallen in an area across a year or several years. Mercury concentrations more accurately reflect patterns in mercury emissions. Figure 27 shows the most recent interpolated average mercury concentrations for monitoring sites across the U.S. (approximate location of THRO is marked with a yellow star). Recent average concentration data indicate

mercury concentrations in the region of THRO are approximately 10-14 ng/L (NADP 2012). Reliable data for both concentration and deposition of mercury prior to 2009 are unavailable.

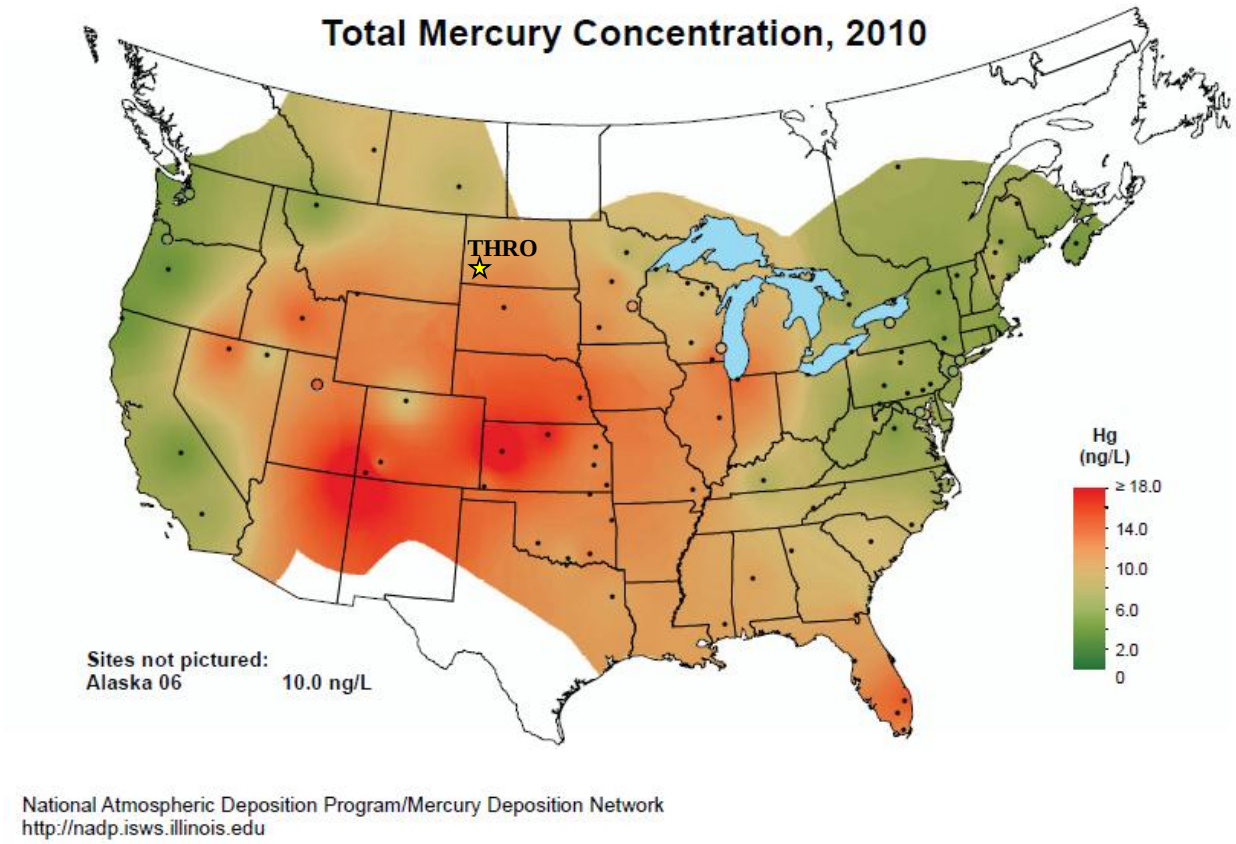


Figure 27. Total mercury concentration near THRO, 2010 (Source: NADP 2012). Yellow star indicates the approximate location of THRO.

Concentration of Particulate Matter ($PM_{2.5}$ and PM_{10})

Concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) are recorded at an IMPROVE monitoring site located in THRO (site THRO1). Data for average concentrations in the park are available from 2001 through 2010, and are summarized as annual average concentrations (IMPROVE 2011). The NAAQS standard for PM_{10} is 150 µg/m^3 over a 24-hour period; this level may not be exceeded more than once per year on average over three years (EPA 2010d). The standard for $PM_{2.5}$ is a weighted annual mean of 15.0 µg/m^3 or 35 µg/m^3 in a 24-hour period over an average of three years (EPA 2010d). Since 2001, $PM_{2.5}$ concentrations have remained stable around 3.5-4.5 µg/m^3, while average concentrations of PM_{10} fluctuated between 8.5-11.5 µg/m^3 (Figure 28) (IMPROVE 2011). Values for both $PM_{2.5}$ and PM_{10} are well within the EPA standards for levels that are protective of human health and visibility.

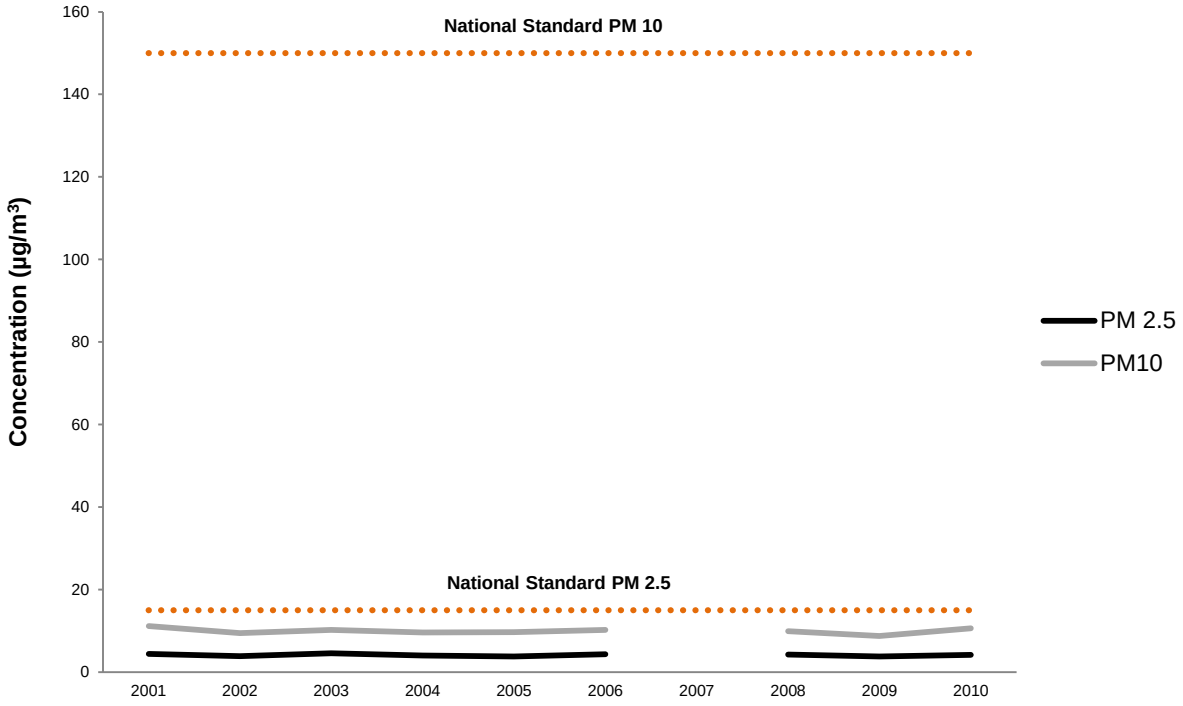


Figure 28. Average annual particulate matter concentration ($PM_{2.5}$ and PM_{10}) in THRO, 2001-2010 (IMPROVE 2011).

Visibility

Visibility impairment occurs when airborne particles and gases scatter and absorb light; the net effect is called "light extinction," which is a reduction in the amount of light from a view that is returned to an observer (EPA 2003). In response to the mandates of the CAA of 1977, federal and regional organizations established IMPROVE in 1985 to aid in monitoring of visibility conditions in Class I airsheds. The goals of the program are to 1) establish current visibility conditions in Class I airsheds; 2) identify pollutants and emission sources causing the existing visibility problems; and 3) document long-term trends in visibility (NPS 2009).

The most current 5-year average (2005-2009) estimates visibility in THRO to be 6.8 dv (this is an estimate minus the estimated natural conditions). This falls into the *Moderate Concern* category for NPS air quality condition assessment (NPS 2011).

The clearest and haziest 20% of days each year also are examined for parks. Figure 29 depicts estimated visibility conditions (in dv) for the 20% haziest and 20% clearest days in THRO. Conditions measured near 0 dv are clear and provide excellent visibility, and as deciview measurements increase, visibility conditions become hazier. Estimated visibility conditions appear relatively consistent for both the 20% haziest and clearest days over the last 10 years. Trend analysis of data from 1999-2008 indicates visibility to be of moderate concern with a stable trend (NPS 2010b).

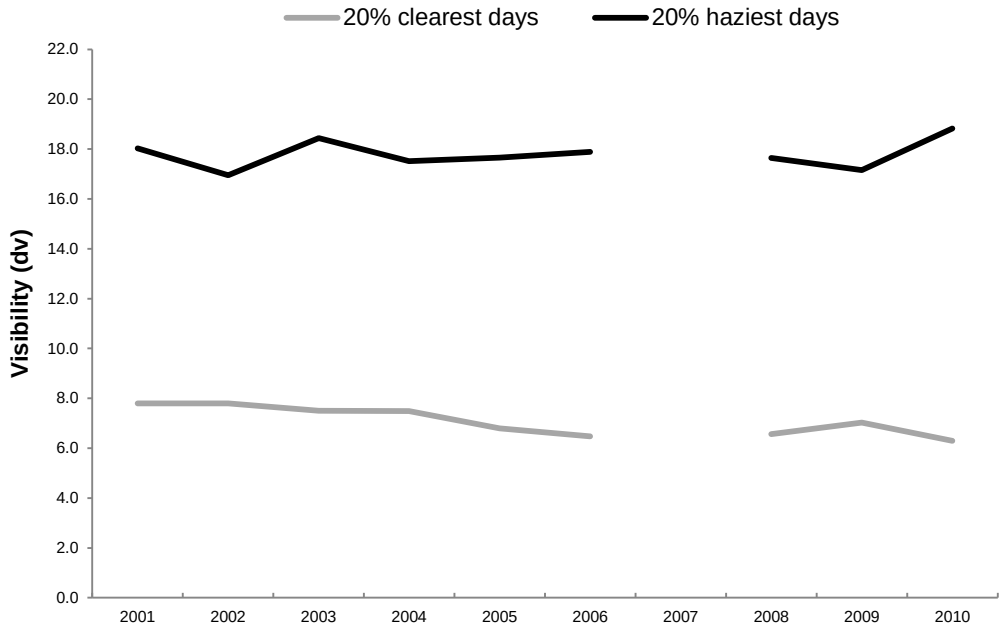


Figure 29. Visibility (in dv) on the 20% clearest and 20% haziest days in THRO, 2001-2010 (IMPROVE 2011).

Threats and Stressor Factors

The most substantial threat to air quality in THRO is energy development in the region, particularly crude oil and natural gas. Western and central North Dakota have experienced a significant increase in oil and gas development in the last two decades (Peterson et al. 1998). The major sources of pollution that could affect protected areas in this region have been associated with oil and gas operations as well as coal-fired power plants; these sources add sulfur dioxide and nitrogen oxide emissions to the air (Peterson et al. 1998). Several power plants, the largest sources of sulfur dioxide emissions in the region, are located near the park (Peterson et al. 1998), where winds can carry emissions into the park. Although THRO is unlikely to be affected by acidification from sulfur dioxide and associated sulfate deposition, these coal-burning power plants also release mercury into the atmosphere that, when transformed to toxic methylmercury in wetlands, can bioaccumulate in fish and wildlife. Nitrogen oxide emissions from oil and gas development may increase nitrogen deposition to THRO grasslands and wetlands, which could affect plant communities and promote growth of annual grasses and invasive species.

Smoke produced by wildfires or human-caused fires have long been a part of the Great Plains ecosystem. Though fires are not considered a long-term source of pollution in the northern Great Plains (including THRO), if persistent and substantial in extent, they may result in periods of decreased visibility and increased concentrations of particulate matter (Peterson et al. 1998).

Data Needs/Gaps

Though monitoring of air quality parameters is quite thorough in THRO, little emphasis has been placed on tracking the plant and animal species that are sensitive to increases in certain pollutants. Peterson et al. (1998) indicate that a primary concern in THRO is sulfur exposure and

the effects of such exposure on native vegetation. Nitrate, sulfate, and ammonium deposition and ozone could become more of a concern in the future as new point and area sources of pollution emerge (e.g., increase in development of oil and gas wells, and operation of coal-fired power plants) and increase ambient pollution levels (Peterson et al. 1998). If air pollution increases in the future, plant and trees species can be monitored to track air pollution impacts.

THRO has a number of species that are quite sensitive to increases in ozone and sulfates (Peterson et al. 1998 provide a detailed list). Several of these species could be used as bioindicators to track potential increases in certain criteria air pollutants as well as long-term health of the ecosystem. Table 32 summarizes the vascular plant and tree species that have known sensitivities, either medium or high, to sulfates and ozone. While it is impractical to monitor all sensitive plant species, park staff may identify key species to use as bioindicators.

Table 32. Plant and tree species of THRO with high or moderate sensitivities to sulfates and ozone (adapted from Peterson et al. 1998; Pohlman and Maniero 2005, NPS 2006b).

Scientific Name	Common Name	SO_2 Sensitivity[1]	O_3 Sensitivity
Amelanchier alnifolia	Saskatoon serviceberry	H	M
Betula papyrifera	Paper birch	H	H
Convolvulus arvensis	Field bindweed	H	
Corylus cornuta	Beaked hazelnut	H	
Fragaria virginiana	Virginia strawberry		H
Fraxinus pennsylvanica	Green ash	M	H
Helianthus anuus	Common sunflower	H	
Pinus ponderosa	Ponderosa pine	M	H
Populus tremuloides	Quaking aspen	H	H
Prunus virginiana	Chokecherry	M	H
Rhus aromatica	Fragrant sumac	H	

[1]Sensitivity: M=medium; H=high

In an effort to quantify harmful pollution levels and set goals for resource protection on federal lands, natural resources managers are increasingly using a "critical loads" approach for tracking and monitoring a variety of pollutants, in particular nitrogen and sulfur compounds (Porter et al. 2005). Critical loads are defined as "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt 1988, as cited in Porter et al. 2005, p. 603). Essentially, critical loads describe the amount of pollution that stimulates negative impacts or harmful changes in sensitive ecosystems (Porter et al. 2005, NPS 2007). Porter et al. (2005) developed an approach for determining critical loads for nitrogen and sulfur using two national parks as case studies, and research is underway in other park units to aid in communicating resource condition. Their methodology can be tailored to fit most national park lands, depending on the baseline information that is available. Since there are a variety of plant species found in THRO that are sensitive to increases in air pollutants and because grasslands are particularly vulnerable to excess deposition of nitrogen (Peterson et al. 1998), park managers at THRO may be able to develop and implement a critical load approach for managing air pollutants and to set goals for resource protection within the park.

Overall Condition

Nitrogen Deposition
The project team defined the *Significance Level* for atmospheric deposition of nitrogen as a 3. Sullivan et al. (2011b) rate the grassland ecosystems in THRO as at very high risk of nutrient enrichment due to nitrogen deposition. NADP data suggest nitrogen deposition may be declining slightly in recent years. NPS (2010b) trend analysis from 1999-2008 indicates nitrogen deposition is of moderate concern with a stable trend. Therefore, deposition of nitrogen is of moderate concern (*Condition Level* = 2).

Sulfur Deposition
The project team defined the *Significance Level* for atmospheric deposition of sulfur as a 3. Sullivan et al. (2011a) suggest the moderate sensitivity to acidification, coupled with a moderate risk of pollutant exposure, make the grassland ecosystems in THRO at high risk of acidification by sulfur and other acids. NADP data suggest sulfur deposition may be declining slightly in recent years and has largely remained stable. Current measurements fall into the moderate concern category based on NPS criteria for rating air quality, however, NPS (2010b) trend analysis from 1999-2008 specifies that sulfate deposition is in good condition with a stable trend. Therefore, deposition of sulfur is of low concern (*Condition Level* = 1).

Ozone Concentration
The project team defined the *Significance Level* for ozone concentration as a 3. Current average ground-level ozone concentrations fall into the good concern category based on NPS criteria for rating air quality, with annual average concentrations (measured in ppm) indicating a stable trend. Therefore, the *Condition Level* for ozone concentration is a 0, of no concern.

Mercury Deposition/Concentration
The project team defined the *Significance Level* for mercury concentration as a 3. Current data suggest mercury deposition and concentration in the northern Great Plains are low relative to other regions of the U.S. However, these data are interpolated from monitoring stations some distance from THRO and serve only as estimates for the region versus data collected in or near the park. Limited data make it impossible to determine a *Condition Level* for this measure.

Particulate Matter Concentration (PM 2.5 and PM 10)
The project team defined the *Significance Level* as 3 for concentration of fine particulate matter (PM 2.5 and 10). Concentrations for both $PM_{2.5}$ and PM_{10} in THRO are well within the EPA standards for levels that are protective of human health. Trends in average concentrations show consistent stability over the last decade. The *Condition Level* for $PM_{2.5}$ and PM 10 is a 0, of no concern.

Visibility
The project team defined the *Significance Level* for visibility as a 3. Current average visibility falls into the moderate concern category based on NPS criteria. Average visibility conditions on the 20% clearest days are improving slightly over the last decade, while visibility for the 20% haziest days may be declining slightly. The *Condition Level* for visibility is a 2, of moderate concern.

Weighted Condition Score
The *Weighted Condition Score* (WCS) for the air quality component is 0.333, indicating the condition is of low concern with a stable trend.



4.12.6 Sources of Expertise
Ellen Porter, Biologist, National Park Service, Air Resources Division.

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4.13 Water Quality

4.13.1 Description

In recent years, water quality monitoring has been identified as a priority for NGPN parks, including THRO, for tracking ecological health in the park, assessing compliance with water quality standards, and detecting threats to human health. A core set of water quality measures will be monitored, including such parameters as dissolved oxygen, concentration of fecal coliform bacteria, pH, and water temperature (NPS 2012).

The Little Missouri River is a primary feature on the THRO landscape, running through all three units of the park. It provides support and habitat for a variety of plants, birds, terrestrial animals, and fish. For many of the park's large animals, such as bison, feral horses, and elk, the Little Missouri River provides one of the only consistent sources of water (NPS 2010). Additionally, some popular visitor activities include fishing, float trips down the river, and wildlife viewing (NPS 2010). Thus, impaired water quality could substantially affect both animals and people in the park.

4.13.2 Measures

- Dissolved oxygen (DO)
- Fecal coliform
- pH
- Macroinvertebrates
- Specific conductance
- Temperature
- Turbidity



Photo 22. Little Missouri River at Juniper Campground in the North Unit of THRO (Photo by Shannon Amberg, SMUMN GSS, 2010).

<u>Dissolved Oxygen</u>

Dissolved oxygen (DO) is critical for organisms that live in water. Fish and zooplankton filter out or "breathe" dissolved oxygen from the water to survive (USGS 2010). Oxygen enters water from the atmosphere or through ground water discharge. As the amount of DO drops, it becomes more difficult for water-based organisms to survive (USGS 2010). The concentration of DO in a water body is closely related to water temperature; cold water holds more DO than does warm water (USGS 2010). Thus, DO concentrations are subject to seasonal fluctuations as low temperatures in the winter and spring allow water to hold more oxygen, and warmer temperatures in the summer and fall allow water to hold less oxygen (USGS 2010).

<u>Fecal Coliform</u>

Fecal coliform bacteria are an accurate indicator of fecal contamination in water by warm-blooded animals. It is tested by counting colonies that grow on micron filters placed in an incubator for 22-24 hours. High numbers of fecal coliform can be an indicator of harmful

bacteria as well as other disease-causing organisms such as viruses and protozoans (USGS 2011).

pH

pH is a measure of the level of acidity or alkalinity of water and is measured on a scale from 0 to 14, with 7 being neutral (USGS 2010). Water with a pH of less than 7.0 indicates acidity, whereas water with a pH greater than 7.0 indicates alkalinity. Aquatic organisms have a preferred pH range that is ideal for growth and survival (USGS 2010). Chemicals in water can change the pH and harm animals and plants living in the water; thus, monitoring pH can be useful for detecting natural and human-caused changes in water chemistry (USGS 2010).

Macroinvertebrates

Because aquatic macroinvertebrates spend most or all of their life cycles in water, they are well known as indicators of watershed health and the quality of water in aquatic systems (EPA 2011b). Some species are tolerant of pollution or poor water quality, while others are highly sensitive to it. Thus, the presence or absence of tolerant and intolerant species can be an indication of the condition of the water body and water quality (EPA 2011b). The life cycles of many macroinvertebrate species are short (sometimes one season in length), though some species live longer, and many have limited mobility; thus, in a discrete area from year to year, it can be easy to detect population fluctuations that may indicate a change (positive or negative) in water quality (EPA 2011b).

Specific Conductance

Specific conductance is a measure of the ability of water to conduct electrical current, which depends largely on the amount of dissolved solids in the water (USGS 2010). Conductivity is affected by inorganic dissolved solids that may be present, such as chloride, nitrate, sulfate, and phosphate anions (having a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (having a positive charge) (EPA 2012a). Water with low amounts of dissolved solids (such as purified or distilled water) will have a low specific conductance, while water with high amounts of dissolved solids (such as salty sea water or other minerals) will have a much higher specific conductance (USGS 2010). Specific conductance is an important water-quality parameter to monitor because high levels can indicate that water is unsuitable for drinking or aquatic life (USGS 2010).

Water Temperature

Water temperature greatly influences water chemistry and the organisms that live in aquatic systems. Not only can it affect the ability of water to hold oxygen, water temperature also affects biological activity and growth within water systems (USGS 2010). All aquatic organisms, from fish to insects to zoo- and phytoplankton, have a preferred or ideal temperature range for existence (USGS 2010). As temperature increases or decreases too far past this range, the number of individuals and species able to live there eventually decreases. In addition, higher temperatures allow some compounds or pollutants to dissolve more easily in water and can be more toxic to aquatic life (USGS 2010).

Turbidity

Turbidity assesses the amount of fine particle matter (such as clay, silt, plankton, microscopic organisms, or finely divided organic or inorganic matter) that is suspended in water by

measuring the scattering effect that solids have on light that passes through water (USGS 2010a). For instance, the more light that is scattered, the higher the turbidity measurement will be. The suspended materials that make water turbid can absorb heat from sunlight, increasing the water temperature in waterways and reducing the concentration of DO in the water (USGS 2010a). The scattering of sunlight by suspended particles decreases photosynthesis by plants and algae, which contributes to decreased DO concentrations in the water (USGS 2010a). Suspended particles also irritate and clog the gill structures of many fish or amphibians, making it difficult to thrive (USGS 2010).

4.13.3 Reference Conditions/Values

The reference condition for THRO's water quality is the North Dakota Standards of Water Quality for the State for surface waters (NDDH 2001). The Little Missouri River is classified as a Class II stream by these standards, requiring that water quality be suitable for propagation or protection, or both, of resident species and other aquatic biota and for swimming, boating, and other water recreation (NDDH 2001). When state standards are unavailable, the EPA's water quality criteria for surface waters were used. The water must be safe for freshwater organisms, for human bathing, and must meet drinking water standards. Table 33 displays water quality parameter standards set by the state of North Dakota and EPA. There are no established thresholds for specific conductance at the state level, although the EPA (2012a) suggests that waterways with conductivity greater than 500 microsiemens per centimeter (µs/cm) may be unsuitable for some species of fish or macroinvertebrates.

Table 33. North Dakota water quality standards (North Dakota Department of Health 2001, EPA 2012b).

Parameter	North Dakota standard
Temperature	<85°F or 29.4°C (for Class II streams)
Dissolved oxygen	≥5 mg/L
Turbidity	50 NTU (EPA standard)
pH	≥7.0 – ≤9.0 (up to 10% of representative samples collected during any 3-year period may exceed this range provided that lethal conditions are avoided)
Fecal coliform	≤126 CFU/100 mL (for recreational waters from May 1 – September 30)

4.13.4 Data and Methods

NPS (1997) presents the results of surface-water quality data retrievals for THRO using six of the EPA national databases: Storage and Retrieval (STORET) water quality database management system, River Reach File (RF3), Industrial Facilities Discharge (IFD), Drinking Water Supplies (DRINKS), Water Gages (GAGES), and Water Impoundments (DAMS) (NPS 1999). Results located nine active or inactive USGS water gages in the study area, which includes the park and surrounding area within the same watershed. Results of the STORET query yielded 19,534 observations for various parameters collected by NPS, USGS, EPA, U.S. Army Corps of Engineers, and the North Dakota Health Department at 76 monitoring sites on the Little Missouri River, tributaries to the Little Missouri River, and ponds and springs in and around THRO. Thirty-three of these sites were located within park boundaries; however, most of these monitoring sites were either single-time or one-year intensive sampling efforts. Four stations on the Little Missouri River (THRO 0005, THRO 0006, THRO 0046, and THRO 0050) yielded the longest-term data for several parameters and accounted for approximately 89% of the total water quality observations in the study area (NPS 1997). Figure 30 and Figure 31 show the locations of all monitoring sites identified in the NPS (1997) inventory.

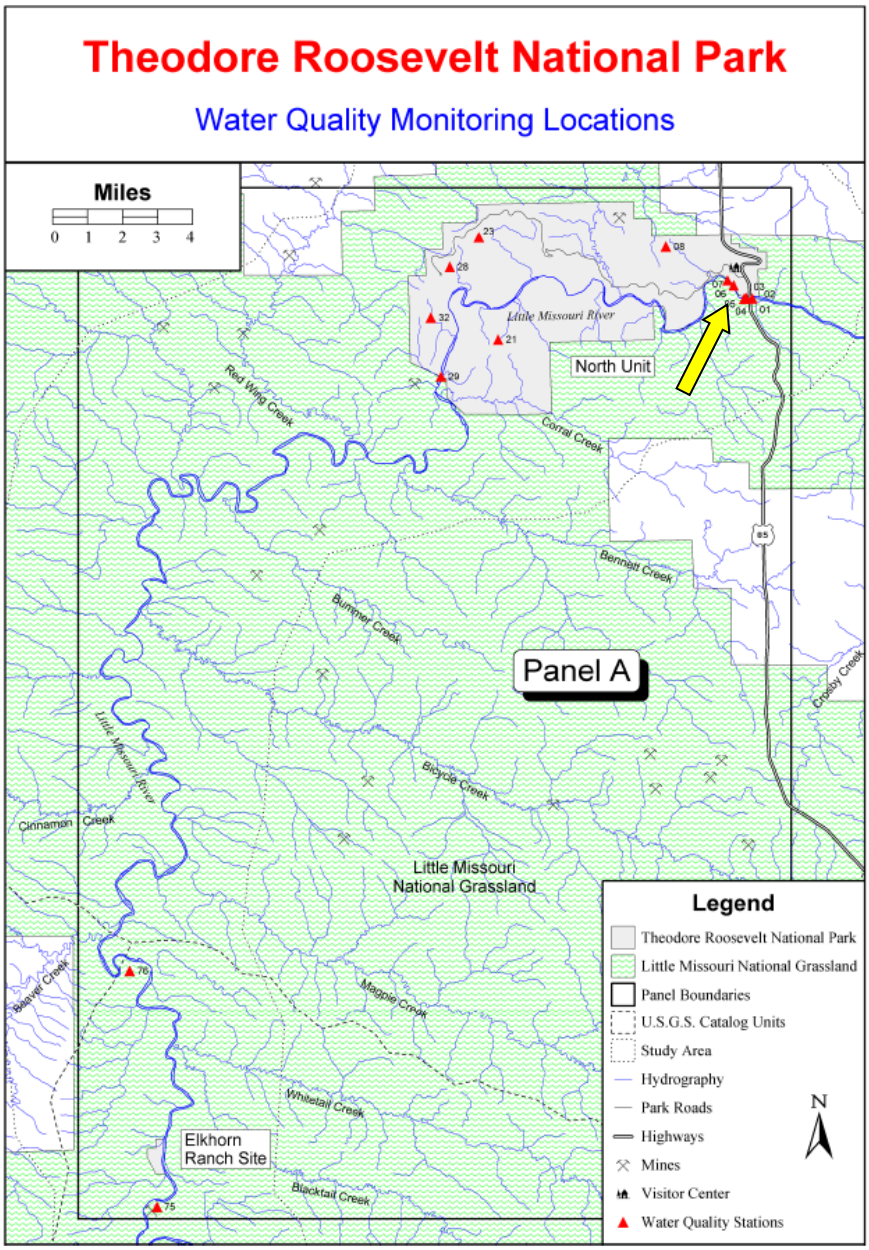


Figure 30. Water monitoring locations in the North Unit of THRO and near the Elkhorn Ranch (Source: NPS 1997). Note: yellow arrow identifies monitoring sites THRO 0005 and 0006, which provide longer-term water quality monitoring data.

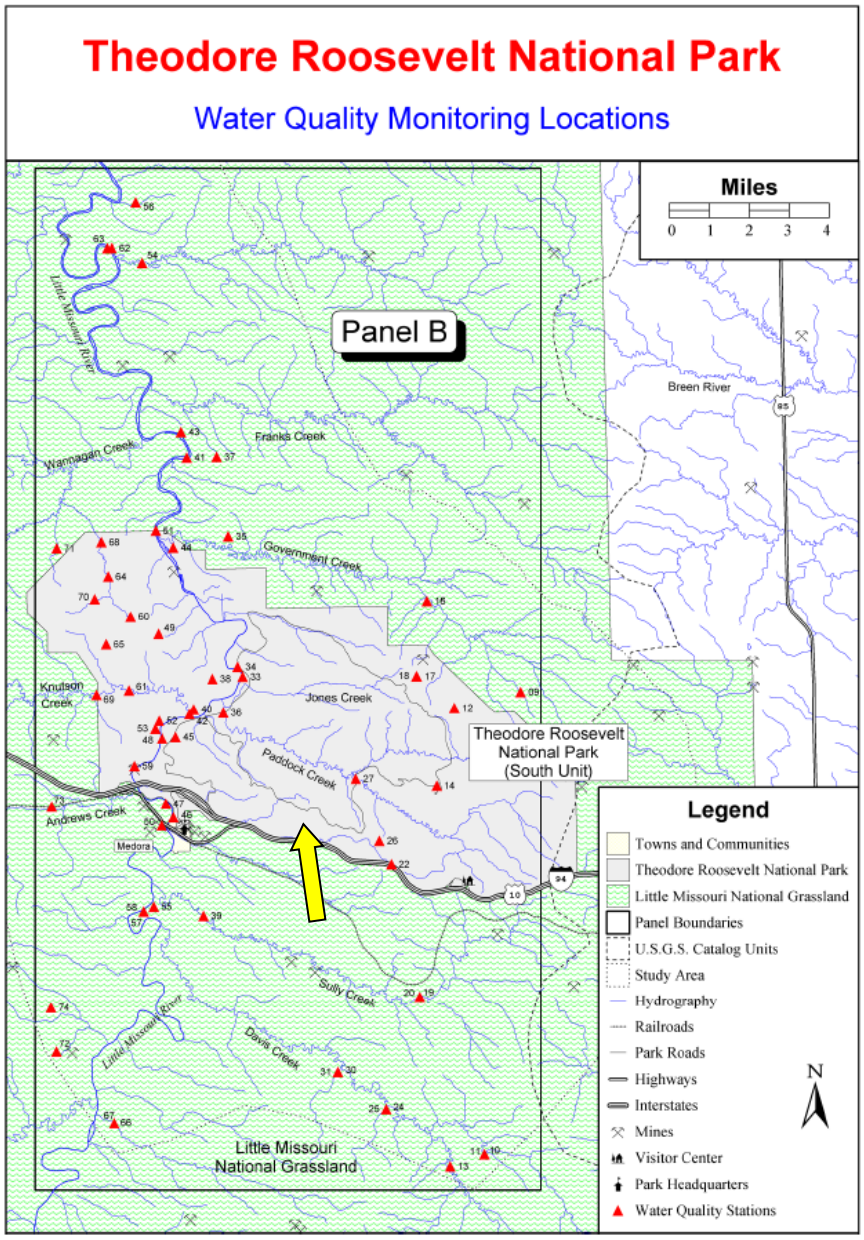


Figure 31. Water monitoring locations in and around the South Unit of THRO (Source: NPS 1997). Note: yellow arrow identifies monitoring sites THRO 0046 and 0050, which provide longer-term water quality monitoring data.

Rust (2006) collected water quality samples for several parameters on the Little Missouri River in 2004-2005. The objective of the research was to provide baseline descriptions of macroinvertebrate communities in the aquatic systems of national parks in the NGPN (including THRO), as well as select optimal metrics for use in future monitoring efforts by park resource managers. Chemical, physical, and aquatic habitat parameters were assessed for the Little Missouri River during the 2004 and 2005 field summer seasons. Water quality parameters measured in the study included dissolved oxygen, temperature, turbidity, fecal coliform concentration, pH, and diversity and abundance of macroinvertebrate species as well as other parameters.

A project to monitor macroinvertebrate communities in the Little Missouri River in THRO is currently underway and led by Dr. Lusha Tronstad, an invertebrate zoologist with the Wyoming Natural Diversity Database (WNDD). In August 2011, Dr. Tronstad collected aquatic invertebrate and water quality samples at four sites along the Little Missouri River at THRO. Parameters examined include diversity of macroinvertebrate taxa, water temperature, dissolved oxygen, specific conductance, salinity, pH, turbidity, and concentration of coliform bacteria. Preliminary results are available for chemical and physical water quality parameters; analysis of macroinvertebrate taxa is still underway (Dr. Lusha Tronstad, WNDD Invertebrate Zoologist, telephone communication, 21 May 2012).

The EPA STORET database provided water quality data recorded from 1996 through 2011 at two North Dakota Department of Health (NDDH) monitoring stations located on the Little Missouri River adjacent to THRO: NDDH station 380022 is located at Medora in the South Unit and station 380059 is located at Hwy 85 at the entrance to the North Unit (EPA 2012c). Data for the parameters of interest were summarized by range (minimum and maximum values), yearly mean, and median values where appropriate. There are two USGS gage stations located near the park, one in Medora and one in Watford City. Data collected at these two stations include measurements for water temperature, specific conductance, and pH parameters. However, only two observations have been collected each year since 2005 for each parameter. Because water quality parameters can vary largely on a daily, monthly, and seasonal basis, data from these gaging stations were determined to offer little insight for this assessment.

4.13.5 Current Condition and Trend

Dissolved Oxygen

NPS (1997) reported that dissolved oxygen was measured 794 times at five monitoring stations on the Little Missouri River from 1968 through 1994. Of these observations, three were less than the 5 mg/L state criterion for protection of freshwater aquatic life. Across five stations, DO measurements ranged from 0.9 to 13.3 mg/L. Measurement ranges are consistent for the river in both the North and South Units. Median DO concentrations were approximately 10.0 mg/L in the Little Missouri River in both units of the park.

In 2004 and 2005, Rust (2006) collected 90 DO samples along three reaches (10 transects/reach) of the Little Missouri River throughout the park; two reaches were located in the South Unit and one reach was located in the North Unit. DO levels ranged from 7.2 to 9.1 mg/L. The mean and median DO levels during this time were 8.2 and 8.3 mg/L respectively.

In August 2011, Dr. Lusha Tronstad recorded dissolved oxygen levels at four sites along the Little Missouri River; three sites were located near Medora and one site was located in the North Unit near the Hwy 85 bridge. DO levels ranged from 8.0 to 8.3 mg/L in the South Unit and 8.8 mg/L in the North Unit. These measurements, and the Rust (2006) observations, are well within EPA criterion for protection of freshwater aquatic life.

Two NDDH monitoring stations on the Little Missouri River, one in the North Unit and one in the South Unit of the park, recorded some three to eight dissolved oxygen observations per year from 1996 through 2011. Figure 32 shows the mean annual dissolved oxygen concentrations at each monitoring station for the last 15 years. During this time, mean DO concentrations ranged

from 8.8 to 10.96 mg/L; observations ranged from 4.6 to 15.4 mg/L (EPA 2012c). All mean values are well above the minimum standards for protection of coldwater aquatic organisms (EPA ≥ 4 mg/L, State of North Dakota ≥ 5 mg/L).

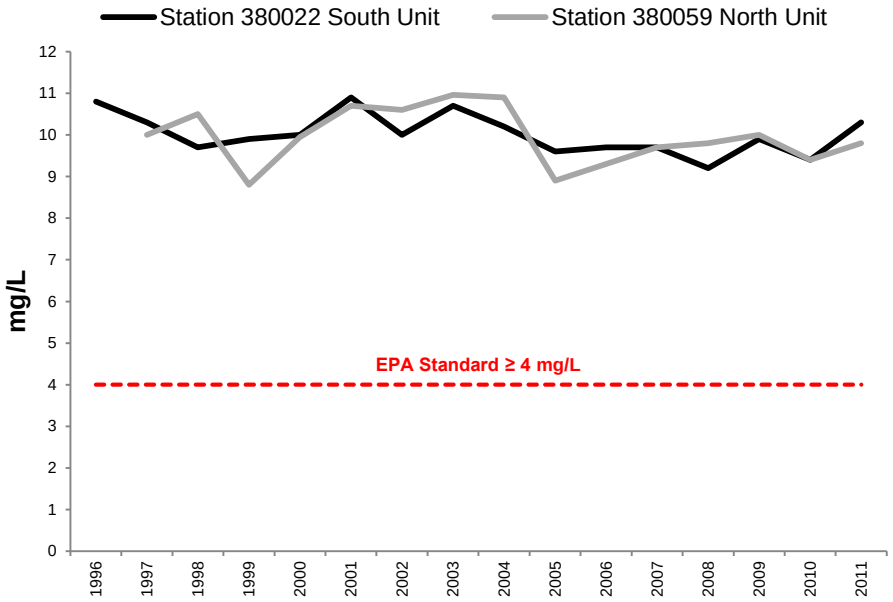


Figure 32. Mean annual dissolved oxygen concentrations (in mg/L) recorded at two monitoring stations on the Little Missouri River in the North and South Units of THRO, 1996-2011 (Source: EPA 2012c). Note: NDDH monitoring station 380022 is located at Medora (South Unit) and NDDH monitoring station 380059 is located at Hwy 85 (North Unit).

Fecal Coliform

NPS (1997) reported that total coliform concentrations were measured 98 times at three monitoring sites (THRO 0004, 0006, and 0050) on the Little Missouri River from 1968 through 1976. Measurements ranged from 1.0 to 300,000 CFU/100 mL; the median was 200 CFU. Thirty-seven observations at two stations (THRO 0004 [North Unit] and 0050 [South Unit]) exceeded the criteria for safe bathing (1,000 CFU/100 mL). Thirty-six of these observations were recorded in the Little Missouri River at Medora (THRO 0050) from 1969-1976.

NPS (1997) also summarized fecal coliform concentrations recorded at various locations in the park from 1971-1994. A total of 220 observations were recorded at four monitoring sites along the Little Missouri River in THRO (THRO 0004, 0005, 0006, and 0050). Measurements ranged from 2 – 46,000 CFU/100 mL; the median was 80 CFU. Fifty-four observations exceeded the WRD criteria for safe bathing water (200 CFU/100 mL). Just over 60% of exceedences, including the highest recorded value of 46,000 CFU (June 1977), occurred in the Little Missouri River at Medora (THRO 0050) from 1972-1992.

Rust (2006) collected three fecal coliform samples on the Little Missouri River in THRO in the summer months of 2004 and 2005. Two measurements were recorded in the South Unit (20 and

2,300 CFU/100 mL), the higher of which exceeded the state water quality criteria for safe bathing. A third observation was recorded in the North Unit (40 CFU/100 mL).

In August 2011, Dr. Lusha Tronstad recorded fecal coliform samples along the Little Missouri River; three sites were sampled near Medora and one site was sampled in the North Unit near the Hwy 85 bridge. Fecal coliform concentrations exceeded the maximum concentration that is measurable without dilution (L. Tronstad, pers. comm., 2012). All measurements exceeded state standards for safe bathing.

Two NDDH monitoring stations on the Little Missouri River, in both the North and South Units of the park, recorded anywhere from two to eight samples per year from 1996 through 2009 to test for presence and prevalence of fecal coliform bacteria. Figure 33 shows mean annual fecal coliform concentrations at each monitoring station from 1996 through 2009. Mean calculations are based on samples with quantifiable bacteria counts; some samples collected contained bacteria concentrations but they were present above or below the quantification limits for a specific test used (EPA 2012c). Overall, fecal coliform bacteria concentrations fluctuated widely from 1996 to 2009. During this time, individual bacterial colony concentrations ranged from 0 to 6,200 CFU/100 mL. A number of annual means exceeded the North Dakota criterion for safe bathing (EPA ≤200 CFU/100 mL). However, some years experienced as few as two observations, and thus, the data may not reflect normal conditions in the Little Missouri River.

As of 2010, a large reach of the Little Missouri River immediately upstream from Medora and bordering the South Unit of THRO was listed as 303[d] impaired for fecal coliform contamination. Likewise, a large reach of the Little Missouri flowing through the North Unit of THRO also was listed as 303[d] impaired for fecal coliform bacteria (EPA 2011a).

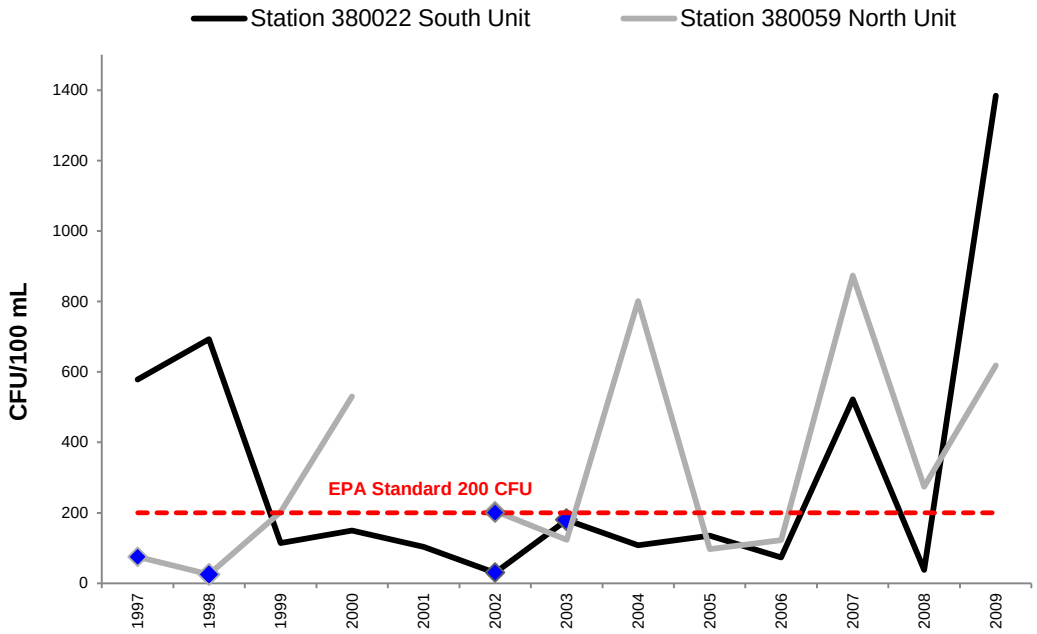


Figure 33. Mean annual fecal coliform concentrations (in CFU/100 mL) recorded at two monitoring stations in the Little Missouri River in the North and South Units of THRO, 1996-2009 (Source: EPA 2012c). Data points marked in blue represent averages based on only two observations. Note: NDDH monitoring station 380022 is located at Medora (South Unit) and NDDH monitoring station 380059 is located at Hwy 85 (North Unit).

Macroinvertebrates

In 2004 and 2005, Rust (2006) sampled benthic macroinvertebrates from five randomly chosen transects along three reaches in the Little Missouri River. Samples at each reach were pooled into one composite sample for that reach on each sample date; each reach was sampled on three different dates for a total of nine combined samples. Mean total abundance of macroinvertebrates found in the Little Missouri River in THRO was 25, with a range of 3 to 100 individuals collected across nine samples. Species richness was low, with an average of six species represented across nine samples (range = 2 to 12 species observed). The majority (47%) of these species were Diptera, while 24% represented Ephemeroptera, Plecoptera, and Trichoptera (EPT), the three pollution-sensitive orders of macroinvertebrates commonly used to assess water quality. The richness of species considered tolerant and intolerant of poor water quality was similar for all sampling in the Little Missouri during this time.

In August 2011, Dr. Lusha Tronstad collected macroinvertebrate samples at four sites along the Little Missouri River; three sites were sampled near Medora and one site was sampled in the North Unit near the Hwy 85 bridge. Examination of taxa diversity and abundance is currently underway (L. Tronstad, pers. comm., 2012).

pH

NPS (1997) reported that pH was measured 1,011 times at 52 monitoring sites throughout THRO from 1949 through 1996. Of these, three observations on the Little Missouri River were outside

of the pH range (7.0-9.0) considered by state standards to be protective for freshwater aquatic life. Two observations were found to be above 9.0, while one was below 6.5. pH values in the Little Missouri River at Medora in the South Unit (monitoring sites THRO 0046 and 0050) ranged from 6.9-8.8, while values recorded in the North Unit (THRO 0005 and 0006) ranged from 4.3-9.23.

Rust (2006) collected 90 pH measurements on the Little Missouri River during the summer months of 2004 and 2005. During this sampling, pH levels ranged from 7.6 to 8.6. The median pH level during this time was 8.5 (no mean was given). All samples fell within the state criteria range for protection of aquatic life.

In August 2011, Dr. Lusha Tronstad collected pH samples at four sites along the Little Missouri River; three sites were sampled near Medora and one site was sampled in the North Unit near the Hwy 85 bridge. pH ranged from 8.41 to 8.49 (L. Tronstad, pers. comm., 2012). All samples were within the state criteria range for protection of aquatic life.

NDDH monitoring stations in the North and South Units recorded three to 10 pH measurements per year from 1996 through 2011. Figure 34 shows the mean annual pH at each monitoring station for the last 15 years. During this time, mean pH ranged from 7.8 to 8.7, and individual observations ranged from 6.9 to 10.7 (EPA 2012c). Although several individual measurements were at the lower and upper end of the thresholds protective of aquatic life, most observations and all annual mean values were well within the state criterion for protection of freshwater aquatic organisms ($\geq 7.0 - \leq 9.0$).

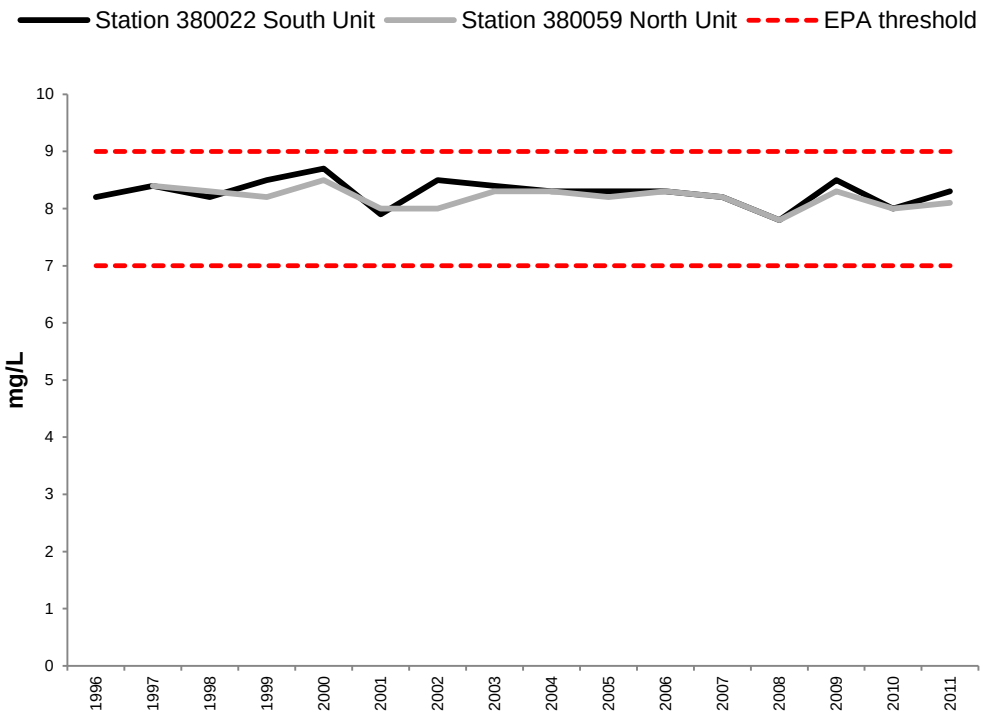


Figure 34. Mean annual pH (in Standard Units) recorded at two monitoring stations on the Little Missouri River in the North and South Units of THRO, 1996-2011 (Source: EPA 2012c). Note: NDDH monitoring station 380022 is located at Medora (South Unit) and NDDH monitoring station 380059 is located at Hwy 85 (North Unit).

Specific Conductance

NPS (1997) reported that specific conductance was measured 860 times at 39 monitoring sites throughout the study area from 1949 through 1996. Approximately half of these observations occurred from 1985 through 1996. Specific conductance values in the Little Missouri River measured at Medora (THRO 0046 and 0050) ranged from 300-4,200 µs/cm; median values were 1,655 µs/cm at THRO 0050 and 1,590 µs/cm at THRO 0046. Values recorded in the North Unit (THRO 0005 and 0006) ranged from 400-4,900 µs/cm; median values were 1,580 µs/cm at THRO 0005 and 1,630 µs/cm at THRO 0006.

Rust (2006) collected 90 measures for specific conductance on the Little Missouri River throughout THRO in the summer months of 2004 and 2005. Conductivity ranged from 167 to 1,684 µs/cm; mean and median conductivity were 1,289 and 1,303 µs/cm respectively. These data suggest that, during the time of sampling, the Little Missouri in THRO contained higher levels of dissolved inorganic solids.

In August 2011, Dr. Lusha Tronstad collected specific conductance samples at four sites along the Little Missouri River; three sites were sampled near Medora and one site was sampled in the North Unit near the Hwy 85 bridge. Specific conductance ranged from 2,421 to 2,617 µs/cm during this time (L. Tronstad, pers. comm., 2012), indicating higher levels of dissolved inorganic solids.

NDDH monitoring stations in the North and South Units recorded four to eight specific conductance measurements per year from 1996 through 2011. Figure 35 shows the mean annual specific conductance at each monitoring station for the last 15 years. During this time, mean conductivity ranged from 1,350 to 2,780 µs/cm, and individual observations ranged from 400 to 5,300 µs/cm (EPA 2012c). These measurements indicate high levels of dissolved inorganic solids in the Little Missouri River.

There is no established standard or threshold for specific conductance in waterways, mainly because conductivity can vary widely depending on the geology of the area through which a waterway flows as well as water temperature. Thus, high conductivity could be a natural characteristic of a waterway based on these factors. The highly erodible landscape in THRO likely contributes to the high conductivity conditions in the Little Missouri River. Despite this, the EPA suggests that waterways with conductivity greater than 500 µs/cm may be unsuitable for some species of fish or macroinvertebrates (2012a) and as a result, waterways with naturally high conductivity will likely support a different diversity of aquatic life.

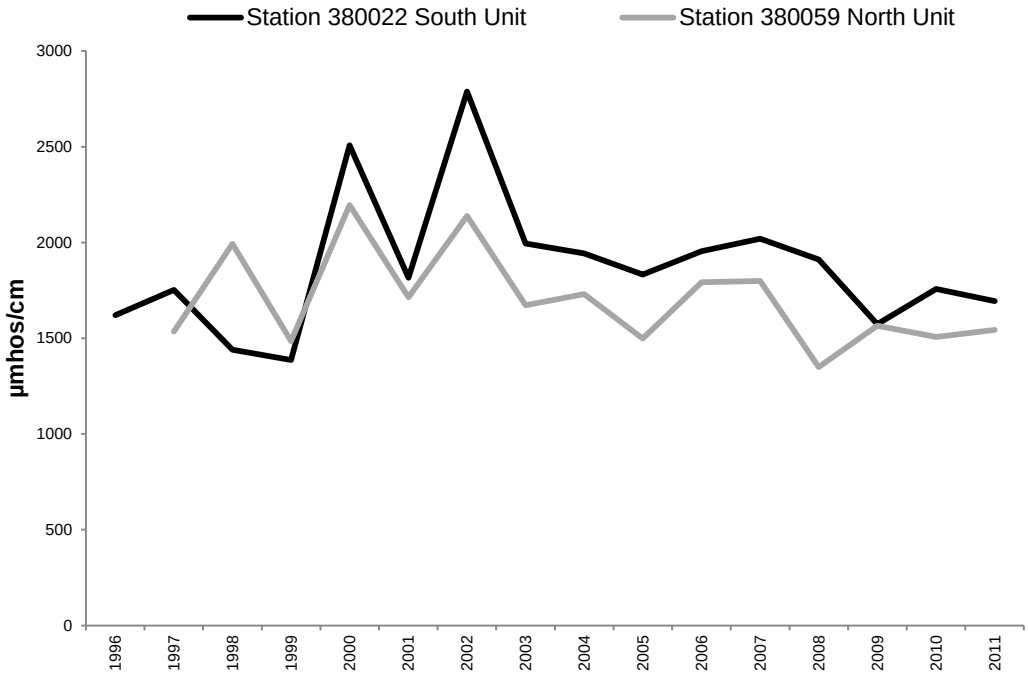


Figure 35. Mean annual specific conductance (in µmhos/cm) in the Little Missouri River in the North and South Units of THRO, 1996-2011 (Source: EPA 2012c). Note: NDDH monitoring station 380022 is located at Medora (South Unit) and NDDH monitoring station 380059 is located at Hwy 85 (North Unit).

Water Temperature

NPS (1997) reported that water temperature was measured 949 times at 16 monitoring sites in the study area from 1949 through 1996. Values on the Little Missouri at Medora (THRO 0046 and 0050) ranged from -1 to 30.5°C throughout sampling, while values in the North Unit (THRO 0005 and 0006) ranged from 0 to 28.5°C.

Rust (2006) collected 30 temperature measurements on the Little Missouri River in THRO during the summer months of 2004 and 2005. During this sampling, temperature measurements ranged from 12.1 to 29.2°C. Mean and median temperatures during this time were 20.5° and 20.6°C respectively.

In August 2011, Dr. Lusha Tronstad recorded water temperatures at four sites along the Little Missouri River; three sites were sampled near Medora and one site was sampled in the North Unit near the Hwy 85 bridge. Water temperatures ranged from 19.9 to 25.5°C (L. Tronstad, pers. comm., 2012). All measurements were within the state standards for Class II streams.

NDDH monitoring stations in the North and South Units recorded three to eight temperature measurements throughout each year from 1996 through 2011. In total, 182 observations were recorded: 97 observations were recorded in the South Unit at Medora and 85 were recorded in the North Unit. Temperature measurements during this time ranged from -0.2 to 28.3°C in the South Unit and -2.1 to 27.7°C in the North Unit.

It should be noted that temperature data presented here are not time-series data, meaning samples were not collected consistently on a daily or monthly basis. Thus, it can be difficult to determine the trends in high, low, and mean temperatures on a daily or monthly basis. This should be taken into account when considering overall condition.

Turbidity

NPS (1997) reported that turbidity was measured 182 times at 24 monitoring sites in the study area from 1971 through 1994. A total of 116 observations at 10 monitoring sites exceeded WRD screening criterion (50 NTU); 111 of these observations were collected on the Little Missouri River. Monitoring sites THRO 0005 and 0006 in the North Unit of the park recorded 84% of the observations that exceeded water quality criterion during this time, including the highest reported value of 15,000 NTU recorded in May 1974 at THRO 0005.

Rust (2006) collected six turbidity measurements in the Little Missouri River in THRO during the summer months of 2004 and 2005. Sample measurements ranged from 157 to 116,000 NTU. The mean and median turbidity measurements were 20,632 NTU and 1,430 NTU respectively. Rust (2006) described the Little Missouri as a turbid river based on these measurements, all of which exceeded the EPA criterion. Rust's 2006 report represented the most recent data on turbidity for the Little Missouri River in THRO.

Threats and Stressor Factors

Runoff from agricultural, development, and ranching activities upriver from THRO can contribute to water quality impairment by increasing the concentration of various nutrients in the water (such as nitrogen, phosphorus, and ammonium) and levels of suspended sediment and dissolved solids in the waterway. Runoff from heavy precipitation events, coupled with the highly erosive badlands landscape that is characteristic of THRO, may also significantly contribute to elevated turbidity and total suspended and dissolved solids levels in the Little Missouri River.

Currently, there is a golf course located next to the Little Missouri River immediately upriver from Medora and THRO; fertilizer applications and runoff from this operation may contribute to

higher than normal nutrient concentrations in the river. Rust (2006) measured concentrations of various nutrients in the Little Missouri River in THRO and found that nitrates exceeded North Dakota water quality standards in two of six samples (July 2004 and June 2005) and total phosphorus exceeded water quality standards in eight of nine samples (range=0.222-4.650 mg/L). Consistent monitoring of nutrients in the Little Missouri River would provide greater insight to managers about condition of the main water resource in the park.

Other potential anthropogenic sources of contaminants include wastewater effluent; mining and quarrying operations; and oil and natural gas development (NPS 1997).

Data Needs/Gaps

Currently, consistent monitoring of water quality parameters does not occur in THRO. The NGPN will initiate long-term monitoring of water quality and *E. coli* at the USGS Medora stream gaging station and at the USGS Watford City stream gaging station in 2013. It is possible to query (through STORET) and analyze data collected at water quality stations managed by other agencies, as was done for this assessment. While these monitors will provide access to the basic water quality parameters for understanding threats to human health, these parameters may not always meet park needs for understanding water quality for protection of freshwater aquatic organisms in THRO. Likewise, there are two active USGS stream gages adjacent to THRO, one at Medora and one located near the entrance to the North Unit on Hwy 85. However, since 2005, only one to two observations per year have been collected at these gages for temperature, specific conductance, and turbidity. Scant observations of parameters may not be representative of consistent conditions of the water quality throughout the course of each year.

In addition, consistent monitoring of aquatic macroinvertebrate populations in the park is lacking. The presence or absence of species that are tolerant and intolerant to pollution can be an indication of the condition of the water body and water quality. To date, Rust (2006) represents the most recent examination of the benthic macroinvertebrate community in the Little Missouri River in THRO that has been completed. In August 2011, Dr. Lusha Tronstad collected aquatic invertebrate samples at four sites along the Little Missouri River. Three sites were located upstream from the park entrance at Medora in the South Unit and one site was located in the North Unit at the Hwy 85 bridge. Examination of Dr. Tronstad's macroinvertebrate samples is still underway and results should be available in late 2012. Results from these two surveys could be used as baseline information to which the results from future monitoring efforts may be compared.

Overall Condition

Dissolved Oxygen

The project team defined the *Significance Level* for dissolved oxygen as a 3. Water quality monitoring data on the Little Missouri River across the last 60 years indicate that dissolved oxygen concentrations are consistently well above the EPA criterion for freshwater aquatic organisms. Thus, the condition of dissolved oxygen is currently of no concern (*Condition Level* = 0).

Fecal Coliform
The project team defined the *Significance Level* for fecal coliform as a 3. Fecal coliform measurements have fluctuated widely since 1996, with many observations far exceeding EPA and North Dakota standards for safe bathing. As of 2010, a large reach of the Little Missouri River bordering the South Unit of the park, as well as a large reach flowing through the North Unit, were listed as 303[d] impaired for fecal coliform contamination. Therefore, the condition of fecal coliform concentration is of high concern (*Condition Level* = 3).

Macroinvertebrates
The project team defined the *Significance Level* for macroinvertebrates as a 3. Rust (2006) compiled nine different composite samples from 2004 - 2005. Total abundance and total richness were both found to be low, and richness of species considered tolerant and intolerant of poor water quality were similar (Rust 2006). However, these data are nearly 10 years old and may not reflect current conditions in this stretch of river. Therefore, a *Condition Level* for macroinvertebrates was not assigned.

pH
The project team defined the *Significance Level* for pH as a 3. pH measurements consistently have remained between 7.5 and 8.5 since 1996. All but just a few observations have occurred well within the EPA and North Dakota criterion for protection of freshwater aquatic organisms. Therefore, the condition of pH is of no concern (*Condition Level* = 0).

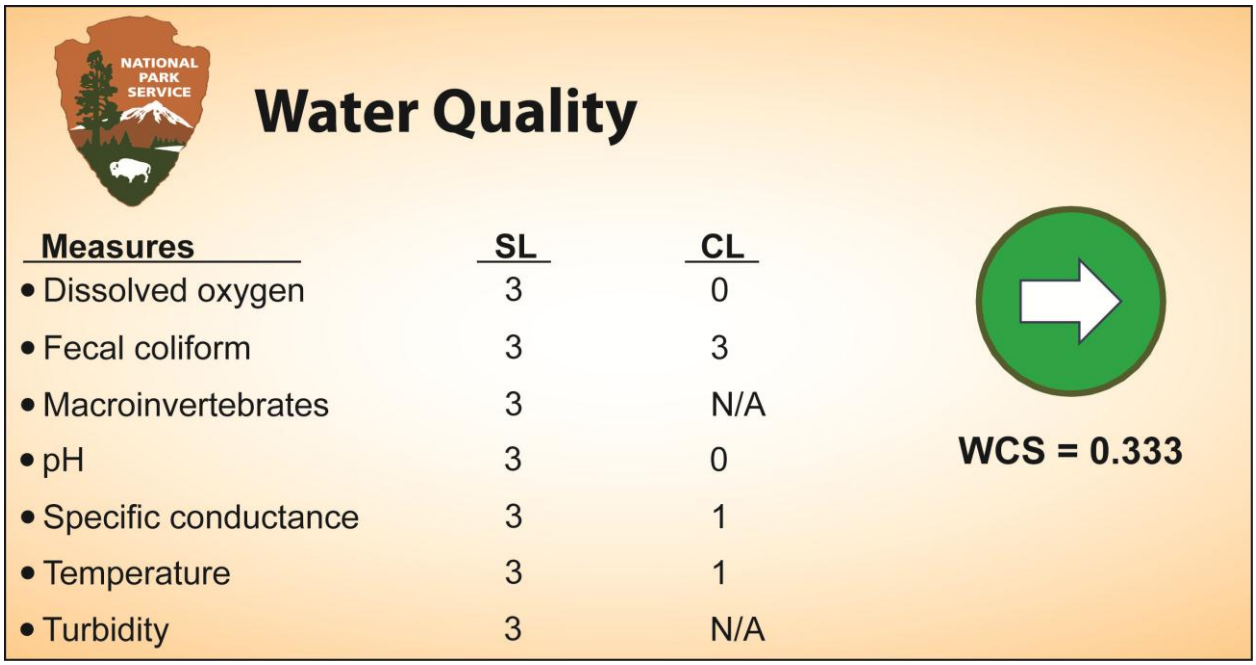
Specific Conductance
The project team defined the *Significance Level* for specific conductance as a 3. In the last 15 years, mean conductivity ranged from 1,350 to 2,780 µs/cm, with some observations ranging as high as 5,300 µs/cm. These measurements indicate higher-than-typical levels of dissolved inorganic solids in the Little Missouri River. High conductivity can be a natural characteristic of a waterway based on the geology of the region and water temperature, and the highly erodible landscape in THRO likely contributes to the high conductivity conditions in the Little Missouri River. However, it is not clear if conductivity has always been this high or if increased development or other activities upriver from THRO contribute to the amount of dissolved solids in the river or if aquatic life in the river has been affected over time. Thus, the condition for specific conductance is of low concern (*Condition Level* = 1).

Temperature
The project team defined the *Significance Level* for temperature as a 3. Over the last 50 years, water temperature observations in the Little Missouri River have ranged from approximately 0 to 30.0°C. Temperatures fluctuate during summer and winter seasons, and some temperatures in the summer months may reach as high as 28 to 30°C for short periods of time. This may affect some fish species' ability to thrive in the Little Missouri River, but may suit other species better adapted to warmer water temperatures. Thus, the condition for water temperature is of low concern (*Condition Level* = 1).

Turbidity
The project team defined the *Significance Level* for turbidity as a 3. Turbidity observations through 1994 indicated measurements consistently above EPA criterion. Likewise, Rust's (2006) observations indicated that the Little Missouri River was highly turbid, with all observations

exceeding EPA criterion. Rust's (2006) observations represent the most recent turbidity monitoring for the park and are nearing 10 years old. Thus, these measurements may not represent the current conditions for turbidity in the Little Missouri River. For these reasons, a *Condition Level* for turbidity was not assigned.

Weighted Condition Score
The *Weighted Condition Score* for water quality in THRO is 0.333, indicating water quality is in good condition with a stable trend.



4.13.6 Sources of Expertise
Dr. Lusha Tronstad, Invertebrate Zoologist, Wyoming Natural Diversity Database

4.13.7 Literature Cited

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4.14 Soundscape

4.14.1 Description

The definition of a soundscape in a national park is the total ambient sound level of the park, comprised of both natural ambient sound and human-made sounds (NPS 2000). The National Park Service's mission is to preserve natural resources, including the natural soundscape associated with the national park units. According to a survey conducted by the NPS, many visitors come to national parks to enjoy, equally, the natural soundscape and natural scenery. Intrusive sounds are of concern to park visitors, as they detract from their natural and cultural resource experiences (Gramann 1999). The General Management Plan for THRO identifies noise pollution as a resource management concern for the park (NPS 1986).

4.14.2 Measures

- Occurrence of human-caused and unnatural sounds
- Natural ambient sound level

4.14.3 Reference Conditions/Values

The reference condition for soundscape in THRO is a natural experience, or a soundscape not influenced by unnatural sounds.

4.14.4 Data and Methods

No quantitative soundscape data are currently available for THRO. This assessment relies on qualitative descriptions of non-natural sounds present in the park.

4.14.5 Current Condition and Trend

Occurrence of Human-caused and Unnatural Sounds

Oil and gas developments are very common on public and private lands around and adjacent to THRO, creating a major source of unnatural sounds in the park, which can carry for miles under favorable atmospheric conditions (NPS 1991). Drilling also creates extra vehicle traffic in the area, generating additional non-natural sounds. At lower densities, these activities can be mitigated by restricting oil drilling and trucking to periods of low visitor use and locating future oil wells and roads behind ridges or slopes (NPS 1991). However, development in the THRO area has now become so dense that mitigation may no longer be possible (C. Sexton, pers. comm., 2012).

Rosendahl et al. (2002) conducted a visitor survey at THRO in 2001, in which one question asked visitors to rate the effect of noise from outside park boundaries on their experience of the park. A total of 13.3% of respondents said that outside noise detracted from their experience, ranging from 'slightly detracted' to 'very seriously detracted'; the remaining 86.7% of respondents were unaffected by noise (Rosendahl et al. 2002).

Threats and Stressor Factors

Oil drilling and other forms of development are threats to the natural soundscape in THRO. The park is located in the Williston Basin, which is a highly productive oil and gas development area in western North Dakota (KellerLynn 2007). Hundreds of oil wells are located on the public and private lands surrounding the park. Drilling occurs 24 hours a day for weeks at a time, creating

noise that can carry for miles and disrupt both wildlife and humans within the park (NPS 1991). Unnatural noises can arise from a variety of mining activities related to oil and gas development, including exploration, drilling, blasting, stripping (overburden removal), hauling, maintenance, and beneficiation (KellerLynn 2007).

Road traffic is another threat to the natural soundscape of THRO as Interstate 94 passes through a portion of the South Unit and Highway 85 passes through the North Unit. Trains frequently pass through the Little Missouri River valley, introducing unnatural noise into the park soundscape. The park staff is particularly concerned with traffic noise near the Elkhorn Ranch site which is historically significant as Theodore Roosevelt's "home ranch" and treasured for the peace and solitude it once offered. The soundscape of the ranch is threatened by traffic noise as well as oil development in the area (NPS 2010). Drilling recently began near Elkhorn Ranch and many development sites are now visible from the entrance roads (L. Richardson, pers. comm., 2012).

Data Needs/Gaps

Acoustic monitoring is needed in order to quantify levels of ambient and unnatural sounds in and around THRO. Visitor surveys could be repeated to determine if visitor experience has been impacted by noise from increased development outside the park. In August 2012, a park request was approved for technical assistance in monitoring energy development impacts on THRO's natural soundscapes. This assessment could provide insight into current impacts to soundscape and identify long-term needs for soundscape management in the park.

Overall Condition

Occurrence of Human-caused and Unnatural Sounds

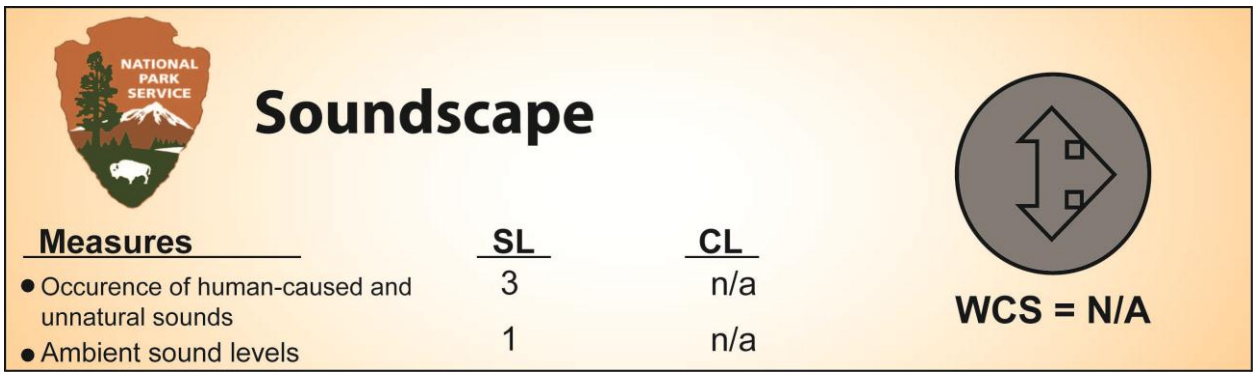
During initial scoping meetings, THRO staff assigned the measure of human-caused and unnatural sounds a *Significance Level* of 3. This indicates that the measure is vital to define condition of this component. Since no acoustic monitoring has been conducted in the park, a *Condition Level* cannot be assigned.

Natural Ambient Sound Levels

THRO staff assigned the measure of natural ambient sound levels a *Significance Level* of 1, indicating that the measure is of minimal use in defining the condition of this component. Natural ambient sound levels are not a concern related to soundscape, but rather provide a baseline from which to measure unnatural sounds. Because no data have been collected on the ambient sound levels in the park, a *Condition Level* cannot be assigned.

Overall Condition

A *Weighted Condition Score* (WCS) cannot be assigned without data on the component measures.



4.14.6 Sources of Expertise

Chad Sexton, Geographic Information Systems Analyst, THRO
Laurie Richardson, Botanist, THRO

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4.15 Dark Night Skies

4.15.1 Description

A lightscape is a place or environment characterized by the natural rhythm of the sun and moon cycles, clean air, and of dark nights unperturbed by artificial light (NPS 2007). The NPS directs each of its units to preserve, to the greatest extent possible, these natural lightscapes (NPS 2006). Natural cycles of dark and light periods during the course of a day affect the evolution of species and other natural resource processes such as plant phenology (NPS 2006, 2007). Several species require darkness to hunt, hide their location, navigate, or reproduce (NPS 2007). In addition to the ecological importance of dark night skies, park visitors expect skies to be free of light pollution and allow for star observation.

4.15.2 Measures

- V magnitude
- Ambient light pollution

4.15.3 Reference Conditions/Values

The reference condition for THRO is the absence of anthropogenic light pollution, which is in accordance with NPS management policies.

4.15.4 Data and Methods

No dark night skies data have been summarized by the NPS in THRO. The NPS Night Sky Team visited the North Unit of the park (near the Oxbow Overlook), but no data or summary report are available. Albers and Duriscoe (2001) assigned a Schaff scale score to the park, but data used in this assignment were not collected in the park and did not utilize V magnitude measurements.

4.15.5 Current Condition and Trend

Darkness - V Magnitude

The NPS uses a charged coupled device (CCD) digital camera connected to a robotic mount and laptop computer to conduct night sky assessments and to determine darkness of park nightscapes (NPS 2007). A mosaic image of the entire night sky is created by stitching together multiple short exposure images (NPS 2007). The images are filtered using a green filter to approximate human night vision sensitivity, and the data are calibrated using the known brightness of certain stars. The resulting data are in units of V magnitude, which is an astronomical brightness system (NPS 2007). Weather conditions and phases of the moon limit the number of suitable nights for measuring V magnitude (NPS 2007). Data from the Night Sky Team's visit to THRO are not yet available for this assessment.

Ambient Light Pollution

NPS defines ambient light pollution as "the illumination of the night sky caused by artificial light sources, decreasing the visibility of stars and other natural sky phenomena" (NPS 2007). Unfortunately, ambient light pollution has not been recorded or monitored in THRO.

Schaff Scale Scores

Albers and Duriscoe (2001) developed a GIS that evaluated the nighttime visibility of NPS units. This model used the Schaaf scale, which is a 1 through 7 scale with a value of 1 representing

extreme light pollution and a value of 7 representing pristine skies. Albers and Duriscoe (2001) overlaid Schaff scale score maps with park boundaries, and then extracted the mean Schaff score for the entire area of a given park. THRO received a Schaaf score of 7.00 out of 7.00; this score represents pristine night sky conditions (Albers and Duriscoe 2001). This value must be interpreted with caution though, as the original Schaff scale maps were from 1991 and no park-specific data were used in the calculation. In addition, this model is not sensitive to small amounts of light pollution and tends to over-predict sky quality in dark locations. The clear air and high altitudes of the western United States make distant cities more visible (C. Moore, pers. comm., 2011).

Threats and Stressor Factors

Light pollution is highest in areas with high human densities and can include glare, the use of light or intrusion of light in areas not requiring lighting, and any other disturbance of the natural nighttime lightscape (NPS 2007).

The major negative impact to THRO's dark night environment stems from the nearby development from oil and gas facilities (NPS 1991). THRO lies within one of the largest structural and sedimentary basins in North America. The basin has been active in oil and gas development since the mid 1970s. In the past 20-30 years, many wells have been developed outside of the park boundaries on public and private lands; some of the wells are within a few hundred feet of THRO's boundary (NPS 1991). In 2008, the National Parks Conservation Association (NPCA) identified THRO as one of ten National Parks most threatened by pollution from new coal-fired plants (NPCA 2008). The lights associated with these structures have the potential to affect THRO visitor's night sky viewing experience. KellerLynn (2007, p. 6) stated,

> Energy development on lands adjacent to the park is negatively affecting air and water quality; scenic views; dark night skies; wildlife and plants, including threatened and endangered species; cultural resources; and natural quiet.

Another threat also associated with oil and gas development is the large scale "flaring" or burning of waste natural gas and other gaseous compounds at production wells (Sexton, pers. comm., 2012). This practice has dramatically increased near the park's boundaries in the past two years and represents a major threat to the quality and integrity of the dark night skies in the park.

Another source of point-source light pollution is the city of Medora, ND. Medora is located on the South Unit's southern border and is a busy tourist hub location during the summer months. Shop lights, traffic lights, and traffic along U.S. Interstate 94 are all sources of light pollution that may influence the overall quality of darkness in THRO.

In addition to human sources of light, airborne particulates also affect night sky brightness (NPS 2007). Chapter 4.12 of this document provides detailed information about airborne particulates in THRO.

Data Needs/Gaps

There has been no collection of baseline data at THRO in regards to dark night skies. Without this data, an assessment of the condition of the night skies cannot be completed. An investigation

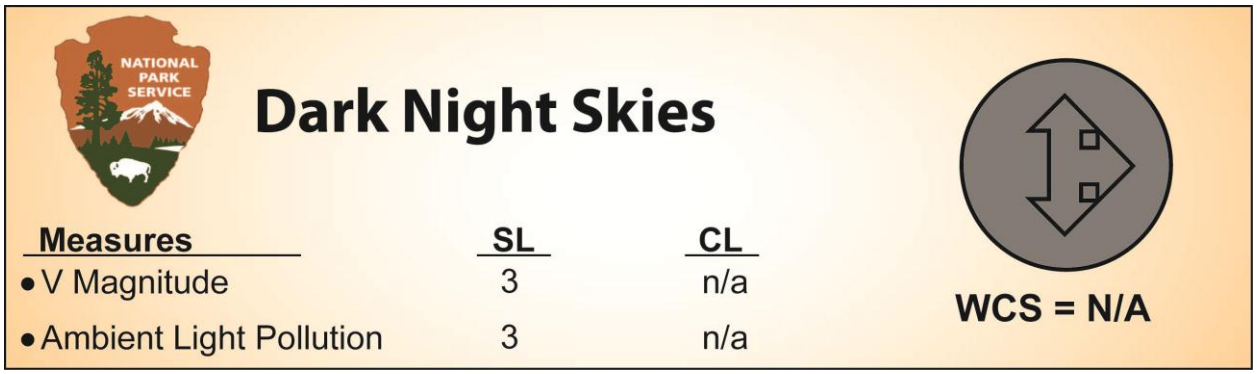
into the effects of "flaring" operations is also necessary; Bill Whitworth, THRO Chief of Resource Management, has indicated that plans for such an investigation are currently in development (pers. comm., 2012).

Overall Condition

V Magnitude
During initial scoping meetings, THRO staff assigned the measure of V magnitude a *Significance Level* of 3. However, due to the lack of appropriate data, a *Condition Level* for V magnitude cannot be assigned at this time.

Ambient Light Pollution
Ambient light pollution was also assigned a *Significance Level* of 3. Overall, there is insufficient data describing ambient light pollution. Albers and Duriscoe (2001) rated the night skies in the park as 7.00 out of 7.00 in terms of schaff scale scores, which is the only quantitative estimate of dark night skies for THRO. However, this rating must be taken with caution as no measurements were taken within THRO. SMUMN GSS did not assign this measure a *Condition Level* as there is insufficient data for such an assessment.

Weighted Condition Score
Because SMUMN GSS could not assign condition levels to the component, no *Weighted Condition Score* was assigned.



4.15.6 Sources of Expertise
Bill Whitworth, THRO Chief of Resource Management.
Chad Moore, NPS Night Sky Program Manager.
Chad Sexton, THRO GIS Analyst

4.15.7 Literature Cited

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4.16 Surface Water Availability

4.16.1 Description

THRO is located in the semi-arid region of the Northern Great Plains, which makes surface water an important and scarce resource in the park (Berkley et al. 1998). The Little Missouri River is the main surface water resource in the park, flowing through 23 km of the North Unit, 14 km of the South Unit, and along Elkhorn Ranch (NPS 1994). The river's flow varies greatly, depending on the season and weather conditions (NPS 1994). Tributaries of the Little Missouri River within THRO include Knutson, Paddock, Jones, Jules, and Squaw Creeks, many of which are intermittent streams (Berkley et al. 1998).

Seeps and springs are another source of surface water in THRO. These sources provide water for wildlife in the park's backcountry (Berkley et al. 1998, Photo 23). Flow rate and chemical characteristic data have been collected for 10 developed springs and 15 flowing wells in the park, while an innumerable number of other seeps and springs have not been inventoried or studied (NPS 1994). According to Berkley et al. (1998), little information and data is available for surface water features (springs and seeps) in THRO, including surface and ground water quantity and quality.



Photo 23. Wannagan Seeps in THRO's South Unit (photo by Nathan King).

4.16.2 Measures

- Precipitation
- Prevalence (location) of seeps and springs
- Flow rates of man-made water developments

4.16.3 Reference Conditions/Values

The reference condition for precipitation is the historic period of record (pre-2000) for the two weather stations near THRO. Reference conditions could not be established for prevalence of seeps and springs or flow rates of man-made water developments.

4.16.4 Data and Methods

Precipitation data acquired by the High Plains Regional Climate Center (HPRCC) was analyzed by decadal monthly average. Weather stations at Medora and Watford City, North Dakota (near THRO's South and North Units respectively), were analyzed to show a regional perspective of precipitation.

Many of the park's seeps and springs have been developed to provide water for wildlife. These locations were provided by the park in a GIS layer. Several additional undeveloped springs were identified on USGS topographic quad maps of the park from 1997. These locations were digitized to create a map of all known springs and seeps in the park.

4.16.5 Current Condition and Trend

Precipitation

The average annual precipitation in western North Dakota is 38 cm (15 in) (Berkley et al. 1998). Around THRO precipitation occurs quickly in rain showers, with some areas receiving up to several inches of rain per hour (KellerLynn 2007). About 50% of the total annual precipitation falls between May and July (Berkley et al. 1998). No significant change in precipitation has been detected at weather stations near THRO during the period of record (Figure 36 and Figure 37) (HRPCC 2011).

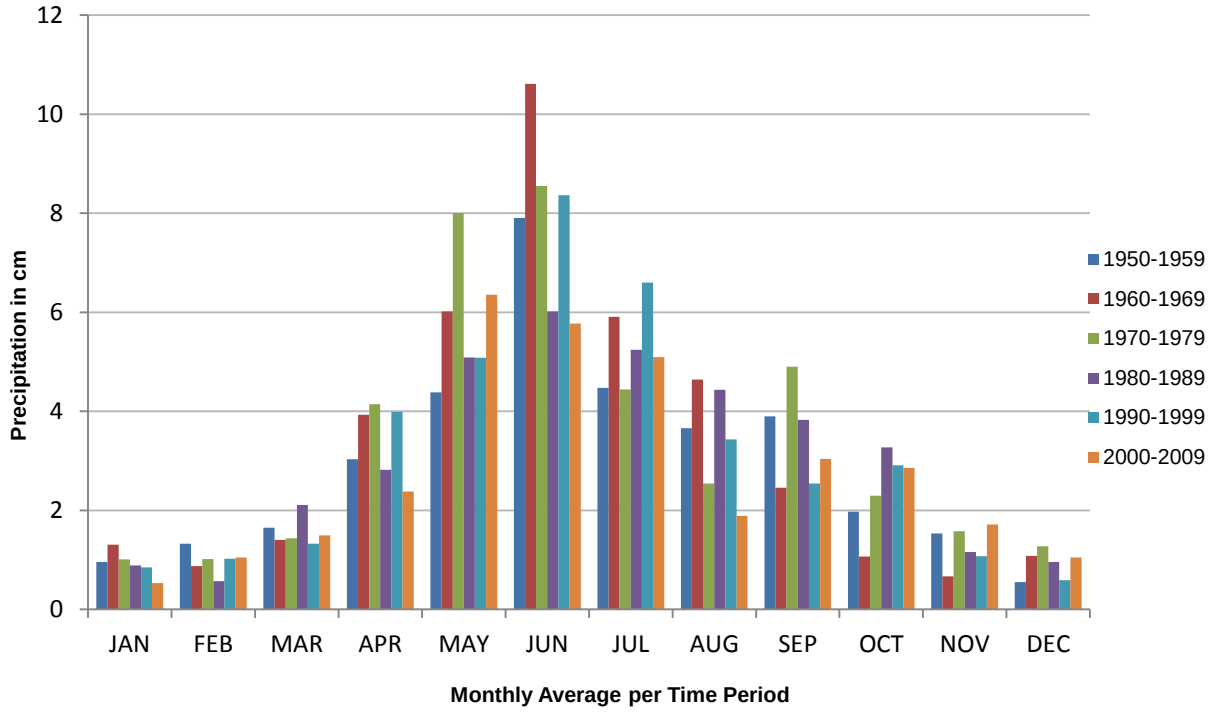


Figure 36. Monthly average precipitation at Medora, North Dakota per decade from 1950-2009 (HPRCC 2011). Months with more than five days missing were excluded from monthly averages (based on methodology from the High Plains Regional Climate Center).

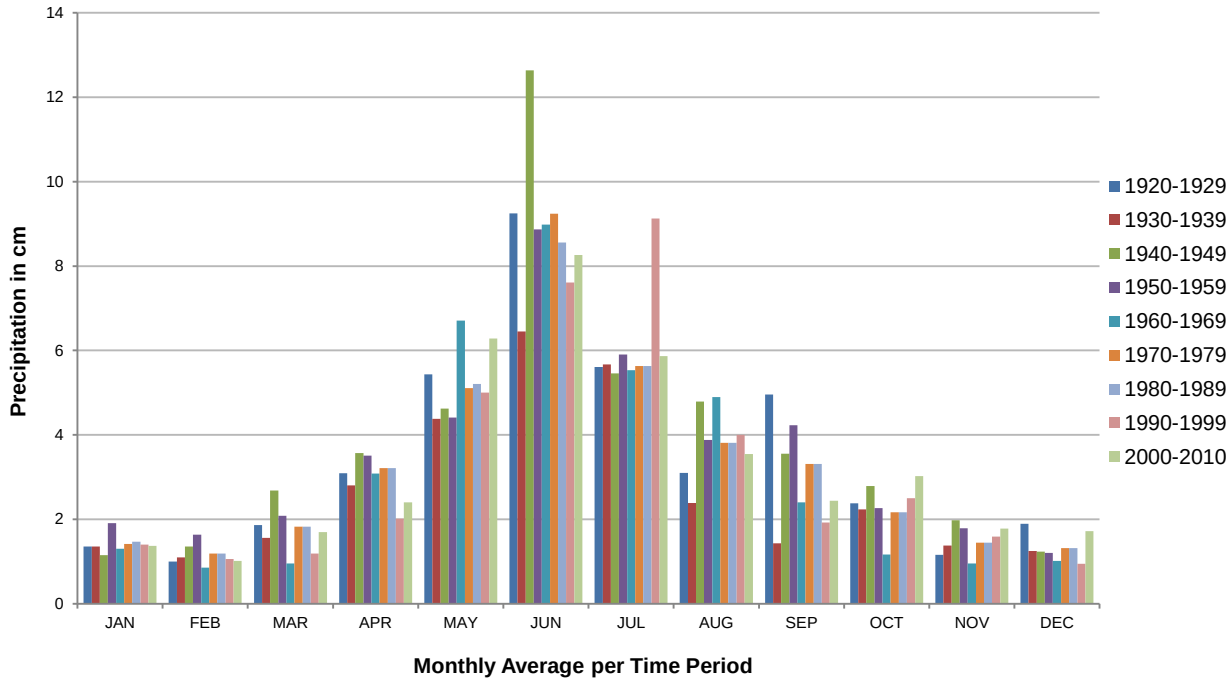


Figure 37. Monthly average precipitation at Watford City, North Dakota per decade from 1920-2010 (HPRCC 2011). Months with more than five days missing were excluded from monthly averages (based on methodology from the High Plains Regional Climate Center).

Prevalence of Seeps and Springs

The locations of 14 seeps and springs identified in park GIS data and on USGS topographic maps are shown in Plate 23 and Plate 24. Five of these springs are in the North Unit and nine are in the South Unit. Most of these water sources are in the western portions of both the North and South Units. Ground-truthing may be necessary to confirm that these springs are still producing water. The presence of water at some springs may depend on precipitation; in dry years, groundwater recharge and therefore the water table may decline, causing springs and seeps to dry up.

Flow Rates of Man-made Water Developments

Man-made water developments in the park include drilled wells and natural springs and seeps developed to capture water for animals. Most of these developments occurred before the park's establishment and were meant to provide reliable water for livestock and, in some cases, for fire protection (Oehler and Sexton 2010). Some were developed later by the NPS to provide water for wildlife. A typical spring-fed water development is shown in Figure 38.



Photo 24. Collection tank at Tomamichael Well (NPS photo).

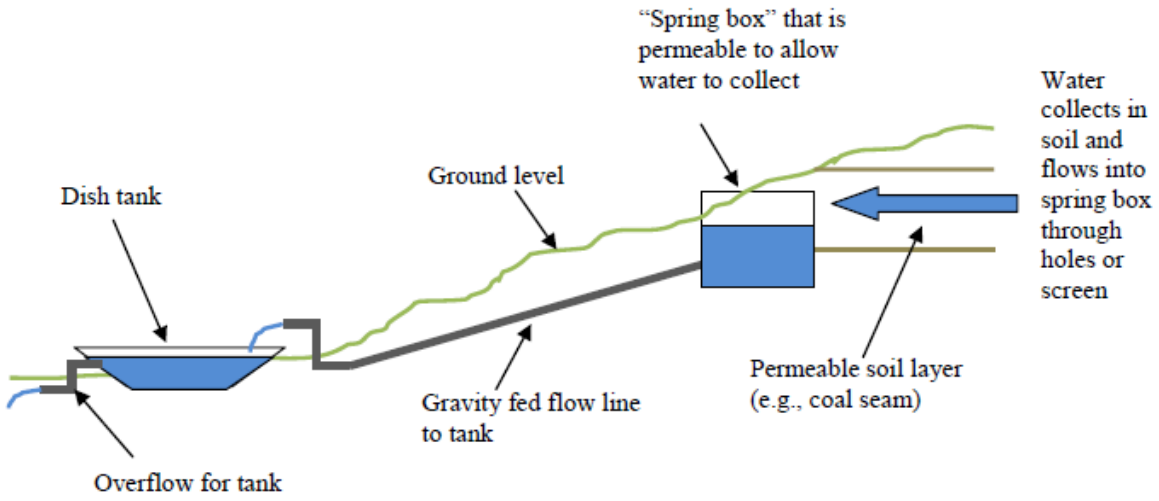


Figure 38. Diagram of a typical spring or seep fed water development in THRO (Oehler and Sexton 2010).

Flow rate data is available for several springs or wells in the park that have been developed to provide water for wildlife (Table 34). However, the majority of this data is from the 1980s, with only a few measurements taken from 2007-2009. Flow rates generally vary depending on precipitation and distance to remote water sources (Oehler and Sexton 2010). Most park water developments have not been maintained since the 1990s or earlier due to the considerable cost of maintenance, and many have fallen into disrepair. Spring boxes, pipes, and tanks may be leaking, allowing water to escape from the collection system before reaching the tank. As a result, recent measurements may not be comparable to historic data when these developments were maintained, since flow rate measurements are typically taken at collection tanks (C. Sexton, pers. comm., 2012). A number of these developments occur in the Wilderness Area of the park (Plate 23 and Plate 24) and may be removed when they stop functioning in an effort to restore the wilderness character of the park, unless they serve "a compelling need" for wildlife or visitors (M. Oehler and C. Sexton 2010, Photo 25).



Photo 25. Non-functional water developments at Sheep Pasture Spring in the South Unit's wilderness area (NPS photo).

Table 34. Flow rates (in gallons per minute) from man-made water developments in THRO over time (Berkley et al. 1998, Oehler and Sexton 2010, unpublished data).

Spring/Well	Unit	1982	1983	1985	1986	1988	1990	1992	2007	2008	2009	Status
Achenbach Spring	North		30		40					1.9	0.06	
Stevens Spring	North				15	12	9	13		0.02	0.01	
Hagen Spring	North				45	23	30	15		1.1	0.8	
Overlook Spring	North		300		300	300		300				
Ekblom Well	South		60	68		103			1.6	1.9		Operational
Tomamichael Well	South	6	6	5		5			0.01	0.1	0.08	Functional, in need of maintenance
Rough Rider Well	South	78		68	68	64						
SE Corner Spring	South	0		37		28	24	17				Seep is active, developments non-functional
Sheep Creek Well	South			152		180						
Sheep Butte Spring	South	15	75	7		10		7				Seep active, but developments non-functional
Mike Auney Well	South	138	30	42		126				0.2	0.07	Operational
Lone Tree Spring	South	30	60	35	35	16		13	0.4			Seep active, but developments non-functional
Big Plateau Spring	South	60	30	19	19	15		15				Active natural seep
Boicourt Spring	South	12	4	6	6	2		7				Operational
VA Well	South		15	11		10		6				Ceased functioning after 2004
Jones Creek Well	South	168	180	146		140				0.2	0.5	Operational
Sheep Pasture Spring	South											No apparent flow

Threats and Stressor Factors

Water Retention in Stock Dams
Water retention in stock dams (in upriver tributaries and draws) can change the flow and flooding patterns of the Missouri River. There is no current literature explaining the effects of water retention in stock dams in upriver tributaries and draws of the Missouri River.

Ice Jamming (impacts to stream banks and vegetation)
Ice jams are frequent during the spring melting season (Everitt 1968, Miller 2005) and were responsible for the spring flooding of the Little Missouri River in 2009 (Macek-Rowland and Gross 2011). The Little Missouri River is unusual in that it flows to the north. As weather to the south of North Dakota warms, snow and ice flows downstream to the colder north, where the water is still frozen (Macek-Rowland and Gross 2011). The snow and ice flowing to the north meets a frozen channel and an ice jam forms. River stage rises and the flow spills over the banks (Macek-Rowland and Gross 2011). These high spring flows can undercut the river bank, leading to channel instability (Miller 2005). Cottonwood seedlings and saplings can be destroyed by ice and major floods (Friedman et al. 1998); however, scouring and sand bar development due to flooding can also create new substrates for cottonwood development.

Changes in Flood Regime
High-flow events causing significant floodplain destruction have occurred every 5-10 years on the Little Missouri River (Miller and Friedman 2009). Over the last century, there has been a reduction in the magnitude of peak flows on the Little Missouri River (Miller and Friedman 2009). Since the Little Missouri River is largely unregulated, climatic factors such as temperature and precipitation are thought to be the primary drivers in the overall reduction of peak flow magnitude during the 20th century. Flooding is discussed further in section 4.3 of this assessment.

Data Needs/Gaps
A park-wide inventory of springs and seeps would identify additional surface water sources and regular monitoring could help to determine if spring flows are changing over time. A study of the relationship between coal seams, ground water, and surface water would also be beneficial. Research investigating the number, location, and extent of man-made developments (e.g., stock dams) in the upstream tributaries of the Little Missouri River would be a first step in better understanding how these might be affecting surface waters in THRO. Quantifying the impact of these developments upon water flow, while more difficult, would help managers understand the severity of this threat to park surface water availability. A survey of groundwater use in the region could also be helpful in understanding impacts on the water table, which may influence the supply of water for seeps and springs.

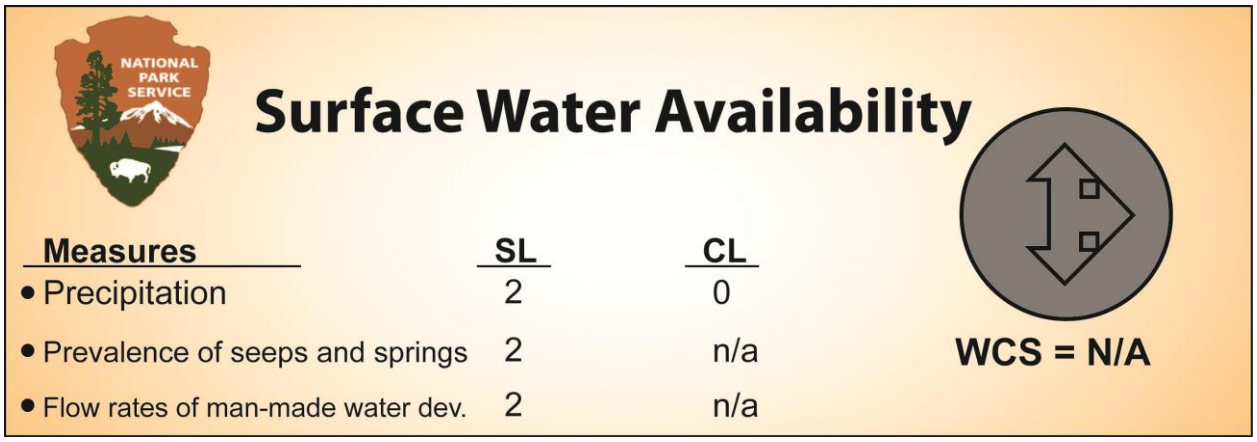
Overall Condition

Precipitation
The *Significance Level* for precipitation was a 2. No significant changes in precipitation have been observed at the two weather stations near the park. The *Condition Level* for precipitation is 0, indicating the component is of no concern.

Prevalence (locations) of Seeps and Springs
The *Significance Level* for prevalence of seeps and springs was a 2. Information regarding the locations of seeps and springs in the park is somewhat limited. The full extent of these features throughout the park may be difficult to determine, as the park's geology allows seeps to develop across the landscape (C. Sexton, pers. comm., 2012). Since the data available for spring and seep locations are not conducive to an analysis of change in prevalence over time, a *Condition Level* could not be assigned for this measure.

Flow Rates of Man-made Water Developments
The *Significance Level* for flow rates of man-made water developments was a 2. Flow rate data for the park is sporadic and recent measurements are not directly comparable to historic data since these developments are no longer maintained. Many developments, particularly those in wilderness areas, may be removed when they cease functioning. Therefore, a *Condition Level* could not be assigned.

Weighted Condition Score
Since *Condition Levels* could not be assigned for two of this component's three measures, a *Weighted Condition Score* was not calculated. The overall condition of surface water availability is unknown.



4.16.6 Sources of Expertise
Chad Sexton, Geographic Information Systems Analyst, THRO
Jeff Hughes, Hydrologist, NPS
Eleanor Griffin, Hydrologist, USGS
Jonathan Friedman, Research Hydrologist, USGS

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U.S. Geological Survey (USGS). 2011. USGS flood tracking 06336000 Little Missouri River at Medora, ND. http://nd.water.usgs.gov/floodtracking/charts/0633600.html (accessed 19 April 2011).

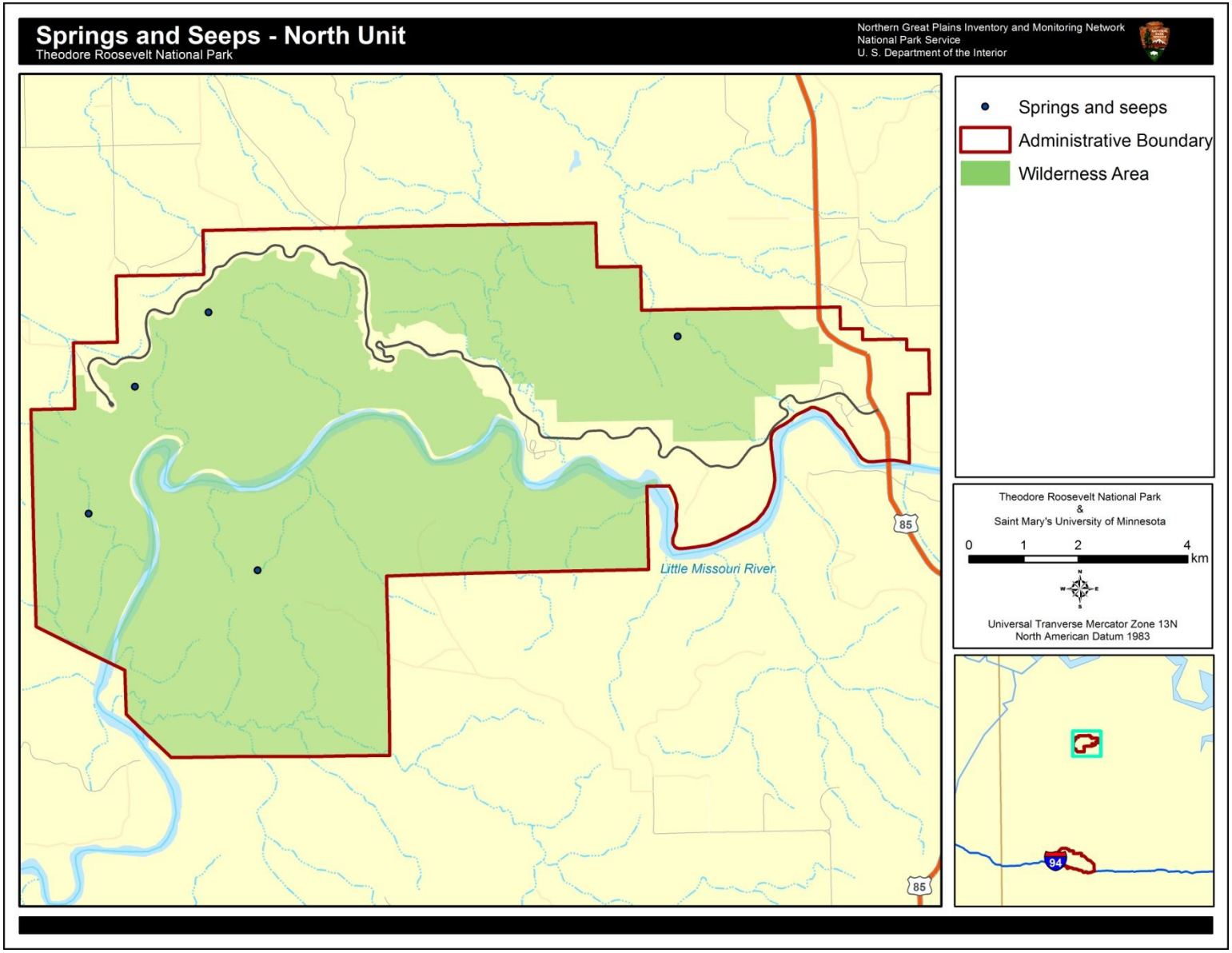


Plate 23. Known spring and seep locations in the North Unit of THRO.

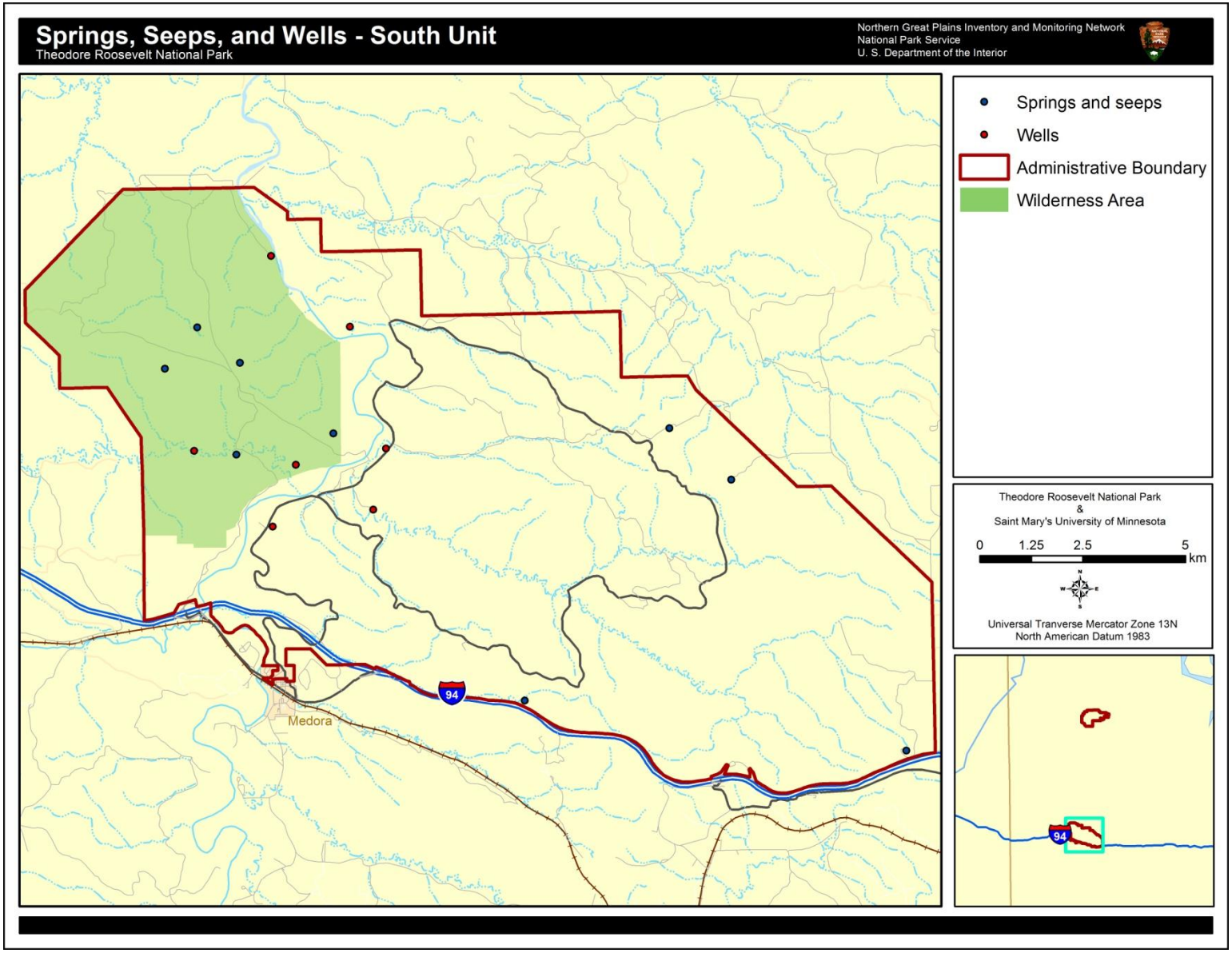


Plate 24. Known spring, seep, and well locations in the South Unit of THRO.

4.17 Paleontological Features

4.17.1 Description

Paleontological features (i.e., fossils) are "the remains, imprints and traces of once living organisms preserved in the earth's crust" (DOI 2000, p. 13). These features are vital in providing insight to the history of life on earth (e.g., mass extinctions, genealogical relationships between species), and how life responds to changing conditions, including effects of anthropological caused changes, as well as effects on biological diversity and ecological structure due to environmental changes (DOI 2000). Fossils also provide evidence of physical changes to the earth over time such as changes in the positions of continents, climate change cycles, and mountain building (DOI 2000).

Fossils are found in both of THRO's primary exposed rock formations: the Bullion Creek Formation and the overlying Sentinel Butte Formation (Hoganson and Campbell 1997). These formations were formed during the Paleocene Epoch (60-55 Ma), when sediments carried from the uplifting Rocky Mountains were deposited on the Central Plains by fluvial and lacustrine systems, forming generally flat beds (Figure 39). For example, the Bullion Creek Formation, only exposed in the South Unit of THRO, consists of poorly lithified claystones, mudstones, and siltstones, with minor amounts of fine-grained sandstone and lignite. The formation is yellow and tan in color and approximately 61 m (200 ft) thick (Hoganson and Campbell 1997). The Sentinel Butte Formation is found in both the South and North Units of the park. It is composed of similar lithologies as the Bullion Creek Formation; however, it is gray to brown in color. This formation can be greater than 213 m (700 ft) thick in the North Unit and 91 m (300 ft) thick in the South Unit. Generally, the contact between these two formations can be recognized by a pink rock layer identified as the HT Butte clinker (Hoganson and Campbell 1997).

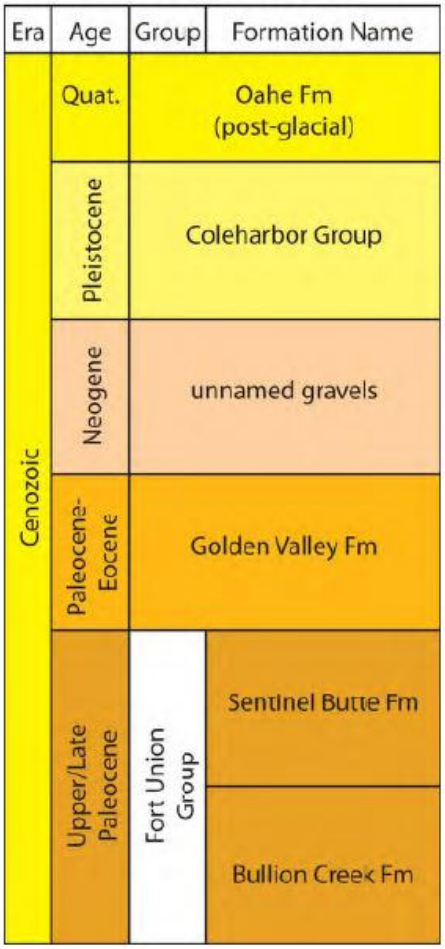


Figure 39. Schematic stratigraphic column of rock formations in THRO (from Tweet et al. 2011).

The fossils in THRO indicate that the historical (Paleocene) climate was subtropical with hot and humid swampy lowlands. There were periods with well-established forests composed of ferns, cycads, figs (*Ficus* spp.), bald cypress (*Taxodium* spp.), *Ginkgo*, katsura (*Cercidiphyllum* spp.), *Magnolia*, sycamore (*Platanus* spp.), and dawn redwoods (*Metasequoia* spp.) (Hoganson and Campbell 1997). These forests provided an extensive habitat and food source for insects and birds. Rivers, streams, ponds, and swamps provided habitat for invertebrates such as pill clams, mussels, snails, insects, and minute crustaceans, as well as predators such as crocodiles (*Borealosuchus*), alligators (genus not identified), and *Champsosaurus* (crocodile-like creatures). The swampy lowland forests supported mammals similar to present-day lemurs (Hoganson and Campbell 1997).

The NPS recognizes paleontological sites as a sensitive resource in need of protection. On 30 March 2009, the Omnibus Public Land Management Act of 2009 was passed into law. Subtitle D, the Paleontological Resources Preservation Act, mandates the Secretaries of the Interior and Agriculture to implement a paleontological resource management program on federal lands, with the requirements to increase protection, enhance management tools, and increase scientific and public understanding of fossil resources (Tweet et al. 2011).

4.17.2 Measures

- Distribution and abundance of paleontological resources
- Protection of collections

4.17.3 Reference Conditions/Values

A reference condition has not been determined for this component.

4.17.4 Data and Methods

Hoganson and Campbell (1997) conducted a detailed study of 25.9 km^2 (10 mi^2) of THRO (about 1/10 of the entire park area), and mapped 400 fossil sites. Fossils collected during this study are housed at the North Dakota Heritage Center in Bismarck and cataloged in their North Dakota State Fossil Collection (J. Hoganson, pers. comm., 2012).

The NPS Geologic Resource Evaluation (GRE) Program conducted scoping meetings with park staff and geologic experts, with the purpose of reviewing available geologic maps and discussing geologic issues, features, and processes. Then, using a GIS data model, the team converted geologic maps identified in the scoping meeting into digital data sets. Finally, a park specific report was produced (KellerLynn 2007) to provide the park with an overview of the geology and related resource management issues.

Tweet et al. (2011) prepared a paleontological resource summary report for the parks of the NGPN, based on an extensive literature review and interviews with park staff and professional geologists and paleontologists in the region.

4.17.5 Current Condition and Trend

Distribution and Abundance

The presence of fossils in THRO has been known for many years; however, up until the 1990s, the documented diversity was limited to the abundant petrified wood. In 1994, the park entered into a cooperative agreement with the North Dakota Geological Survey "to identify, map and assess the significance of fossils and paleontological sites in the park, for the intent to use that information in overall resource management planning" (Hoganson and Campbell 1997, p. 1). This survey effort mapped 400 fossil sites in a 26 km^2 (10 mi^2) study area of THRO, with an average of 40 fossil sites per 2.6 km^2 (1 mi^2). They concluded that the Bullion Creek and Sentinel Butte Formations were relatively fossiliferous, predominantly consisting of freshwater mollusk fossils (Hoganson and Campbell 1997). Petrified wood, located at several levels within the Bullion Creek and Sentinel Butte formations, remains the most abundant fossil in the park, and has proven impractical to map completely. Poor preservation of these remains makes it difficult to determine the original tree taxa; however, it is thought that most trees were conifers of the genus *Metasequoia* (Tweet et al. 2011). Vertebrate fossils are found throughout the park,

located in both the Bullion Creek and Sentinel Butte Formations. The most abundant vertebrate fossil was the aquatic reptile *Champsosaurus* (Tweet et al. 2011). Table 35 contains a list of fossils documented in THRO, along with the formation in which they were found.

Table 35. Fossils at Theodore Roosevelt National Park (Hoganson and Campbell 1997, as cited in KellerLynn 2007).

Fossil type	Formation
Petrified wood	Bullion Creek and Sentinel Butte
Freshwater mollusks	Bullion Creek and Sentinel Butte
Ostracods (small bivalved crustaceans)	Sentinel Butte
Coleoptera (beetle)	Sentinel Butte
Leaves (e.g., angiosperms and ferns)	Bullion Creek and Sentinel Butte
Seeds (e.g., *Cercidiphyllum* [katsura tree])	Bullion Creek and Sentinel Butte
Twigs, roots, and branches	Taylor bed of the Golden Valley Formation
Champsosaurs (crocodile- like creature), including common *Champsosaurus* and extremely rare *Simoedosaurus*	Bullion Creek and Sentinel Butte
Crocodiles (probably *Borealosuchus*)	Bullion Creek and Sentinel Butte
Alligators	Sentinel Butte
Turtles (*Protochelydra* - chelydrid [snapping turtle], and *Plastomenus* - plastomenid [soft- shelled turtle])	Sentinel Butte
Fish (*Amia* [bowfin] and *Lepisosteus* gar.)	Bullion Creek and Sentinel Butte
Giant salamander (*Piceoerpeton*)	Sentinel Butte
Plesiadapis (lemur- like mammal)	Sentinel Butte
Bison	Quaternary alluvial and colluvial deposits



Photo 26. Fossils from the Sentinel Butte Formation (l-r): A leaf, a crocodile scute and tooth, and petrified wood (photos from Hoganson and Campbell 1997).

The Wannagan Creek Quarry (part of the Bullion Creek Formation), just west of the South Unit of the park, has a diverse fossil assemblage. The floral record is composed of spores, pollen (Melchior and Hall 1983, as cited in Tweet et al. 2011), and over 100 taxa including both aquatic and terrestrial plants (Erickson 1982, 1991, 1999, as cited in Tweet et al. 2011). Animal fossils include invertebrates (e.g., mollusks and insects), fish, amphibians, reptiles, and mammals (e.g., marsupials, early primate relatives) (Melchior and Hall 1983, Erickson 1991, as cited in Tweet et al. 2011).

Protection of Collections

NPS museums study, interpret, and provide visitors the opportunity to view natural and cultural resources that have been collected and preserved (Hitchcock and Floray 2006). The primary responsibility of a museum is to document the collection, and continue to collect according to its written "Scope of Collections" statement (required for each museum under Director's Order #24 – see Floray and Knapp 2003). Preservation of the collection is the second responsibility, as museum specimens lose their value if they are damaged or if their documentation is lost. The third responsibility of the museum is to provide access, use, and interpretation of the collection (Hitchcock and Floray 2006).

To meet these responsibilities, the park must consider many factors such as lighting, dust, storage, handling, fire security, and theft and/or vandalism. Light levels affect glues and preservatives; however, they do not adversely affect the fossil itself (McDonald et al. 2005). Fossils with remaining organic constituents can also be vulnerable to high humidity or ultraviolet light. The leading source of degradation is improper storage and handling of a fossil (McDonald et al. 2005). Dust can be abrasive if it settles on specimens that are not stored properly. Fossils can be damaged with gentle cleaning, so it is recommended to eliminate dust by storing specimens in enclosed areas with filtered circulating air. If a closed area is not available, dust covers should be used on open rack shelving (McDonald et al. 2005). Fossils are particularly susceptible to improper handling because most fossils cannot sustain their own weight. To prevent damage, museum staff should practice good maintenance procedures and use methods outlined in its Museum Housekeeping Plan (see NPS 1998).

Fossils are susceptible to fire damage; it is important for the museum to practice and train staff in fire prevention. All NPS museums should have an up-to-date Emergency Operations Plan, which includes information about hazardous material, and special needs of the collection (McDonald et al. 2005). All structures containing the collection should have an appropriate level of fire protection. Security is also important as many of the specimens are very valuable. Fossils are very collectible, and there are opportunities to sell fossils in a black market (McDonald et al. 2005). In particular, trilobites, dinosaur parts, amber, and shark's teeth are very popular fossils. Petrified wood also is sought after as some specimens are considered to be of gemstone quality. It is important for museums to discuss security with the regional/SO curator, park protection staff, and/or regional law enforcement specialist. To protect the collection from theft or vandalism, doors, exhibit cases, and storage cabinets should remain locked (McDonald et al. 2005).

THRO's collection consists of 55 catalog numbers for fossil objects, representing approximately 230 specimens (Tweet et al. 2011). The majority of the catalog numbers were from the Sentinel Butte Formation, with the remaining catalog numbers from the Bullion Creek Formation, the White River Formation, and Quaternary deposits. While plant fossils are most abundant in the collection, it also includes brachiopods, bivalves, gastropods, fish, reptiles, mammals, and some unknown fossils (Tweet et al. 2011).

Understanding the geology and geographic abundance, occurrence, and distribution of fossils as well as threats and stressors (e.g., erosion, human activity) is critical when managing and protecting paleontological resources (KellerLynn 2007). NPS paleontologists have established protocol to monitor baseline changes and to quantify resource loss. Park staff monitors locations

of fossils through normal patrol activities. However, some areas of the park are more difficult to monitor, such as the backcountry and the Petrified Forest Plateau area, which is a particularly sensitive area (KellerLynn 2007). The locations of paleontological resources in the park differ extensively in terms of rock types, degree of preservation, geomorphic characteristics, and accessibility. A specific inventory may not be useful or appropriate at all fossil sites within the park. A combination of monitoring strategies (e.g., baseline inventory and patrols) provides a useful approach to assess or measure impacts to in situ resources in THRO (KellerLynn 2007).

Threats and Stressor Factors

Threats to paleontological features include any natural (physical, chemical, and biological) or human factor (theft or vandalism) that has the potential to cause degradation or loss (Santucci and Koch 2003). Erosion is an important natural process that aids in the discovery of paleontological resources. However, it is also a major threat because once a fossil is exposed, it can rapidly be destroyed (NPS 2004). Climatic factors such as precipitation and wind can influence weathering and erosion of paleontological resources (Santucci et al. 2009).

Precipitation (rain, snow, hail, etc.) can influence the stability of in situ paleontological resources (Santucci et al. 2009), and rainfall has been described as the initial and essential driving force for erosion variation (Wei et al. 2009). Erosion rates are directly proportional to precipitation levels and intensity. Areas with greater or intense seasonal periods of precipitation generally have higher rates of erosion (Santucci et al. 2009). Hydrologic factors such as flooding and droughts can significantly influence the stability of in situ paleontological features. Periods of flooding can increase erosion of resources located along riverbanks. Droughts may cause river levels to drop, exposing previously submerged fossils (Santucci et al. 2009).

Wind has the potential to influence the stability of in situ resources in two ways. Abrasive wind transportation (eolian) of unconsolidated sediments can smooth exposed fossils at the surface. In contrast, winds can cause sediments to accumulate in the form of dunes. Degradation can occur as the dune migrates; resources may be buried, exposed, or destroyed (Santucci et al. 2009).

Theft and vandalism are of concern at THRO (Tweet et al. 2011). Data compiled by the NPS in 1999 for 721 incidents of theft or vandalism indicate that humans pose a significant threat to paleontological resources (Santucci 1999, as cited in Santucci and Koch 2003). Fossils and fragments can have high commercial value. Many people collect fossils with the purpose of selling them to museums or private collectors (DOI 2000). Park management and adequate baseline data is critical to prevent degradation due to human causes (Santucci and Koch 2003).

Development in THRO could also pose a threat to paleontological resources if projects are not managed properly. According to the NPS (2004) Paleontological Resources Management policy, any area with the potential for paleontological resources must receive a surface assessment prior to any disturbance or development. If paleontological resources are found, then the site will be avoided or, if necessary, the resources will be collected before development begins and properly cared for. These areas also must be monitored during development (NPS 2004).

Data Needs/Gaps

There is a need for a complete park paleontological survey to aid in resource management. Prior to the 1990s, little was known about the abundance of paleontological features; only 10% of the

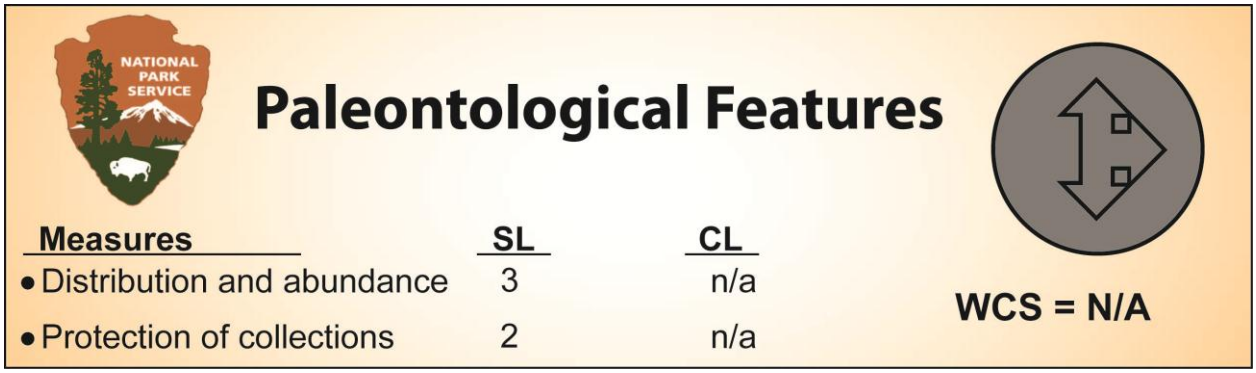
park was surveyed by Hoganson and Campbell (1997). It is also critical for sites to be resurveyed to monitor any changes in the condition of in situ fossils.

Overall Condition

Distribution and Abundance
The measure of distribution and abundance was assigned a *Significance Level* of 3. Due to the limited amount of paleontological survey work that has been conducted in the park, a *Condition Level* cannot be assigned at this time.

Protection of Collections
The protection of collections measure was assigned a *Significance Level* of 2. Because it is not clear if protection of collections at THRO meets NPS standards for preservation, *Condition Level* for this measure cannot be assigned at this time.

Weighted Condition Score
A *Weighted Condition Score* (WCS) cannot be assigned at this time due to lack of data on component measures.



4.17.6 Sources of Expertise
John Hoganson, State Paleontologist, North Dakota Geological Survey.
Rachel Benton, Geologist, Badlands National Park.

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Chapter 5 Discussion

Chapter 5 provides an opportunity to summarize the assessment findings and discuss the overarching themes and common threads that have emerged for the featured components. Specifically, the data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also discussed is how condition analysis relates to the overall natural resource management issues of the park.

5.1 Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but are needed to help inform the status or overall condition of a key resource component in the park. Data gaps and needs exist for most key resource components assessed in this NRCA. Table 36 provides a detailed list of the key data gaps by component. Each data gap or need is discussed in detail in the individual component assessments in Chapter 4.

Some data gaps, if addressed, would provide managers with more information for resource protection and enhancement for multiple components in the project framework. Such is the case for the vegetation communities featured in this NRCA. For all vegetation components, carrying out updated surveys of species composition, capturing the extent/distribution of the communities, and assessing the prevalence of non-native species presence in these communities would help to fill data gaps and provide a more complete understanding of the current condition of each community. In addition, the condition of several other featured components and natural resources may be affected by the health and integrity of the native vegetation communities. These include the frequency and behavior of fire on the landscape, rates of erosion by wind and water, and the health of animals such as breeding birds, prairie dogs, and grazing and browsing ungulates managed within the park (bison, elk, and feral horses, etc.). Filling in data gaps for each vegetation community would help managers determine an accurate current condition of these communities, as well as provide insight into how the health and diversity of these vegetative systems affect the organisms that depend on them for habitat. Data gaps for other featured biotic components, breeding birds and aquatic communities, include updated surveys of species diversity and abundance to understand population trends.

Data gaps vary for the chemical and physical components in THRO, including water quality, air quality, and surface water availability. Since THRO is a Class I airshed, monitoring of air quality conditions in the park is quite thorough. However, identifying and monitoring sensitive plant and tree species that serve as bioindicators for air pollutants could help managers understand, at early stages, the degree of impact from air pollution on the landscape. The Little Missouri River is a major water feature in all three units of THRO. Though much data are available on water quality parameters courtesy of outside agency monitoring stations adjacent to the park's North and South Units, very little monitoring is conducted within the park through an established NPS monitoring program. In addition, these monitoring stations do not survey the macroinvertebrate communities in the Little Missouri River within the park; macroinvertebrates can be important indicators of poor or good water quality. Any monitoring of water quality parameters that does occur within park boundaries is sporadic and does not allow for assessing long-term trends in water quality. To date, the largest data gap for water quality is a consistent survey of macroinvertebrate species diversity and abundance in the park.

Components featuring natural disturbance regimes, including fire, erosion from wind and water, and flooding on the Little Missouri River, are important in shaping the landscape both ecologically and physically. Wind and water erosion are largely responsible for shaping the dramatic badlands formation that are characteristic of the park landscape. However, no research has been conducted on the rate at which these processes affect the landscape. Regular flooding of the Little Missouri River is essential for the proliferation and health of various floodplain woodlands, particularly the regeneration of cottonwood woodlands. Currently, it is unclear how development and the extent of water draw down activities upriver from THRO or on tributaries to the river may affect the rate and magnitude of flooding and availability of surface water within the park. Fire in THRO, almost exclusively occurring as prescription burns, is monitored regularly through data collected before, during, and after burn events. Managers could continue to benefit from continual, detailed monitoring of established vegetation plots to estimate the effects of fire on desired vegetation outcomes. These data would help managers further understand the condition of fire and its usefulness in meeting management objectives for the native plant communities in the park.

Soundscape and dark night skies are components commonly thought of as "goods and services" for visitors; however, quantitative data related to these in THRO is very limited. National programs and sampling standards have been developed by NPS in order to monitor soundscape and dark night skies conditions in all parks. Currently, baseline data do not exist for dark night skies conditions or the levels of unnatural sounds in the park. Implementing the NPS protocol for these resources would provide a better understanding of the components' conditions.

Table 36. Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Fire	➢ Continued and consistent monitoring of established vegetation plots to characterize the effects of fire and parameters that correlate with desired vegetation outcomes ➢ Record of burn severity and intensity and its correlative effects on native vegetation
Wind and water erosion	➢ No research has been conducted on this component
Flooding (Little Missouri River)	➢ Consistent monitoring of peak magnitude and peak gage height at Medora, ND ➢ Understanding of the amount and extent of water permits near the Little Missouri River to understand drawn down statistics ➢ Summary of the amount, location, and extent of stock dams in upstream tributaries of the Little Missouri River
Native grasslands	➢ An updated vegetation mapping effort to characterize extent of juniper and other woody encroachment ➢ Updated survey of grassland composition
Juniper forests	➢ Updated data on density and stand structure ➢ Updated distribution and extent of juniper stands

Table 37. Identified data gaps or needs for the featured components. (continued)

Component	Data Gaps/Needs
Floodplain forests	➢ Specific information on the species composition and abundance of floodplain woodland alliances ➢ Cottonwood woodland stand age data to understand regeneration and mortality ➢ Updated extent and distribution data for floodplain woodlands
Woody draws	➢ Prevalence of diseases affecting species in the woody draws ➢ Data representing changes in woody draw communities over time ➢ More detailed examination of non-native species prevalence/abundance
Upland shrublands	➢ Updated information on plant species composition with an emphasis on the prevalence and impact of non-native species ➢ Updated extent and distribution of upland shrubland communities
Aquatic communities	➢ Species surveys during normal and low flow periods to understand diversity and abundance ➢ Updated survey of species diversity ➢ Updated survey of macroinvertebrate diversity and abundance in the Little Missouri River
Prairie dogs	➢ Continued monitoring efforts that include mapping of prairie dog town extents
Breeding birds	➢ Greater frequency of surveys to understand population trends ➢ Increased sampling under the IMBCR spatially balanced land bird protocol ➢ Consistent monitoring of priority species populations ➢ Raptor specific monitoring
Air quality	➢ Periodic monitoring of air pollutant sensitive plants that may act as bioindicators of declining air quality conditions
Water quality	➢ Consistent monitoring of water quality parameters within THRO, including macroinvertebrate populations
Soundscape	➢ Acoustic monitoring to quantify levels of ambient and unnatural sounds
Dark night skies	➢ Baseline data on dark night skies ➢ Study of effects of oil and gas “flaring” activities on night skies
Surface water availability	➢ Park-wide inventory of springs and seeps and regular monitoring of these features ➢ Summary of the number, location, and extent of man-made developments in the tributaries of the Little Missouri River in and around THRO
Paleontological features	➢ A complete park paleontological survey to aid resource management ➢ Resurvey of sites to monitor for changes in the condition of in situ fossils

5.2 Component Condition Designations

Table 38 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics are located in Figure 40 following Table 38). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols used in Table 38) is based on a number of factors and an assessment of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing or long-term datasets and monitoring information and expertise by NPS and other non-NPS scientists, while other components lack historic data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information.

Data are unavailable or insufficient for many of the measures of the featured components and, thus, it is not possible to define current condition for these components. In other instances, reference condition data were limited or unavailable for components, making comparisons inappropriate or invalid. Current condition was not able to be determined for 10 of the 17 components (58%) due to these significant data gaps.

For featured components with available data and fewer data gaps, assigned conditions varied. For some components, enough data exist to determine a trend in condition over time; however, for others the lack of long-term or comparable data prevented the determination of trends. Several components were determined to be in good condition with a stable trend, including air quality, water quality, fire, and the prairie dog population. Flooding on the Little Missouri River in the park was determined to have a condition of moderate concern but with a stable trend, meaning the condition is not believed to be degrading or improving from past conditions. Native grasslands and woody draws were also determined to be of moderate concern, but a lack of historical data does not allow for designating a trend in condition over time. A discussion of these designations is presented in the following section.

Table 38. Summary of current condition and condition trend for featured NRCA components.

Component	WCS	Condition
Ecosystem Extent and Function		
Disturbance Regimes		
Fire	0.333	
Wind and water erosion	N/A	
Flooding (Little Missouri)	0.666	
Biological Composition		
Ecological communities		
Native grasslands	0.500	

Table 39. Summary of current condition and condition trend for featured NRCA components. (continued)

Component	WCS	Condition
Juniper forests	N/A	
Floodplain forests	N/A	
Woody draws	0.500	
Upland shrubland communities	N/A	
Aquatic communities	N/A	
Grazing animals		
Prairie dogs	0*	
Birds		
Breeding birds	N/A	
Environmental Quality		
Air quality	0.333	
Water quality	0.333	
Soundscape	N/A	
Dark night skies	N/A	
Physical Characteristics		
Hydrologic & Geologic		
Surface water availability	N/A	
Paleontological features	N/A	

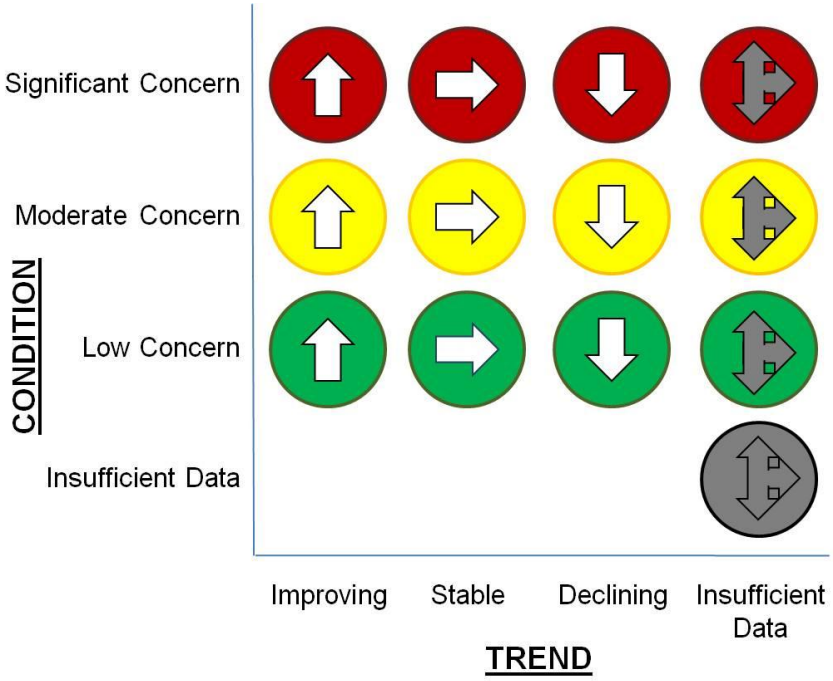


Figure 40. Symbols used for individual component assessments with condition or concern designations along the vertical axis and trend designations along the horizontal.

5.3 Park-wide Condition Observations

The landscape in THRO is rich in natural resources that are diverse and complex. As a result, a number of components featured in the NRCA are interrelated, with the condition of many being dependent on the condition and healthy functioning of others. In particular, the native vegetation communities and the natural disturbance patterns in the park (i.e., fire and flooding along the Little Missouri River) seem to be an important influence on the condition of many other biotic components in the park.

Native Vegetation Communities

THRO managers agree that the native vegetation communities within the park are integral to the healthy functioning of the overall ecological landscape and that the health of the vegetation communities can significantly influence the condition of many of the species that also reside in the park. For example, the condition of the vegetation communities in the park is an important factor in the health of ungulate populations (such as bison, elk, and feral horses), as well as small mammals and breeding birds that utilize these communities for habitat. Thus, the health and composition of the native plant communities is important for many of the species present in the park.

Data gaps for three of the five native vegetation communities featured in the NRCA prevent the determination of current condition or any trends that may be occurring over time. The juniper forests, floodplain woodlands, and upland shrublands components substantially lack data for most or all component measures to be able to determine current condition or any trends that may be occurring over time. Enough data were available to assign condition for the woody draws and

native grasslands components, both of which were determined to be of moderate concern. Both native grasslands and woody draws were determined to be of moderate concern due to the presence of invasive non-native species that threaten to alter native species composition and abundance in these two communities. Particularly aggressive species, such as leafy spurge and Canada thistle, are treated actively in both native communities to limit spread and shift of native composition. Non-native grasses (e.g., field brome and cheatgrass) also threaten the composition of the native grasslands throughout the park. Unfortunately, the lack of long-term community-specific monitoring data prevents the identification of any trends in condition over time for either woody draws or native grasslands in the park.

Disturbance Regimes

Disturbance regimes (e.g., fire, flooding, or erosion) can play a signicant role in the evolution and adaptation of vegetation communities across a landscape, as well as influence the current condition of these communities. In THRO, frequent burning of the landscape, by either natural-caused wildfires or prescribed fires, is an important factor in maintaining species composition in native vegetation communities, for example, by limiting the encroachment of woody shrubs and junipers into open areas and regenerating native grasslands. However, fire suppression has significantly altered the rate at which fires historically occurred in and around THRO. As a result, in order to obtain the beneficial effects of wildfires throughout the park, fire is managed heavily, with nearly all fires occurring as prescribed burns. Because of the high degree of planning and control of location, time of year, intensity, and frequency for burning to occur in THRO, fire was determined to be in good condition with a stable trend. Although fires are not as frequent on the landscape as they once were, current prescribed burn efforts aim to distribute fire throughout the park to benefit native plant communities.

Regular flooding events on the Little Missouri River also are important, particularly for the floodplain forest communities, where regular flooding and extended periods of inundation of the floodplain are necessary for the regeneration of cottonwood stands along the Little Missouri River. Without this regeneration, the cottonwood woodlands would age and slowly die away. This would effectively contribute to a decrease in important habitat for various breeding birds and raptors, among other associated impacts. As a component, flooding events along the Little Missouri River in THRO were determined to be of moderate concern. Of particular concern is the decreased frequency of periods of inundation in the floodplains, which are necessary for the regeneration of cottonwood stands in the floodplain woodlands along the river. In May 2011, the Little Missouri River experienced a 100-year flood event that left floodplains inundated for several weeks. This event and available data indicate that the trend for flooding is stable.

Other Biotics

Animals featured as NRCA components included prairie dogs and breeding birds. Prairie dog colonies are allowed to expand and contract naturally within park boundaries and active management is required only when disease threatens individual populations or when prairie dogs move into non-tolerance areas such as leach fields and corrals. Plague has been found sporadically in the park over the last several years, however, managers have little concern about the rates of colony growth and spread of disease. To date, no action has been taken to reduce plague when it occurs. Thus, praire dogs were determined to be in good condition with a stable trend. Breeding birds are also an important resource in the park, but significant data gaps make it impossible to determine condition of populations at this time.

Environmental Quality

Environmental quality is important in maintaining healthy functioning ecosystems. The health of terrestrial and aquatic organisms in parks can be affected substantially by the condition of air and water quality. Designated as a Class I airshed, THRO closely monitors air quality in the park. Current data suggest air quality is in good condition with a stable trend; this is in part likely due to THRO's location in rural North Dakota, away from any major population center. However, recent exponential growth in energy development around the park has the potential to impact air quality in the future through increased emissions and atmospheric deposition.

With the exception of a few sporadic, short-term sampling studies conducted throughout the years, consistent monitoring of basic water quality parameters is not performed within park boundaries. To understand the state of water quality in the park, managers must rely on monitoring stations established and maintained by other agencies. Historic and current data indicate that, in the stretches of the Little Missouri River that flow through the park, water quality is in good condition with a stable trend. However, certain elements of water quality are of particular concern, such as the high concentration of fecal coliform bacteria, which have warranted EPA 303[d] impaired waters listing for large sections of the Little Missouri River flowing through the park. Also of slight concern are higher measures of specific conductance, indicating high levels of dissolved solids in the Little Missouri River. Higher specific conductance in a waterway can occur naturally as a result of geology (such as a stream running through a highly erodible landscape) and water temperature (warmer water has higher conductivity than cold water). However, it is not clear how much natural variability contributes to specific conductance measures in the Little Missouri River in THRO and what may be contributed by development, agriculture, or other activities upriver from the park.

Park-wide Threats and Stressors

Several park-wide threats and stressors will continue to influence the condition of resources in THRO. Those of primary concern include establishment of non-native and invasive species, increased oil and gas industry development, and air pollution, especially increased emissions from nearby oil, gas, and powerplant development.

The presence of non-native and invasive species, especially plants, poses a significant threat for the native vegetation communities in THRO. Some invasive plant species present in THRO, such as leafy spurge and Canada thistle, have the ability to overtake native plant communities if left unchecked. Major changes in vegetation communities, from native to more non-native species, could have a significant impact on the animal species that use these communities for habitat. A more complete understanding of the prevalence of non-natives in the different vegetation communities throughout the park would help managers strategize about potential management actions.

Land development around THRO is mainly associated with the growth and expansion of the oil and gas industry. This development has increased exponentially in western North Dakota and around THRO over the last decade. Such development affects different aspects of park resources including impacts to viewscapes with the building of new structures that can be seen from various points in the park, impacts to soundscapes with increased industrial activity and vehicle traffic at development sites, and greater stresses to air quality from increased vehicle and industrial emissions.

Overall Conclusions

This assessment serves as a review and summary of available data and literature for featured natural resources in the park. The information presented here may serve as a baseline against which any changes in condition of components in coming years may be compared. Establishing a number of monitoring programs would begin to fill in data gaps for the resources viewed as important by THRO managers and would help managers better understand the current state of these resources throughout the park. Of those components that had sufficient available information, current condition was determined to be either good or of moderate concern. Understanding this can help managers prioritize management objectives and better focus conservation strategies.

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Appendix A: Fire History in THRO, 1946 to 2010

Fire Year	Fire Name	Fire Cause	Start Date	Park Unit[a]	Area	
					ac	ha
1946	EAST_ENTRANCE	HUMAN	3/28/1946	SU	14.0	5.7
1949	EAST_ENTRANCE	HUMAN	4/22/1949	SU	11.0	4.5
1949	EAST_ENTRANCE_#2	LIGHTNING	7/16/1949	SU	200.0	80.9
1951	BUCK_HILL_#3	LIGHTNING	8/17/1951	SU	38.0	15.4
1951	COOPER_PASTURE	LIGHTNING	8/17/1951	SU	1.0	0.4
1951	EAST_BORDER	LIGHTNING	8/17/1951	SU	19.0	7.7
1952	PAINTED_CANYON	HUMAN	10/16/1952	SU	1.0	0.4
1954	DEDICATION_HILL	HUMAN	8/14/1954	SU	3.0	1.2
1954	HEADQUARTERS_DUMP	HUMAN	7/26/1954	SU	1.0	0.4
1955	BUCK_HILL	COAL_SEAM	4/10/1955	SU	36.0	14.6
1955	NORTH_PADDOCK_CREEK	LIGHTNING	8/23/1955	SU	37.0	15.0
1955	SQUAW_CREEK	HUMAN	9/30/1955	NU	110.0	44.5
1956	CEDAR_CANYON	HUMAN	5/19/1956	SU	1.0	0.4
1957	CORRAL_CREEK	LIGHTNING	7/27/1957	NU	35.0	14.2
1958	NORTH_RIM	LIGHTNING		NU	5.0	2.0
1958	RIDGELINE	HUMAN	9/21/1958	SU	17.0	6.9
1959	BIG_PLATEAU_#1	LIGHTNING	6/7/1959	SU	2.0	0.8
1959	TWO	UNKNOWN	6/7/1959	SU	2.0	0.8
1962	APPLE_BOTTOM	LIGHTNING	8/21/1962	NU	1.0	0.4
1963	BOICOURT_SPRING	LIGHTNING	7/26/1963	SU	1.0	0.4
1963	GARLAND_BOTTOM	LIGHTNING	9/10/1963	NU	1.0	0.4
1963	MILLER_BOTTOM	UNKNOWN	5/21/1963	NU	1.0	0.4
1963	PAINTED_CANYON_OVERLOOK	HUMAN	10/25/1963	SU	1.0	0.4
1966	CORRAL_CREEK_PRAIRIE_DOG_TOWN	LIGHTNING	7/8/1966	NU	1.0	0.4
1966	JOHNSON'S_PLATEAU	HUMAN	5/30/1966	SU	1.0	0.4
1966	SHEEP_BUTTE	LIGHTNING	9/12/1966	SU	15.0	6.1
1967	PEACEFUL_VALLEY_PICNIC_AREA	HUMAN	10/22/1967	SU	1.0	0.4
1967	SHEEP_CREEK_#1	HUMAN	8/1/1967	SU	1.0	0.4
1967	SHEEP_CREEK_#2	HUMAN	8/17/1967	SU	1.0	0.4
1967	SHEEP_CREEK_#3	HUMAN	8/19/1967	SU	2.0	0.8
1967	SHEEP_CREEK_#4	HUMAN	8/31/1967	SU	1.0	0.4
1967	SQUAW_CREEK_CAMPGROUND	HUMAN	8/14/1967	NU	3.0	1.2
1968	STONE_HILLS	LIGHTNING	9/14/1968	NU	14.0	5.7
1974	RIDGELINE	HUMAN	7/14/1974	SU	2.0	0.8
1976	FIREWORKS	HUMAN	7/4/1976	SU	1.0	0.4
1976	GLACIAL_NORTH	HUMAN	7/26/1976	NU	1.0	0.4
1976	GLACIAL_SOUTH	HUMAN	7/27/1976	NU	1.0	0.4
1976	OVER_SPRING	HUMAN	7/24/1976	NU	2.0	0.8

Fire Year	Fire Name	Fire Cause	Start Date	Park Unit[a]	Area	
					ac	ha
1976	SPERATI_POINT	LIGHTNING	8/18/1976	NU	30.0	12.1
1977	HIGHWAY 85 WEST	HUMAN	5/13/1977	NU	1.0	0.4
1978	BUFFALO_CORRAL	HUMAN	5/22/1978	NU	9.0	3.6
1978	PLATEAU	LIGHTNING	8/22/1978	SU	275.0	111.3
1979	KNUTSON_CREEK	LIGHTNING	7/8/1979	SU	1.0	0.4
1979	TOWER_FIRE	LIGHTNING	6/30/1979	SU	80.0	32.4
1980	MAN_AND_GRASS	LIGHTNING	6/3/1980	NU	84.0	34.0
1980	PAINTED_CANYON	LIGHTNING	8/22/1980	SU	1.0	0.4
1981	PAINTED_CANYON	HUMAN	3/23/1981	SU	13.0	5.3
1981	ROUGHRIDER	HUMAN	3/13/1981	SU	8.0	3.2
1983	JOHNSON	HUMAN	8/25/1983	SU	100.0	40.5
1983	SQUAW_CREEK	HUMAN	4/24/1983	NU	1.0	0.4
1983	SQUAW_CREEK_DOG	LIGHTNING	8/28/1983	NU	1.0	0.4
1984	SQUAW_CREEK	HUMAN	8/8/1984	NU	3.0	1.2
1984	SU_ENTRANCE	PRESCRIBED		SU	0.0	0.0
1984	TUESDAY	LIGHTNING	8/14/1984	NU	10.0	4.0
1985	FATHERS_DAY	HUMAN	6/16/1985	SU	27.0	10.9
1985	NORTH_UNIT_CORRAL	PRESCRIBED	4/11/1985	NU	250.0	101.2
1988	BUCK_HILL	LIGHTNING	7/27/1988	SU	197.0	79.7
1988	SOUTH_UNIT_HEADQUARTERS	PRESCRIBED	4/19/1988	SU	2.0	0.8
1988	TR_CABIN	HUMAN	3/26/1988	SU	1.0	0.4
1989	PADDOCK_CREEK	LIGHTNING	8/30/1989	SU	1.0	0.4
1991	CHIP	LIGHTNING	6/29/1991	NU	1.0	0.4
1992	MAINTENANCE	HUMAN	7/5/1992	SU	1.0	0.4
1992	MEDIAN	HUMAN	2/25/1992	SU	1.0	0.4
1992	MEDIAN	HUMAN	2/25/1992	SU	1.0	0.4
1992	NORTH_UNIT_SLASH	PRESCRIBED	4/10/1992	NU	0.0	0.0
1992	TIMBERS	PRESCRIBED	2/14/1992	SU	0.0	0.0
1993	CORRAL	HUMAN	3/22/1993	SU	25.0	10.1
1993	RAMIREZ	HUMAN	4/17/1993	NU	1.0	0.4
1993	RESIDENCE 188C	HUMAN	12/22/1993	NU	1.0	0.4
1993	TRAP	LIGHTNING	3/3/1993	NU	6.0	2.4
1993	TRAP	LIGHTNING	3/3/1993	SU	6.0	2.4
1994	COTTON_#1	HUMAN	5/29/1994	SU	1.0	0.4
1994	COTTON_#2	HUMAN	5/29/1994	SU	1.0	0.4
1994	COTTON_#3	HUMAN	6/5/1994	SU	1.0	0.4
1994	HAYSTACK	HUMAN	4/21/1994	NU	1.0	0.4
1995	LEAVES	HUMAN	2/7/1995	SU	1.0	0.4
1995	LEAVES	HUMAN	2/7/1995	SU	1.0	0.4
1995	RESIDENCE_101	HUMAN	12/30/1995	SU	1.0	0.4

Fire Year	Fire Name	Fire Cause	Start Date	Park Unit[a]	Area	
					ac	ha
1996	INTERSTATE	LIGHTNING	6/8/1996	SU	6.0	2.4
1996	INTERSTATE	LIGHTNING	6/8/1996	SU	6.0	2.4
1996	SHUT_DOWN	HUMAN	1/13/1996	NU	1.0	0.4
1997	COTTON_#3	HUMAN	6/1/1997	SU	1.0	0.4
1997	RIVER_BEND	LIGHTNING	6/22/1997	NU	1.0	0.4
1997	RIVER_BEND	LIGHTNING	6/22/1997	NU	1.0	0.4
1997	UNKNOWN_2	HUMAN	6/20/1997	NU	1.0	0.4
1998	BOICOURT	LIGHTNING	8/10/1998	SU	15.1	6.1
1998	CHALKCLIFF	UNKNOWN	5/31/1998	NU	18.0	7.3
1998	CHASER	LIGHTNING	8/10/1998	SU	1.0	0.4
1998	NORTH_UNIT_HOUSING	LIGHTNING	8/14/1998	NU	1.0	0.4
1998	VOLUNTEER	LIGHTNING	8/10/1998	SU	2.0	0.8
1999	BURN_HILLS	HUMAN	7/30/1999	SU	1.0	0.4
1999	JOHNSON'S_PLATEAU	LIGHTNING	6/25/1999	SU	1.0	0.4
1999	LITTLE_MISSOURI	PRESCRIBED	9/21/1999	NU	504.3	204.1
1999	LITTLE_MISSOURI	PRESCRIBED	9/21/1999	NU	100.6	40.7
1999	PUMPKIN	UNKNOWN	10/23/1999	NU	1.0	0.4
1999	RAIL_CAR	LIGHTNING	6/25/1999	SU	1.0	0.4
1999	SE_CORNER	PRESCRIBED	4/19/1999	SU	304.8	123.3
1999	SE_CORNER	PRESCRIBED	4/19/1999	SU	167.6	67.8
1999	SOUTH_UNIT_HEADQUARTERS	PRESCRIBED	4/14/1999	SU	0.0	0.0
2000	BURLINGTON	HUMAN	10/10/2000	SU	2.0	0.8
2000	BURNT_TREE	LIGHTNING	9/19/2000	SU	1.0	0.4
2000	PAINTED_CANYON	LIGHTNING	8/28/2000	SU	277.6	112.3
2000	PETRIFIED	LIGHTNING	8/26/2000	SU	2.0	0.8
2000	SE_CORNER	PRESCRIBED	4/11/2000	SU	331.0	133.9
2000	WIND_CANYON	HUMAN	7/29/2000	SU	1.0	0.4
2001	ELKHORN_FIRE	LIGHTNING	8/31/2001	EHR	158.0	63.9
2001	NOTHWEST_CORNER	PRESCRIBED		NU	827.2	334.7
2002	INTERSTATE_94	PRESCRIBED	10/10/2002	SU	227.5	92.1
2002	INTERSTATE_94	PRESCRIBED	5/2/2003	SU	306.6	124.1
2002	KNUTSON_CREEK_RESEARCH	PRESCRIBED	4/24/2002	SU	0.0	0.0
2002	LITTLE_MISSOURI	PRESCRIBED	5/13/2002	NU	540.5	218.7
2002	MIX_PIT	UNKNOWN	8/16/2002	SU	1.0	0.4
2002	NORTHWEST_CORNER	PRESCRIBED		NU	160.0	64.7
2002	OLSEN_WELL_RESEARCH	PRESCRIBED	10/17/2002	SU	0.0	0.0
2002	PEACEFUL_VALLEY	PRESCRIBED	5/29/2002	SU	625.9	253.3
2002	SKYLINE_VISTA	PRESCRIBED	10/9/2002	SU	588.9	238.3
2002	SPAGHETTI	HUMAN	8/15/2002	SU	2.0	0.8
2003	BIGHORN	LIGHTNING	9/14/2003	NU	2.0	0.8

Fire Year	Fire Name	Fire Cause	Start Date	Park Unit[a]	Area	
					ac	ha
2003	COTTONWOOD_CAMPGROUND	PRESCRIBED	4/24/2003	SU	155.5	62.9
2003	FA #1	UNKNOWN	9/5/2003	SU	1.0	0.4
2003	LOST_BISON	LIGHTNING	9/9/2003	NU	50.0	20.2
2003	SMOOTH_BROME_RESEARCH	PRESCRIBED	10/22/2003	SU	0.0	0.0
2003	WIND_CANYON	HUMAN	7/22/2003	SU	1.0	0.4
2004	JULES_CREEK	LIGHTNING	7/9/2004	SU	8.0	3.2
2004	SE_CORNER	PRESCRIBED	4/22/2004	SU	910.0	368.3
2006	MILE_36	LIGHTNING	8/10/2006	SU	1.0	0.4
2007	HORSECAMP	PRESCRIBED	4/24/2007	SU	92.1	37.3
2007	LOOP_1	PRESCRIBED	4/17/2007	SU	17.2	6.9
2007	LOOP_2	PRESCRIBED	4/17/2007	SU	24.5	9.9
2007	LOOP_3	PRESCRIBED	4/17/2007	SU	5.7	2.3
2007	LOOP_4	PRESCRIBED	4/17/2007	SU	43.9	17.7
2007	LOOP_5	PRESCRIBED	4/24/2007	SU	40.3	16.3
2007	RADIOTOWER	PRESCRIBED	10/4/2007	SU	94.9	38.4
2008	CORRAL_FIRE	LIGHTNING	6/23/2008	NU	3.5	1.4
2008	LOOP_6	PRESCRIBED	4/13/2008	SU	38.8	15.7
2008	LOOP_7	PRESCRIBED	4/13/2008	SU	92.9	37.6
2008	LOOP_8	PRESCRIBED	4/13/2008	SU	19.7	8.0
2008	LOOP_9	PRESCRIBED	4/13/2008	SU	70.0	28.3
2008	NORTHWEST_CORNER_1	PRESCRIBED	10/9/2008	NU	68.9	27.9
2008	NORTHWEST_CORNER_2	PRESCRIBED	10/9/2008	NU	326.8	132.3
2008	NORTHWEST_CORNER_3	PRESCRIBED	10/9/2008	NU	296.8	120.1
2009	CAR 1	HUMAN	7/13/2009	SU	0.0	0.0
2009	ELKHORN_RANCH_1	PRESCRIBED	5/7/2009	EHR	2.9	1.2
2009	ELKHORN_RANCH_2	PRESCRIBED	5/7/2009	EHR	11.1	4.5
2009	ELKHORN_RANCH_3	PRESCRIBED	5/7/2009	EHR	4.1	1.6
2009	JUNIPER CAMPGROUND	PRESCRIBED		NU	150.0	60.7
2009	LOOP UNIT 1	PRESCRIBED		NU	10.8	4.4
2009	MUD FIRE	LIGHTNING	5/12/2009	NU	1.0	0.4
2009	NORTH_LOOP_BURN	PRESCRIBED	5/3/2009	NU	149.6	60.5
2010	SE_CORNER_6	PRESCRIBED	4/22/2010	SU	250.1	101.2
2011	SHEEP	PRESCRIBED	9/14/2011	NU	3641	1474
2011	LONGHORN FLATS	PRESCRIBED	9/16/2011	NU	460	186

[a] NU=North Unit, SU=South Unit, EHR=Elkhorn Ranch Unit

Appendix B: Peak Flow Data for the Little Missouri River at Medora, ND

Water Year	Gage Height (ft)	Streamflow (cfs)	Date of Peak Flow
1904	11.2	11,600	9-Jun-04
1905	10.2	8,500	2-Jul-05
1906	12	13,900	8-Jun-06
1907	16	29,000	24-Jun-07
1908	10.7	10,800	6-Jun-08
1909	11.5	12,400	31-May-09
1910	9.5	7,550	16-Mar-10
1911	8.6	5,540	17-May-11
1912	8.7	5,750	8-Jul-12
1913	n.d.	n.d.	n.d.
1914	6.3	1,850	3-Apr-14
1915	14.1	24,700	16-Jun-15
1916	9.1	6,630	16-Mar-16
1917	n.d.	n.d.	n.d.
1918	n.d.	n.d.	n.d.
1919	n.d.	n.d.	n.d.
1920	n.d.	n.d.	n.d.
1921	n.d.	n.d.	n.d.
1922	n.d.	n.d.	n.d.
1923	n.d.	n.d.	n.d.
1924	13.8	18,500	4-Apr-24
1925	n.d.	n.d.	n.d.
1926	n.d.	n.d.	n.d.
1927	n.d.	n.d.	n.d.
1928	n.d.	n.d.	n.d.
1929	17.2	38,700	7-Jun-29
1930	7	4,700	13-Sep-30
1931	4.52	1,610	22-Jun-31
1932	9.66	12,500	28-Apr-32
1933	12.44	20,800	24-May-33
1934	4.5	1,850	12-Jun-34
1935	n.d.	n.d.	n.d.
1936	n.d.	n.d.	n.d.
1937	n.d.	n.d.	n.d.
1938	n.d.	n.d.	n.d.
1939	n.d.	n.d.	n.d.
1940	n.d.	n.d.	n.d.
1941	n.d.	n.d.	n.d.

Water Year	Gage Height (ft)	Streamflow (cfs)	Date of Peak Flow
1942	n.d.	n.d.	n.d.
1943	n.d.	n.d.	n.d.
1944	n.d.	n.d.	n.d.
1945	n.d.	n.d.	n.d.
1946	8.75	9,310	24-Jun-46
1947	20.5	65,000	23-Mar-47
1948	13.5	24,100	23-Mar-48
1949	11.2	14,600	27-Mar-49
1950	13	25,600	8-Apr-50
1951	8.5	5,200	22-Mar-51
1952	17.32	42,500	8-Apr-52
1953	8.21	8,820	21-Jun-53
1954	5.99	4,320	7-Apr-54
1955	13.9	25,600	27-Jun-55
1956	4.05	2,030	27-Mar-56
1957	7.45	7,900	22-Jun-57
1958	5.9	5,050	4-Jul-58
1959	7.47	6,650	20-Mar-59
1960	8.72	8,100	22-Mar-60
1961	5.22	3,540	24-May-61
1962	9.85	10,800	30-May-62
1963	n.d.	11,000	3-Mar-63
1964	9.11	9,170	10-Jun-64
1965	n.d.	15,000	3-Apr-65
1966	7.98	6,800	14-Mar-66
1967	11.73	15,700	11-May-67
1968	5.35	3,000	7-Mar-68
1969	10	11,200	23-Mar-69
1970	7.31	6,550	9-May-70
1971	12.82	21,200	6-Jun-71
1972	18	40,000	11-Mar-72
1973	5.72	3,820	20-Jun-73
1974	6.9	5,230	21-May-74
1975	14	22,800	9-May-75
1976	n.d.	6,000	21-Jun-76
1977	n.d.	n.d.	n.d.
1978	n.d.	n.d.	n.d.
1979	n.d.	n.d.	n.d.
1980	n.d.	n.d.	n.d.
1981	n.d.	n.d.	n.d.

Water Year	Gage Height (ft)	Streamflow (cfs)	Date of Peak Flow
1984	n.d.	n.d.	n.d.
1985	n.d.	n.d.	n.d.
1986	n.d.	n.d.	n.d.
1987	n.d.	n.d.	n.d.
1988	n.d.	n.d.	n.d.
1989	n.d.	n.d.	n.d.
1990	n.d.	n.d.	n.d.
1991	n.d.	n.d.	n.d.
1992	n.d.	n.d.	n.d.
1993	n.d.	n.d.	n.d.
1994	n.d.	n.d.	n.d.
1995	n.d.	n.d.	n.d.
1996	n.d.	n.d.	n.d.
1997	n.d.	n.d.	n.d.
1998	n.d.	n.d.	n.d.
1999	n.d.	n.d.	n.d.
2000	n.d.	n.d.	n.d.
2001	n.d.	7,840	12-Mar-01
2002	5.62	1,680	11-Jun-02
2003	7.46	2,500	18-Mar-03
2004	9.51	5,500	10-Mar-04
2005	11.41	7,680	30-Jun-05
2006	13.61	12,700	25-Apr-06
2007	11.77	9,110	9-Jun-07
2008	11.9	8,810	10-May-08
2009	16.43	20,800	19-Apr-09
2010	8.69	4,330	24-Mar-10
2011	20.39	35,100	25-May-11

Appendix C. Peak Flow Data for the Little Missouri River at Watford City, ND

Water Year	Gage Height (ft)	Streamflow (cfs)	Date of Peak Flow
1935	10.6	20,500	11-Jul-35
1936	8	8,800	10-Mar-36
1937	7.85	8,990	15-Jun-37
1938	9.4	14,600	15-Mar-38
1939	13.05	26,500	22-Mar-39
1940	6.83	4,270	23-Sep-11
1941	9	13,000	11-Jun-41
1942	9.59	12,600	11-Mar-42
1943	n.d.	25,000	22-Feb-43
1944	14.4	32,600	8-Apr-44
1945	14.4	30,000	14-Mar-45
1946	8.75	8,000	24-Feb-46
1947	24	110,000	25-Mar-11
1948	11.56	16,000	24-Mar-11
1949	13.7	26,000	28-Mar-49
1950	21.42	60,000	9-Apr-50
1951	13.82	18,000	27-Mar-51
1952	15.53	42,200	10-Apr-52
1953	7.68	7,650	22-Jun-53
1954	8.37	10,200	14-Jun-54
1955	9.96	17,600	28-Jun-55
1956	6	2,770	30-Jul-56
1957	7.8	6,890	23-Jun-57
1958	9.94	12,000	25-Mar-58
1959	10.13	12,800	20-Mar-59
1960	9.83	18,900	22-Mar-60
1961	3.76	2,920	25-May-61
1962	6.71	12,100	31-May-62
1963	n.d.	10,000	5-Mar-63
1964	7.82	12,000	5-Jul-64
1965	n.d.	20,000	10-Apr-65
1966	7.06	12,000	12-Mar-66
1967	16.07	30,000	22-Mar-67
1968	6.38	7,900	1-Mar-68
1969	8.04	15,300	23-Mar-69
1970	7.3	13,400	9-May-70
1971	15.27	31,000	28-Mar-71
1972	14.68	52,800	13-Mar-72
1973	6.42	7,500	28-Feb-73
1974	5.45	6,750	21-May-74

Water Year	Gage Height (ft)	Streamflow (cfs)	Date of Peak Flow
1975	8.4	17,500	11-May-75
1976	6	7,600	24-Jun-76
1977	5.4	6,430	17-Jun-77
1978	11.08	31,500	30-Mar-78
1979	6.45	10,000	17-Apr-79
1980	3.09	865	14-Jun-80
1981	3.54	1,390	23-Oct-81
1982	n.d.	11,000	21-Feb-82
1983	8.41	13,500	23-Feb-83
1984	5.77	6,200	24-Jun-84
1985	5.1	4,540	24-Mar-85
1986	7.9	14,500	28-Feb-86
1987	5.47	6,740	1-Apr-87
1988	2.18	400	24-Mar-88
1989	7.44	5,000	11-Mar-89
1990	6.81	6,000	5-Mar-90
1991	8.15	8,900	15-Sep-91
1992	4.7	1,000	28-Feb-92
1993	n.d.	12,000	27-Jul-93
1994	11.79	10,000	6-Mar-94
1995	11.6	15,300	15-May-95
1996	17.23	10,000	15-Mar-96
1997	n.d.	20,500	22-Mar-97
1998	5.55	3,520	2-Apr-98
1999	6.31	4,960	16-Mar-99
2000	4.46	1,400	26-Feb-00
2001	n.d.	12,000	13-Mar-01
2002	4.91	2,360	23-Jun-02
2003	n.d.	8,000	17-Mar-03
2004	6.99	5,900	14-Mar-04
2005	8.01	6,770	2-Jul-05
2006	10.61	12,770	27-Apr-06
2007	8.21	8,710	10-Jun-07
2008	8.38	7,110	12-May-08
2009	13.68	20,800	21-Apr-09
2010	5.16	4,550	26-Mar-10
2011	16.70	34,000	27-May-11

Appendix D: Non-native Plant Species Documented in THRO

Non-native plant species documented in THRO through May 2011. A number of additional species are classified as "probably present" in the park or "unconfirmed" and are therefore not listed here. The full list can be found at http://science.nature.nps.gov/im/units/ngpn/monitor/exoticplant/docs/THRO_Park_Exotics.pdf.

Scientific Name	Common Name	Life cycle[1]	Growth form[2]	High priority?
Acroptilon repens	Russian knapweed	P	F	x
Agropyron cristatum	Crested wheatgrass	P	G	
Artemisia absinthium	Absinth wormwood	P	F-SS	x
Asparagus officinalis	Garden asparagus	P	F	
Asperugo procumbens	German-madwort	A	F	
Bassia scoparia	Burning bush	A	F	
Bromus inermis	Smooth brome	P	G	
Bromus arvensis	Field brome	A	G	
Bromus tectorum	Cheatgrass	A	G	x
Camelina microcarpa	Littlepod false flax	A-B	F	
Capsella bursa-pastoris	Shepherd's purse	A	F	
Cardaria draba	Whitetop	P	F	x
Carduus nutans	Musk thistle	B-P	F	x
Centaurea stoebe ssp. *micranthos*	Spotted knapweed	B-P	F	x
Ceratocephala testiculata	Bur buttercup	A	F	
Chenopodium album	Lambsquarters	A	F	
Chenopodium glaucum	Oakleaf goosefoot	A	F	
Cirsium arvense	Canada thistle	P	F	x
Cirsium vulgare	Bull thistle	B	F	x
Conringia orientalis	Hare's ear mustard	A	F	
Convolvulus arvensis	Field bindweed	P	F-V	x
Cynoglossum officinale	Houndstongue	B	F	x
Descurainia sophia	Flixweed	A-B	F	
Echinochloa crus-galli	Barnyard grass	A	G	
Elaeagnus angustifolia	Russian olive	P	S-T	x
Eragrostis cilianensis	Stinkgrass	A	G	
Erysimum cheiranthoides	Wormseed wallflower	A-B	F	
Euphorbia esula	Leafy spurge	P	F	x
Hyoscyamus niger	Black henbane	A-B	F	x
Lactuca serriola	Prickly lettuce	A-B	F	
Lappula squarrosa	European stickseed	A-B	F	
Lepidium perfoliatum	Clasping pepperweed	A-B	F	
Linaria vulgaris	Yellow toadflax	P	F	
Malva rotundifolia	Low mallow	A-B	F	
Medicago lupulina	Black medick	A-P	F	
Medicago sativa	Alfalfa	A-P	F	
Melilotus alba	White sweetclover	A-B-P	F	
Melilotus officinalis	Yellow sweetclover	A-B-P	F	
Nepeta cataria	Catnip	P	F	
Pennisetum glaucum	Pearl millet	A-P	G	
Poa compressa	Canada bluegrass	P	G	
Poa pratensis	Kentucky bluegrass	P	G	
Polygonum arenastrum	Oval-leaf knotweed	A-P	F	
Polygonum aviculare	Prostrate knotweed	A-P	F	
Polygonum convolvulus	Black bindweed	A	F-V	
Polygonum persicaria	Spotted ladysthumb	A-P	F	

Scientific Name	Common Name	Life cycle[1]	Growth form[2]	High priority?
Rumex crispus	Curly dock	P	F	
Rumex stenophyllus	Narrowleaf dock	P	F	
Salsola kali	Russian thistle	A	F	
Salsola tragus	Prickly Russian thistle	A	F	
Schedonorus pratensis	Meadow fescue	P	G	
Setaria viridis	Green foxtail	A	G	
Silene cserei	Balkan catchfly	B-P	F	
Silene latifolia ssp. *alba*	Bladder campion	B-P	F	
Sisymbrium altissimum	Tumbling mustard	A-B	F	
Sonchus arvensis	Perennial sowthistle	P	F	
Tamarix ramosissima	Saltcedar	P	S-T	x
Taraxacum officinale	Common dandelion	P	F	
Thlaspi arvense	Field pennycress	A	F	
Tragopogon dubius	Yellow salsify	A-B	F	
Trifolium repens	White clover	P	F	
Typha angustifolia	Narrowleaf cattail	P	F	
Ulmus pumila	Siberian elm	P	S-T	
Verbascum thapsus	Common mullein	B	F	x
Vicia sativa ssp. *nigra*	Garden vetch	A	F-V	

[1] A = Annual, B = Biennial, P = Perennial

[2] F = Forb, G = Graminoid, S = Shrub, SS = Subshrub, T = Tree, V = Vine

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Effect of stress induced by gathers and removals on reproductive success of feral horses

Michael C. Ashley and Dale W. Holcombe

Abstract Successful management of many species often relies on actions that involve intensive handling of individuals. Knowledge of how such handling may affect reproduction of a particular species is important and may be applicable to managing other species. We used pregnancy testing, field observation, Bureau of Land Management (BLM) records, and adopter surveys to determine effects of stress induced by gather and removal management practices on the reproductive success of feral horses in the Garfield Flat (GF) Herd Management Area (HMA) in Nevada. We analyzed pre-release confinement effect data from gathers conducted in August 1993 and January 1997 and data on the additional effect of removal in 1997. We used data for an ungathered population in the Granite Range HMA (GR) in Nevada as controls both years. Data from ungathered GR horses also were used as controls for habitat effects on reproduction. Granite Range and ungathered GF mares in 1997 had similar reproductive success rates (P=0.42). Pregnant removed mares in 1997 had less reproductive success than ungathered mares at GR (P=0.003) and GF (P=0.005). Gathered and released GF mares had less reproductive success than ungathered GF mares (P=0.05). The results suggest that minimizing time that mares are held prior to release will reduce fetal loss.

Key words abortion, horses, management, reproductive success, stress

In several studies, fetal loss in feral and domestic horses has been attributed to stress, often associated with frequent and extensive handling of pregnant mares (Mitchell 1971, Osborne 1975, Roberts 1986). Berger's (1983) study of feral horses in the wild found that forced copulation and social environment change after band takeovers in the Granite Range of Nevada caused abortions.

Most feral horse herds in the United States are managed intensively by the Bureau of Land Management (BLM, Boyles 1986). The Public Rangelands Improvement Act of 1978 authorized excess feral horse removal to preserve the quality of range habitat. Gathers and removals are the principal means to reduce populations to acceptable management levels (AML) for individual herd management areas (HMA; Boyles 1986). Each HMA is assessed by BLM range-condition specialists to determine stocking levels for livestock, feral horses, and game species. A 3- to 5-year interval between gathers and removals is necessary as many horse herds increase ≥20%/year (Wolfe 1980, Eberhardt et al. 1982, Berger 1986, Garrott and Taylor 1990). The removal magnitude depends on number of excess horses and the desired ending population size relative to the AML.

Gathers and removals may induce stress in several ways and for varying periods of time. Large-scale BLM gathers involve helicopter use to chase horses into a funnel trap leading to a corral. Trapped horses are individually restrained, aged, examined for physical

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condition, and segregated for removal or release as adult and juvenile males, lactating mares and foals, and nonlactating mares. *Ad libitum* food and water is provided in corrals to minimize nutritional stress.

Horses released after a gather typically have been held for 2 to 4 days at the capture site. Horses removed for adoption face longer periods of stress. From the capture site horses are trucked to a processing facility, often hundreds of km away. Here they are again individually restrained for blood sampling, aging, and freeze-branding. Some adoption occurs locally; however, many more horses are transported to satellite adoption centers across the country. Horses can spend months in confinement before adoption. We investigated the role that stress plays in reproductive failure following gathers and removals. We feel that the results of this study are valuable to BLM management and are applicable to managing large-bodied ungulates in general, when translocations involve extensive handling or long periods of confinement.

Study sites

For >20 years, BLM has actively managed feral horses at the Garfield Flat (GF) and Granite Range (GR) HMAs in the Great Basin by conducting periodic gathers and removals to control population size. Both areas are subject to cattle grazing. The vegetation at both study areas is predominantly mixed grass and shrubs at lower elevations. At higher elevations, pinyon pine (*Pinus monophylla*) and western juniper (*Juniperus occidentalis*) predominate at GF. Western juniper also occurs at higher elevations at GR with stands of quaking aspen (*Populus tremuloides*) at some springs. The 607-km^2 GF HMA, located in Mineral County in west-central Nevada, is bordered on the east, north, and west by the Garfield Hills and on the south by the Excelsior Mountains. The playa at GF is 1,700 m above sea level (asl), with the Garfield Hills and Excelsior Mountains each rising above 2,400 m asl (United States Department of Interior 1985). Water is available year-round from 4 springs and ephemerally from 4 small catchments, ≤100 m^2 each (Figure 1). The 411-km^2 GR HMA is located in Washoe and Lander counties in northwest Nevada in the Granite

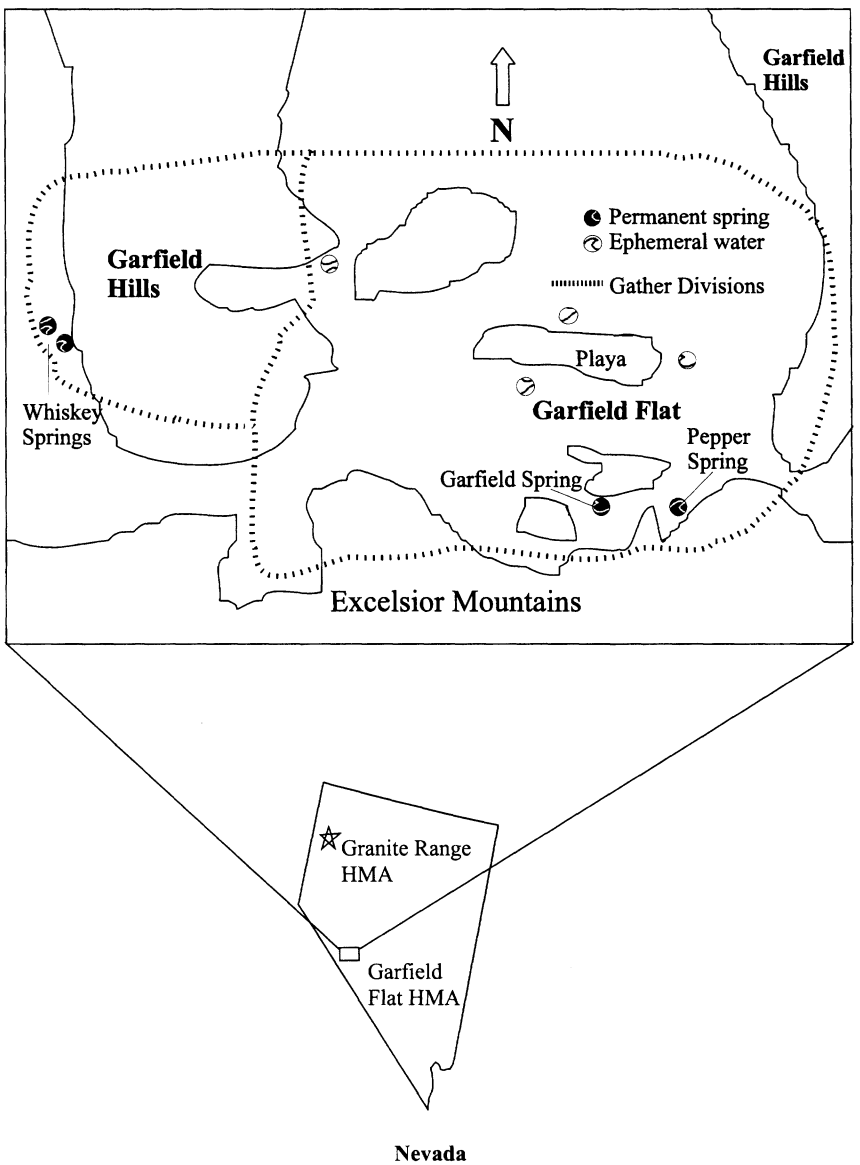


Figure 1. Locations of study sites and representation of the Garfield Flat Herd Management Area, including locations of available water and division of the HMA for the 1993 gather.



A mare being herded toward a squeeze chute for tissue collection and freeze-branding at the 1993 gather.

Range Mountains. Elevations range from 1,200 m asl in the surrounding lowlands to 2,735 m asl at Granite Peak (United States Department of Interior 1981). At this site, water is available year-round from numerous permanent springs and ephemeral ponds ranging from 50 to >400 m^2 in size.

Materials and methods

Gathers and removals

The first gather at GF was conducted in August 1993. The second occurred in January 1997. For both, a helicopter, drift fence, and funnel trap were used to capture horses. In the 1993 gather, resident horses in the eastern portion of the HMA were captured the first day and processed and released the second day. This procedure was repeated for horses in the western portion of the HMA on the following 2 days (Figure 1). Eighty-eight horses from the eastern area and 81 horses from the western area were captured, accounting for about 95% of the total HMA population. All horses gathered in 1993 were released except for 4 foals that were removed and one foal that was destroyed because of injuries. In 1997, horses were captured from the entire HMA over a 2-day period. Processing started immediately and continued for 2 days post-capture, culminating with the release of horses not shipped for adoption. The released horses were held 3 or 4 days, depending on capture order. Horses removed for adoption were trucked on days 3 and 4 to the Palomino Valley Center (PVC), a BLM adoption and processing center 246 km from the study site. Horses from the 1997 gather were examined and freeze-branded at PVC 2 weeks after the conclusion of the gather.

Horses appeared to be stressed at gathers, exhibiting agitated behavior. Confinement kept horses from different bands, groups of ≥1 adult female and any offspring attended by ≥1 adult male, at much closer quarters than we observed on the range. Mares too close to an unrelated foal were often threatened or kicked by the foal's mother. In contrast, we found that intra-band female–female aggression in the field was infrequent and limited to mild threats. Band spacing in the field generally precludes aggressive behavior. Inter-band aggression was usually observed between band stallions that often traveled >100 m to interact. Some bands were permanently disrupted after the release.

Tissue collection

In January 1997, we collected jugular blood samples at the gather site and at PVC in evacuated tubes from horses that would be ≥2 years old the following spring. We separated the serum component on site with a portable centrifuge (5,000 × g for 5 minutes) and stored the samples on ice for transport. We found that centrifugation at greater gravity than applied by Wolfe et al. (1989) efficiently separated the serum in less time. At the lab, we pipetted ≥1 ml serum/sample into individually labeled 1.5-ml microcentrifuge tubes and stored them at −80°C until samples could be assayed. Serum progesterone was determined using a solid phase radioimmunoassay kit (Coat-a-Count, kit #TKP6, Diagnostic Products Corporation, Los Angeles, Calif.; Wolfe et al. 1989). The coefficients of variation for progesterone were 8.1% for intra-assay and 9.7% for inter-assay results. Because nonpregnant mares generally do not cycle during the winter, we classified mares that had titers of ≥2 ng/ml serum progesterone as pregnant (Plotka et al. 1988).

Field methods

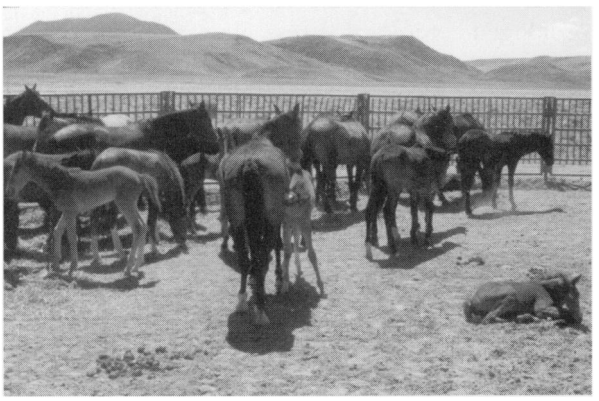
All released horses from both gathers at Garfield Flat were photographed and left-hip freeze-branded with unique numbers. Age (American Association of Equine Practitioners 1981), sex, and distinguishing marks were noted to aid in field identification. In February 1993 and November 1995 the BLM conducted gathers and removals at the GR HMA, releasing 359 and 123 freeze-branded horses, respectively. Identifying marks also were recorded for many of these horses.

We conducted intensive ground surveys of the GF and GR horses from March through August of

1994 and 1997 to assess reproductive success. Using 80-mm, 20X60-power spotting scopes, we identified horses by number and, when necessary, unique markings. To have reasonable confidence of accurately assessing reproductive success or failure, we only used data on mares that were sighted prior to, during, and after the prime foaling season, April to July. These sightings allowed us to assess whether an animal was visibly pregnant and whether a viable foal was produced. Mares classified as pregnant that were not accompanied by a foal by the end of August were scored as reproductive failures. We verified the foaling success or failure of all GF mares released after the 1997 gather. All successful pregnancies at both study sites were detected pre-partum in that surveyed mares seen with foals had been classified correctly as pregnant prior to foaling. Some of these mares at both sites were classified pregnant but were unaccompanied by foals at the end of the season. These reproductive failures of visibly pregnant mares may have included losses to mountain lions (*Puma concolor*) or coyotes (*Canis latrans*), even though we found no direct evidence of predation.

We assessed reproductive success for GR horses in 1994 and 1997 to serve as unmanipulated controls for the GF horses. The GR horses were gathered February 1993 and November 1995, early enough that there should have been no negative impacts on foaling in 1994 and 1997.

We collected GF removed mare reproductive success data in 1997 from BLM adoption records, adopter questionnaire, and telephone interviews with adopters. Unable to separate early foal death from fetal abortion in the field population, we included one stillborn, one death during birth, and the death after 1 day of a premature foal as evidence of reproductive failure for removed horses. In this tally, we also included 3 cases of pregnant removed mares that died prior to adoption. The BLM determined that the cause of these deaths was "poor condition" that could have been influenced by prolonged stress.



Segregated bands of lactating mares and foals at the 1993 gather.

Data analysis

Foaling success is a dichotomous event suitable for 2-by-2 contingency table analysis for pairwise comparisons. We used the 1-tailed Conditional Binomial Exact Test (CBET, Rice 1988) for these analyses, expecting that increased periods of stress would result in lesser foaling rates. This test is robust with moderate to small sample sizes and occasional small cell values.

The tests of differences in 1997 foaling success between gathered Garfield Flat mares and ungathered GR and GF mares are not equal comparisons, as the last 2 classes of mares were not tested for pregnancy. It is unlikely that all of the ungathered GR and GF mares assessed for foaling success were pregnant. Accordingly, this makes the comparisons of foaling success conservative tests.

Results

At GF, 45 (67.2%) of 67 marked mares foaled in 1994. These data represented all but 2 of the mares released in 1993 that would be ≥2 years old the following year. At GR, 20 (71.4%) of the 28 marked mares we surveyed foaled during the 1994 field season. Gathered and released GF mares had a foaling rate little different from GR mares (CBET: $P=0.43$). The minimum age of marked GR mares in 1994 was 4. Garfield Flat mares ≥4 years old ($n=34$) foaled at a greater rate (77.4%) than GR but did not differ significantly (CBET: $P=0.30$).

At the 1997 gather, released horses were held somewhat longer than in 1993, 3 to 4 days depending upon capture order. Removed horses were held ≥21 days before adoption. During the 14-day period prior to blood sampling at PVC, there were 15 to 18 spontaneous miscarriages as evidenced by shed fetuses (Sharon Kipping, PVC Manager, personal communication). One mare died that had a well-developed fetus *in utero*. Two pregnant mares died at interim locations before being adopted.

We pregnancy-tested 21 mares that were released at GF in 1997 and found 18 (85.7%) pregnant. Ten of these mares (55.6%) foaled. Of the mares removed in 1997 (66 tested, 1 autopsied), 43 (64.2%)

were pregnant. We verified the reproduction of 37 pregnant mares with only 17 (45.9%) producing viable foals. We also collected resighting data to determine reproductive success of 17 ungathered mares at GF in 1997. Fourteen (82.4%) produced foals. That same season we identified 54 mares at GR and found that 40 (74.1%) produced foals.



Two bands in the field, summer 1996.

At GF in 1997, stress duration for the 3 classes of mares was 0 days for ungathered ($n = 17$), 3.5 days for gathered and released ($n = 18$), and 21 days for removed mares ($n = 37$). Pairwise comparisons of the 3 classes of mares showed that pregnant mares exposed to longer periods of stress had lesser reproductive success. The greatest difference in reproductive success was between ungathered and removed mares (CBET: $P = 0.005$). There also was a significant difference between ungathered and released mares (CBET: $P = 0.05$). There was, however, no significant difference between released and removed mares (CBET: $P = 0.26$).

The reproductive rates of GR and the ungathered GF horses did not differ (CBET: $P = 0.42$). Granite Range horses had a greater reproductive rate than the pregnant released mares at GF, but the difference was not significant (CBET: $P = 0.08$). As expected, GR horses had greater reproductive success than pregnant mares removed from GF (CBET: $P = 0.003$).

Discussion

The effect of gather-and-removal-induced stress on pregnant feral horses is reduction in foaling success, sensitive to the duration of the stressor. The GF horses that were removed for adoption were transported long distances and subjected to repeated handling. Long-distance transportation has been linked to abortions in 2-year-old domestic mares (Roberts 1986). Mitchell (1971) and Osborne (1975) associated abortions in yearling and 2-year-old domestic mares with extensive handling. Generally, high pregnancy rates for yearlings and 2-year-olds followed by fetal losses have been reported for domestic (Mitchell and Allen 1975) and feral horses (Lucas et al. 1991). The reproductive losses for GF mares, however, were spread across age classes.

Stress, whether acute or chronic, stimulates the release of cortisol and other adrenocorticoids in mammals (Yates and Urquhart 1962). For example, in studies of gray squirrels (*Sciurus carolinensis*, Guthrie et al. 1967) and snowshoe hares (*Lepus americanus*, Boonstra et al.1998), trapping stress elevated serum corticosteroids. Snowshoe hares produced smaller litters during the decline phase of their 10-year cycles because of chronic stress imposed by elevated predation (Boonstra et al. 1998). Decline in serum progesterone has been linked to acute stress (van Niekerk and Morgenthal 1982). Serum progesterone is critical to pregnancy maintenance (Ball 1993). It likely is that severe and chronic reduction of serum progesterone due to prolonged removal stress was responsible for spontaneous abortions at PVC and overall decrease in reproductive success. An examination of serum cortisol and progesterone levels in response to gathers and removals would provide a definitive causal relationship between stress and reduced reproductive success.

Band takeover is another possible source of stress for feral mares. Berger (1983) reported instances of harassment and forced copulation in the Granite Range by stallions that had taken over bands. The stress of forced copulation coupled with changes in social structure caused induced abortions in mares

less than 6 months pregnant (Berger 1983). During our 6 seasons of field work, we observed many cases of harassment but only one forced copulation. The sole forced copulation was performed by a resident band stallion upon an unreceptive yearling mare. Most harassment incidents, however, were performed by bachelor males directed at harem mares. We saw no cases of harassment or forced copulation by stallions that acquired new bands. Further study is necessary to better evaluate the potential effects of forced copulation, harassment, and change in social structure on reproduction.

Removals from managed herds reduce the number of young horses ≤ 5 years old. Interestingly, this has the effect of temporarily increasing the proportion of the more reproductively successful horses in the population (Garrott et al. 1991). Seemingly, this works at cross purposes to desired population sizes at or below AML. To counter this effect, horses of all ages or a greater proportion of prime-age horses should be removed. Additionally, timing of removals can be exploited to extend the period of reduced population size. Gathers conducted in September or October, after the foaling season (Garrott et al. 1991), would reduce the next year's reproduction by interrupting early-stage pregnancies at a time when successful re-impregnation is unlikely. Feral horses are protected federally, and the BLM is charged with maintaining the general health and well-being of those horses under its jurisdiction (Boyles 1986). Such pregnancy disruptions would achieve a temporary reduction in population growth without large impacts on mare condition due to the small resource investment in early-stage fetuses.

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Associate editor: *Ford*

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WILD HORSE AND BURRO COMPREHENSIVE ANIMAL WELFARE PROGRAM

PIM 2021-002
Permanent Instruction Memorandum

December 18, 2020

In Reply Refer To:
4700 (260) P

EMS TRANSMISSION 12/18/2020
Permanent Instruction Memorandum No. 2020- 002

To: All Headquarters Officials and Field Office Officials

Attn: State and Center Directors

From: Assistant Director, Resources and Planning

Subject: Wild Horse and Burro Comprehensive Animal Welfare Program

Program Area: Wild Horse and Burro Program

Purpose: The purpose of this Permanent Instruction Memorandum (PIM) is to re-affirm the Bureau of Land Management's (BLM's) longstanding commitment to ensure the humane treatment of wild horses and burros (WHB) in all on-range and off-range management activities through the Comprehensive Animal Welfare Program (CAWP). The humane treatment of wild horses and burros outlined in this policy reiterates the BLM's longstanding practices but also provides additional clarification to BLM employees. This PIM consolidates current humane practices, incorporates the existing Standard Operating Procedures (SOPs) outlined in Attachments 1 and 2 to ensure humane care and handling of the animals, and increases transparency concerning the humane treatment of wild horses and burros.

Policy/Action: The BLM is committed to continue protecting animal welfare and providing humane care and treatment to WHBs both on and off the range. Consistent with long-standing policies and practices, the handling and treatment provided by the BLM, its contractors, and its partners is based on compassion and concern for the animals' well-being at all times. Animals are managed and cared for to optimize animal condition, health, and safety.

All state, district, and field offices will continue to comply with the WHB CAWP policy within their jurisdiction at all times. The WHB CAWP policy includes:

1. CAWP Standards for Wild Horse and Burro Gathers (Attachment 1): These standards include requirements for trap and temporary holding facility design, capture and handling, transportation, and care after capture. The standards are also incorporated into helicopter gather contracts as specifications for performance.
2. Training for gather operations: All BLM staff associated with gather operations (incident commanders, contracting officer representatives, project inspectors, public affairs officials, and law enforcement officers) and contractor crews are required to complete online training annually for CAWP – Gathers (BLM-TC-4700-13), which is available through DOI Talent.
3. CAWP Standards for Off-Range Corral Facilities, Transportation, and Adoption/Sale Events (Attachment 2): This includes requirements for holding of animals in off-range corrals, transportation, and adoptions/sales events. These SOPs are incorporated into off-range corral contracts as specifications for performance.
4. Training for the Care, Handling, and Transportation of Wild Horses and Burros at off-range corrals and adoption/sales events: All personnel, including contractors and partners involved in the care, handling, and transportation of wild horses and burros at off-range

VIEW ALL POLICIES

ATTACHMENTS

COMPREHENSIVE ANIMAL WELFARE PROGRAM FOR WILD HORSE AND BURRO GATHERS (PDF / 409 KB)
CAWP STANDARDS OFF RANGE CORRAL TRANSPORT ADOPTION SALE EVENTS (PDF / 364 KB)

FISCAL YEAR

2021

corrals and adoption/sale events are required to complete online training annually. Development of this training will begin following issuance of this PIM.

5. CAWP Standards and SOPs (to be developed) for animals on the range, in off-range pastures, and public off-range pastures: All personnel, contractors, and partners involved in management of WHBs on the range, in off-range pastures, or public off-range pastures are required to complete online training annually following the development of these guidelines and SOPs.

The purpose of this PIM is to continue to ensure that the humane care and treatment of WHBs remains the priority for the BLM, its contractors, and its partners. The BLM will continue to use the best available science, husbandry, and handling practices applicable for WHBs. Whenever possible, the BLM will make improvements to its practices while also meeting planned objectives in accordance with current BLM policy, SOPs, as well as contractual and cooperative agreement requirements. The CAWP will be reviewed periodically by WHB program leadership and modified as necessary to strengthen public trust, transparency, and effectiveness in assuring the humane care and treatment of the WHBs.

The authorized officer is the primary party responsible for immediately addressing any actions that are inconsistent with the CAWP. Consistent with applicable BLM delegation of authority manuals, the authorized officer may delegate responsibility to an alternate individual. The authorized officer should promptly notify the employees, contractors, and partners of actions that are not compliant with the CAWP and correct all issues immediately. It is the responsibility of all individuals engaged in actions throughout the WHB program to implement all aspects of the CAWP.

The WHB CAWP Coordinator will lead the implementation, development, and modification of all aspects of the CAWP, including those developed to date as well as future components of the CAWP.

Timeframe: This policy is effective immediately.

Budget Impact: This PIM codifies long-standing policy, practice, and guidance to include mandatory annual training and reporting requirements for BLM personnel, contractors, and partners associated with gather operations. The cost for the required training is approximately $100 per person per year. This PIM also formalizes SOPs for off-range holding, adoptions, sales, and transportation of excess WHB. When fully developed, the CAWP program implementation, oversight, data compilation, and reporting requirements will require an additional 12 to 18 work months per year.

Background: Public Law-195, Wild Free-Roaming Horses and Burros Act of 1971 (as amended) and 43 CFR 4700.0-2 provide the authority for a CAWP for WHB.

This CAWP policy provides a comprehensive approach to long-standing policies and practices within the BLM WHB program. Despite these policies and practices, the BLM has been criticized by some animal protection organizations on its handling and care of wild horses and burros, especially during the gathering activities and transitioning of the horses from public lands to off-range facilities. Some of the criticisms include concerns as to the transportation conditions of the horses, facility design, environmental conditions, handling practices, and nutrition. Similar to policies adopted by other organizations in agricultural and animal research industries, this PIM establishes a framework to ensure there are programs in place to verify humane care and handling of animals. It provides transparency on how the animals are assured humane care and proper handling. This framework seeks to confirm that the WHB program is conducted in a humane and caring manner.

The CAWP for WHB consolidates and highlights the BLM policies, procedures, and ongoing commitment to protect animal welfare; provides training for employees, contractors, and partners on animal care and handling, and implements assessment tools to evaluate adherence to the CAWP SOP by the agency, contractors, and partners.

Manual/Handbook Sections Affected: This PIM affects policies in BLM Manual/Handbooks H-4700-1 “Wild Horse and Burro Management” and H-4750-2 “Adoption of Wild Horses and Burros”.

Coordination: This PIM was coordinated among HQ-100, HQ-200, HQ-260, HQ-600, Deputy State Directors, WHB State Leads, APHIS Veterinarian, WHB Facility Managers, and WHB Specialists.

Contact: If you have any questions, please contact the Wild Horse and Burro Division Chief, at 866-468-7826 or wildhorse@blm.gov.

Signed by:	Authenticated By:
David Jenkins	Ambyr Fowler
Assistant Director	Division of Regulatory Affairs (HQ-630)

Resources and Planning

2 Attachments

1. - CAWP Gather Standards (20 pp)
2. - Comprehensive Animal Welfare Program Standards for Off-Range Corrals, Transportation and Adoption/Sale Events (24 pp)

ATTACHMENT 1: COMPREHENSIVE ANIMAL WELFARE PROGRAM FOR WILD HORSE AND BURRO GATHERS

STANDARDS

Developed by

The Bureau of Land Management
Wild Horse and Burro Program

in collaboration with

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School of Veterinary Medicine

June 30, 2015

WELFARE ASSESSMENT STANDARDS for GATHERS

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STANDARDS

Standard Definitions

Major Standard: Impacts the health or welfare of WH&Bs. Relates to an alterable equipment or facility standard or procedure. Appropriate wording is "must," "unacceptable," "prohibited."

Minor Standard: unlikely to affect WH&Bs health or welfare or involves an uncontrollable situation. Appropriate wording is "should."

Lead COR = Lead Contracting Officer's Representative

COR = Contracting Officer's Representative

PI = Project Inspector

WH&Bs = Wild horses and burros

I. FACILITY DESIGN

A. Trap Site and Temporary Holding Facility

1. The trap site and temporary holding facility must be constructed of stout materials and must be maintained in proper working condition, including gates that swing freely and latch or tie easily. (**major**)
2. The trap site should be moved close to WH&B locations whenever possible to minimize the distance the animals need to travel.(minor)
3. If jute is hung on the fence posts of an existing wire fence in the trap wing, the wire should be either be rolled up or let down for the entire length of the jute in such a way that minimizes the possibility of entanglement by WH&Bs unless otherwise approved by the Lead COR/COR/PI. (minor)
4. Fence panels in pens and alleys must be not less than 6 feet high for horses, 5 feet high for burros, and the bottom rail must not be more than 12 inches from ground level. (**major**)

5. The temporary holding facility must have a sufficient number of pens available to sort WH&Bs according to gender, age, number, temperament, or physical condition. (**major**)
    a. All pens must be assembled with capability for expansion. (**major**)
    b. Alternate pens must be made available for the following: (**major**)
        1) WH&Bs that are weak or debilitated
        2) Mares/jennies with dependent foals
    c. WH&Bs in pens at the temporary holding facility should be maintained at a proper stocking density such that when at rest all WH&Bs occupy no more than half the pen area. (minor)
6. An appropriate chute designed for restraining WH&Bs must be available for necessary procedures at the temporary holding facility. This does not apply to bait trapping operations unless directed by the Lead COR/COR/PI. (**major**)
7. There must be no holes, gaps or openings, protruding surfaces, or sharp edges present in fence panels or other structures that may cause escape or possible injury. (**major**)
8. Padding must be installed on the overhead bars of all gates and chutes used in single file alleys. (**major**)
9. Hinged, self-latching gates must be used in all pens and alleys except for entry gates into the trap, which may be secured with tie ropes. (**major**)
10. Finger gates (one-way funnel gates) used in bait trapping must be constructed of materials approved by the Lead COR/COR/PI. Finger gates must not be constructed of materials that have sharp ends that may cause injuries to WH&Bs, such as "T" posts, sharpened willows, etc. (**major**)
11. Water must be provided at a minimum rate of ten gallons per 1000 pound animal per day, adjusted accordingly for larger or smaller horses, burros and foals, and environmental conditions, with each trough placed in a separate location of the pen (i.e. troughs at opposite ends of the pen). Water must be refilled at least every morning and evening. (**major**)
12. The design of pens at the trap site and temporary holding facility should be constructed with rounded corners. (minor)

13. All gates and panels in the animal holding and handling pens and alleys of the trap site must be covered with materials such as plywood, snow fence, tarps, burlap, etc. approximately 48" in height to provide a visual barrier for the animals. All materials must be secured in place.(**major**)

    These guidelines apply:

    a. For exterior fences, material covering panels and gates must extend from the top of the panel or gate toward the ground.(**major**)
    b. For alleys and small internal handling pens, material covering panels and gates should extend from no more than 12 inches below the top of the panel or gate toward the ground to facilitate visibility of animals and the use of flags and paddles during sorting. (minor)
    c. The initial capture pen may be left uncovered as necessary to encourage animals to enter the first pen of the trap. (minor)

14. Non-essential personnel and equipment must be located to minimize disturbance of WH&Bs. (**major**)
15. Trash, debris, and reflective or noisy objects should be eliminated from the trap site and temporary holding facility. (minor)

B. Loading and Unloading Areas

1. Facilities in areas for loading and unloading WH&Bs at the trap site or temporary holding facility must be maintained in a safe and proper working condition, including gates that swing freely and latch or tie easily. (**major**)
2. The side panels of the loading chute must be a minimum of 6 feet high and fully covered with materials such as plywood or metal without holes that may cause injury. (**major**)
3. There must be no holes, gaps or openings, protruding surfaces, or sharp edges present in fence panels or other structures that may cause escape or possible injury. (**major**)
4. All gates and doors must open and close easily and latch securely. (**major**)

5. Loading and unloading ramps must have a non-slip surface and be maintained in a safe and proper working condition to prevent slips and falls. Examples of non-slip flooring would include, but not be limited to, rubber mats, sand, shavings, and steel reinforcement rods built into ramp. There must be no holes in the flooring or items that can cause an animal to trip. (**major**)
6. Trailers must be properly aligned with loading and unloading chutes and panels such that no gaps exist between the chute/panel and floor or sides of the trailer creating a situation where a WH&B could injure itself. (**major**)
7. Stock trailers should be positioned for loading or unloading such that there is no more than 12" clearance between the ground and floor of the trailer for burros and 18" for horses. (minor)

II. CAPTURE TECHNIQUE

A. Capture Techniques

1. WH&Bs gathered on a routine basis for removal or return to range must be captured by the following approved procedures under direction of the Lead COR/COR/PI. (**major**)
   a. Helicopter
   b. Bait trapping
2. WH&Bs must not be captured by snares or net gunning. (**major**)
3. Chemical immobilization must only be used for capture under exceptional circumstances and under the direct supervision of an on-site veterinarian experienced with the technique. (**major**)

B. Helicopter Drive Trapping

1. The helicopter must be operated using pressure and release methods to herd the animals in a desired direction and should not repeatedly evoke erratic behavior in the WH&Bs causing injury or exhaustion. Animals must not be pursued to a point of exhaustion; the on-site veterinarian must examine WH&Bs for signs of exhaustion. (**major**)

2. The rate of movement and distance the animals travel must not exceed limitations set by the Lead COR/COR/PI who will consider terrain, physical barriers, access limitations, weather, condition of the animals, urgency of the operation (animals facing drought, starvation, fire, etc.) and other factors. (**major**)
    a. WH&Bs that are weak or debilitated must be identified by BLM staff or the contractors. Appropriate gather and handling methods should be used according to the direction of the Lead COR/COR/PI. (**major**)
    b. The appropriate herding distance and rate of movement must be determined on a case-by-case basis considering the weakest or smallest animal in the group (e.g., foals, pregnant mares, or horses that are weakened by body condition, age, or poor health) and the range and environmental conditions present. (**major**)
    c. Rate of movement and distance travelled must not result in exhaustion at the trap site, with the exception of animals requiring capture that have an existing severely compromised condition prior to gather. Where compromised animals cannot be left on the range or where doing so would only serve to prolong their suffering, euthanasia will be performed in accordance with BLM policy. (**major**)
3. WH&Bs must not be pursued repeatedly by the helicopter such that the rate of movement and distance travelled exceeds the limitation set by the Lead COR/COR/PI. Abandoning the pursuit or alternative capture methods may be considered by the Lead COR/COR/PI in these cases. (**major**)
4. When WH&Bs are herded through a fence line en route to the trap, the Lead COR/COR/PI must be notified by the contractor. The Lead COR/COR/PI must determine the appropriate width of the opening that the fence is let down to allow for safe passage through the opening. The Lead COR/COR/PI must decide if existing fence lines require marking to increase visibility to WH&Bs. (**major**)
5. The helicopter must not come into physical contact with any WH&B. The physical contact of any WH&B by helicopter must be documented by Lead COR/COR/PI along with the circumstances. (**major**)
6. WH&Bs may escape or evade the gather site while being moved by the helicopter. If there are mare/dependent foal pairs in a group being brought to a trap and half of an identified pair is thought to have evaded capture, multiple attempts by helicopter may

be used to bring the missing half of the pair to the trap or to facilitate capture by roping. In these instances, animal condition and fatigue must be evaluated by the Lead COR/COR/PI or on-site veterinarian on a case-by-case basis to determine the number of attempts that can be made to capture an animal.(**major**)

7. Horse captures must not be conducted when ambient temperature at the trap site is below 10ºF or above 95ºF without approval of the Lead COR/COR/PI. Burro captures must not be conducted when ambient temperature is below 10ºF or above 100ºF without approval of the Lead COR/COR/PI. The Lead COR/COR/PI will not approve captures when the ambient temperature exceeds 105 ºF. (**major**)

C. Roping

1. The roping of any WH&B must be approved prior to the procedure by the Lead COR/COR/PI. (**major**).
2. The roping of any WH&B must be documented by the Lead COR/COR/PI along with the circumstances. WH&Bs may be roped under circumstances which include but are not limited to the following: reunite a mare or jenny and her dependent foal; capture nuisance, injured or sick WH&Bs or those that require euthanasia; environmental reasons such as deep snow or traps that cannot be set up due to location or environmentally sensitive designation; and public and animal safety or legal mandates for removal. (**major**)
3. Ropers should dally the rope to their saddle horn such that animals can be brought to a stop as slowly as possible and must not tie the rope hard and fast to the saddle so as to intentionally jerk animals off their feet. (**major**)
4. WH&Bs that are roped and tied down in recumbency must be continuously observed and monitored by an attendant at a maximum of 100 feet from the animal. (**major**)
5. WH&Bs that are roped and tied down in recumbency must be untied within 30 minutes. (**major**)
6. If the animal is tied down within the wings of the trap, helicopter drive trapping within the wings will cease until the tied-down animal is removed. (**major**)
7. Sleds, slide boards, or slip sheets must be placed underneath the animal's body to move and/or load recumbent WH&Bs. (**major**)

8. Halters and ropes tied to a WH&B may be used to roll, turn, position or load a recumbent animal, but a WH&B must not be dragged across the ground by a halter or rope attached to its body while in a recumbent position. (**major**)
9. Animals captured by roping must be evaluated by the on-site/on-call veterinarian within four hours after capture, marked for identification at the trap site, and be re-evaluated periodically as deemed necessary by the on-site/on-call veterinarian. (**major**)

D. Bait Trapping

1. WH&Bs may be lured into a temporary trap using bait (feed, mineral supplement, water) or sexual attractants (mares/jennies in heat) with the following requirements:
   a. The period of time water sources other than in the trap site are inaccessible must not adversely affect the wellbeing of WH&Bs, wildlife or livestock, as determined by the Lead COR/COR/PI. (**major**)
   b. Unattended traps must not be left unobserved for more than 12 hours. (**major**)
   c. Mares/jennies and their dependent foals must not be separated unless for safe transport. (**major**)
   d. WH&Bs held for more than 12 hours must be provided with accessible clean water at a minimum rate of ten gallons per 1000 pound animal per day, adjusted accordingly for larger or smaller horses, burros and foals and environmental conditions. (**major**)
   e. WH&Bs held for more than 12 hours must be provided good quality hay at a minimum rate of 20 pounds per 1000 pound adult animal per day, adjusted accordingly for larger or smaller horses, burros and foals. (**major**)
      1) Hay must not contain poisonous weeds, debris, or toxic substances. (**major**)
      2) Hay placement must allow all WH&Bs to eat simultaneously. (**major**)

III. WILD HORSE AND BURRO CARE

A. Veterinarian

1. On-site veterinary support must be provided for all helicopter gathers and on-site or on-call support must be provided for bait trapping. (**major**)

2. Veterinary support must be under the direction of the Lead COR/COR/PI. The on-site/on-call veterinarian will provide consultation on matters related to WH&B health, handling, welfare, and euthanasia at the request of the Lead COR/COR/PI. All decisions regarding medical treatment or euthanasia will be made by the on-site Lead COR/COR/PI. (**major**)

B. Care

1. Feeding and Watering
    a. Adult WH&Bs held in traps or temporary holding pens for longer than 12 hours must be fed every morning and evening with water available at all times other than when animals are being sorted or worked. (**major)**
    b. Water must be provided at a minimum rate of ten gallons per 1000 pound animal per day, adjusted accordingly for larger or smaller horses, burros and foals, and environmental conditions, with each trough placed in a separate location of the pen (i.e. troughs at opposite ends of the pen). . (**major**)
    c. Good quality hay must be fed at a minimum rate of 20 pounds per 1000 pound adult animal per day, adjusted accordingly for larger or smaller horses, burros and foals. (**major**)
        i. Hay must not contain poisonous weeds or toxic substances. (**majo**r)
        ii. Hay placement must allow all WH&Bs to eat simultaneously. (**major**)
    d. When water or feed deprivation conditions exist on the range prior to the gather, the Lead COR/COR/PI should adjust the watering and feeding arrangements in consultation with the onsite veterinarian as necessary to provide for the needs of the animals. (minor)
2. Dust abatement
    a. Dust abatement by spraying the ground with water must be employed when necessary at the trap site and temporary holding facility. (**major**)

3. Trap Site
    a. Dependent foals or weak/debilitated animals must be separated from other WH&Bs at the trap site to avoid injuries during transportation to the temporary holding facility. Separation of dependent foals from mares must not exceed four hours unless the Lead COR/COR/PI authorizes a longer time or a decision is made to wean the foals. (**major**)
4. Temporary Holding Facility
    a. All WH&Bs in confinement must be observed at least once daily to identify sick or injured WH&Bs and ensure adequate food and water. (**major**)
    b. Foals must be reunited with their mares/jennies at the temporary holding facility within four hours of capture unless the Lead COR/COR/PI authorizes a longer time or foals are old enough to be weaned during the gather. (**major**)
    c. Non-ambulatory WH&Bs must be located in a pen separate from the general population and must be examined by the BLM horse specialist and/or on-call or on-site veterinarian as soon as possible, no more than four hours after recumbency is observed. Unless otherwise directed by a veterinarian, hay and water must be accessible to an animal within six hours after recumbency.(**major**)
    d. Alternate pens must be made available for the following: (**major**)
        1) WH&Bs that are weak or debilitated
        2) Mares/jennies with dependent foals
    e. Aggressive WH&Bs causing serious injury to other animals should be identified and relocated into alternate pens when possible. (minor)
    f. WH&Bs in pens at the temporary holding facility should be maintained at a proper stocking density such that when at rest all WH&Bs occupy no more than half the pen area. (minor)

C. Biosecurity

1. Health records for all saddle and pilot horses used on WH&B gathers must be provided to the Lead COR/COR/PI prior to joining a gather, including: (**major**)
   a. Certificate of Veterinary Inspection (Health Certificate, within 30 days).
   b. Proof of:
      1) A negative test for equine infectious anemia (Coggins or EIA ELISA test) within 12 months.
      2) Vaccination for tetanus, eastern and western equine encephalomyelitis, West Nile virus, equine herpes virus, influenza, *Streptococcus equi*, and rabies within 12 months.
2. Saddle horses, pilot horses and mares used for bait trapping lures must not be removed from the gather operation (such as for an equestrian event) and allowed to return unless they have been observed to be free from signs of infectious disease for a period of at least three weeks and a new Certificate of Veterinary Examination is obtained after three weeks and prior to returning to the gather. (**major**)
3. WH&Bs, saddle horses, and pilot horses showing signs of infectious disease must be examined by the on-site/on-call veterinarian. (**major**)
   a. Any saddle or pilot horses showing signs of infectious disease (fever, nasal discharge, or illness) must be removed from service and isolated from other animals on the gather until such time as the horse is free from signs of infectious disease and approved by the on-site/on-call veterinarian to return to the gather. (**major**)
   b. Groups of WH&Bs showing signs of infectious disease should not be mixed with groups of healthy WH&Bs at the temporary holding facility, or during transport. (minor)
4. Horses not involved with gather operations should remain at least 300 yards from WH&Bs, saddle horses, and pilot horses being actively used on a gather. (minor)

IV. HANDLING

A. Willful Acts of Abuse

1. Hitting, kicking, striking, or beating any WH&B in an abusive manner is prohibited. (**major**)
2. Dragging a recumbent WH&B without a sled, slide board or slip sheet is prohibited. Ropes used for moving the recumbent animal must be attached to the sled, slide board or slip sheet unless being loaded as specified in Section II. C. 8. (**major**)
3. There should be no deliberate driving of WH&Bs into other animals, closed gates, panels, or other equipment. (minor)
4. There should be no deliberate slamming of gates and doors on WH&Bs. (minor)
5. There should be no excessive noise (e.g., constant yelling) or sudden activity causing WH&Bs to become unnecessarily flighty, disturbed or agitated. (minor)

B. General Handling

1. All sorting, loading or unloading of WH&Bs during gathers must be performed during daylight hours except when unforeseen circumstances develop and the Lead COR/CO/PI approves the use of supplemental light. (**major**)
2. WH&Bs should be handled to enter runways or chutes in a forward direction. (minor)
3. WH&Bs should not remain in single-file alleyways, runways, or chutes longer than 30 minutes. (minor)
4. Equipment except for helicopters should be operated and located in a manner to minimize flighty behavior . (minor)

C. Handling Aids

1. Handling aids such as flags and shaker paddles must be the primary tools for driving and moving WH&Bs during handling and transport procedures. Contact of the flag or paddle end of primary handling aids with a WH&B is allowed. Ropes looped around the hindquarters may be used from horseback or on foot to assist in moving an animal forward or during loading. (**major**)

2. Electric prods must not be used routinely as a driving aid or handling tool. Electric prods may be used in limited circumstances only if the following guidelines are followed:
    a. Electric prods must only be a commercially available make and model that uses DC battery power and batteries should be fully charged at all times. (**major**)
    b. The electric prod device must never be disguised or concealed. (**major**)
    c. Electric prods must only be used after three attempts using other handling aids (flag, shaker paddle, voice or body position) have been tried unsuccessfully to move the WH&Bs. (**major**)
    d. Electric prods must only be picked up when intended to deliver a stimulus; these devices must not be constantly carried by the handlers. (**major**)
    e. Space in front of an animal must be available to move the WH&B forward prior to application of the electric prod. (**major**)
    f. Electric prods must never be applied to the face, genitals, anus, or underside of the tail of a WH&B. (**major**)
    g. Electric prods must not be applied to any one WH&B more than three times during a procedure (e.g., sorting, loading) except in extreme cases with approval of the Lead COR/COR/PI. Each exception must be approved at the time by the Lead COR/COR/PI. (**majo**r)
    h. Any electric prod use that may be necessary must be documented daily by the Lead COR/COR/PI including time of day, circumstances, handler, location (trap site or temporary holding facility), and any injuries (to WH&B or human). (**major**)

V. TRANSPORTATION

A. General

1. All sorting, loading, or unloading of WH&Bs during gathers must be performed during daylight hours except when unforeseen circumstances develop and the Lead COR/CO/PI approves the use of supplemental light. (**major**)

2. WH&Bs identified for removal should be shipped from the temporary holding facility to a BLM facility within 48 hours. (minor)
    a. Shipping delays for animals that are being held for release to range or potential on-site adoption must be approved by the Lead COR/COR/PI. (**major**)
3. Shipping should occur in the following order of priority; 1) debilitated animals, 2) pairs, 3) weanlings, 4) dry mares and 5) studs. (minor)
4. Planned
5. transport time to the BLM preparation facility from the trap site or temporary holding facility must not exceed 10 hours. (**major**)
6. WH&Bs should not wait in stock trailers and/or semi-trailers at a standstill for more than a combined period of three hours during the entire journey. (minor)

B. Vehicles

1. Straight-deck trailers and stock trailers must be used for transporting WH&Bs. (**major**)
    a. Two-tiered or double deck trailers are prohibited. (**major**)
    b. Transport vehicles for WH&Bs must have a covered roof or overhead bars containing them such that WH&Bs cannot escape. (**major**)
2. WH&Bs must have adequate headroom during loading and unloading and must be able to maintain a normal posture with all four feet on the floor during transport without contacting the roof or overhead bars. (**major**)
3. The width and height of all gates and doors must allow WH&Bs to move through freely. (**major**)
4. All gates and doors must open and close easily and be able to be secured in a closed position. (**major**)
5. The rear door(s) of the trailers must be capable of opening the full width of the trailer. (**major**)
6. Loading and unloading ramps must have a non-slip surface and be maintained in proper working condition to prevent slips and falls. (**major**)

7. Transport vehicles more than 18 feet and less than 40 feet in length must have a minimum of one partition gate providing two compartments; transport vehicles 40 feet or longer must have at least two partition gates to provide a minimum of three compartments. (**major**)
8. All partitions and panels inside of trailers must be free of sharp edges or holes that could cause injury to WH&Bs. (**major**)
9. The inner lining of all trailers must be strong enough to withstand failure by kicking that would lead to injuries. (**major**)
10. Partition gates in transport vehicles should be used to distribute the load into compartments during travel. (minor)
11. Surfaces and floors of trailers must be cleaned of dirt, manure and other organic matter prior to the beginning of a gather. (**major**)

C. Care of WH&Bs during Transport Procedures

1. WH&Bs that are loaded and transported from the temporary holding facility to the BLM preparation facility must be fit to endure travel. (**major**)
    a. WH&Bs that are non-ambulatory, blind in both eyes, or severely injured must not be loaded and shipped unless it is to receive immediate veterinary care or euthanasia. (**major**)
    b. WH&Bs that are weak or debilitated must not be transported without approval of the Lead COR/COR/PI in consultation with the on-site veterinarian. Appropriate actions for their care during transport must be taken according to direction of the Lead COR/COR/PI. (**major**)
2. WH&Bs should be sorted prior to transport to ensure compatibility and minimize aggressive behavior that may cause injury. (minor)
3. Trailers must be loaded using the minimum space allowance in all compartments as follows: (**major**)
    a. 12 square feet per adult horse.
    b. 6.0 square feet per dependent horse foal.
    c. 8.0 square feet per adult burro.
    d. 4.0 square feet per dependent burro foal.

4. The Lead COR/COR/PI in consultation with the receiving Facility Manager must document any WH&B that is recumbent or dead upon arrival at the destination. (**major**)
    a. Non-ambulatory or recumbent WH&Bs must be evaluated on the trailer and either euthanized or removed from the trailers using a sled, slide board or slip sheet. (**major**)
5. Saddle horses must not be transported in the same compartment with WH&Bs. (**major**)

VI. EUTHANASIA OR DEATH

A. Euthanasia Procedure during Gather Operations

1. An authorized, properly trained, and experienced person as well as a firearm appropriate for the circumstances must be available at all times during gather operations. When the travel time between the trap site and temporary holding facility exceeds one hour or if radio or cellular communication is not reliable, provisions for euthanasia must be in place at both the trap site and temporary holding facility during the gather operation. (**major**)
2. Euthanasia must be performed according to American Veterinary Medical Association euthanasia guidelines (2013) using methods of gunshot or injection of an approved euthanasia agent. (**major**)
3. The decision to euthanize and method of euthanasia must be directed by the Authorized Officer or their Authorized Representative(s) that include but are not limited to the Lead COR/COR/PI who must be on site and may consult with the on-site/on-call veterinarian. (**major**)
4. Photos needed to document an animal's condition should be taken prior to the animal being euthanized. No photos of animals that have been euthanized should be taken. An exception is when a veterinarian or the Lead COR/COR/PI may want to document certain findings discovered during a postmortem examination or necropsy. (minor)
5. Any WH&B that dies or is euthanized must be documented by the Lead COR/COR/PI including time of day, circumstances, euthanasia method, location, a

description of the age, gender, and color of the animal and the reason the animal was euthanized. (**major**)

6. The on-site/on-call veterinarian should review the history and conduct a postmortem physical examination of any WH&B that dies or is euthanized during the gather operation. A necropsy should be performed whenever feasible if the cause of death is unknown. (minor)

B. Carcass Disposal

1. The Lead COR/COR/PI must ensure that appropriate equipment is available for the timely disposal of carcasses when necessary on the range, at the trap site, and temporary holding facility. (**major**)
2. Disposal of carcasses must be in accordance with state and local laws. (**major**)
3. WH&Bs euthanized with a barbiturate euthanasia agent must be buried or otherwise disposed of properly. (**major**)
4. Carcasses left on the range should not be placed in washes or riparian areas where future runoff may carry debris into ponds or waterways. Trenches or holes for buried animals should be dug so the bottom of the hole is at least 6 feet above the water table and 4-6 feet of level earth covers the top of the carcass with additional dirt mounded on top where possible. (minor)

CAWP

REQUIRED DOCUMENTATION AND RESPONSIBILITIES OF LEAD COR/COR/PI

Required Documentation

Section	Documentation
II.B.5	Helicopter contact with any WH&B.
II.C.2	Roping of any WH&B.
III.B.3.a and III.B.4.b	Reason for allowing longer than four hours to reunite foals with mares/jennies. Does not apply if foals are being weaned.
III.C.1	Health status of all saddle and pilot horses.
IV.C.2.h	All uses of electric prod.
V.C.4	Any WH&B that is recumbent or dead upon arrival at destination following transport.
VI.A.5	Any WH&B that dies or is euthanized during gather operation.

Responsibilities

Section	Responsibility
I.A.10	Approve materials used in construction of finger gates in bait trapping
II.A.1	Direct gather procedures using approved gather technique.
II.B. 2	Determine rate of movement and distance limitations for WH&B helicopter gather.
II.B.2.a	Direct appropriate gather/handling methods for weak or debilitated WH&B.
II.B.3	Determine whether to abandon pursuit or use other capture method in order to avoid repeated pursuit of WH&B.
II.B.4	Determine width and need for visibility marking when using opening in fence en route to trap.
II.B.6	Determine number of attempts that can be made to capture the missing half of a mare/foal pair that has become separated.
II.B.7	Determine whether to proceed with gather when ambient temperature is outside the range of 10°F to 95°F for horses or 10°F to 100°F for burros.
II.C.1	Approve roping of any WH&B.
II.D.1.a	Determine period of time that water outside a bait trap is inaccessible such that wellbeing of WH&Bs, wildlife, or livestock is not adversely affected.
III.A.2	Direct and consult with on-site/on-call veterinarian on any matters related to WH&B health, handling, welfare and euthanasia.

III.B.1.e	Adjust feed/water as necessary, in consultation with onsite/on call veterinarian, to provide for needs of animals when water or feed deprivation conditions exist on range.
III.B.4.c	Determine provision of water and hay to non-ambulatory animals.
IV.C.2.g	Approve use of electric prod more than three times, for exceptional cases only.
V.A.1	Approve sorting, loading, or unloading at night with use of supplemental light.
V.A.2.a	Approve shipping delays of greater than 48 hours from temporary holding facility to BLM facility.
V.C.1.b	Approve of transport and care during transport for weak or debilitated WH&B.
VI.A.3	Direct decision regarding euthanasia and method of euthanasia for any WH&B; may consult with on-site/on-call veterinarian.
VI.B.1	Ensure that appropriate equipment is available for carcass disposal.

COMPREHENSIVE ANIMAL WELFARE PROGRAM

STANDARDS

OFF-RANGE CORRAL FACILITIES

TRANSPORTATION

ADOPTION EVENTS

Developed by

The Bureau of Land Management
Wild Horse and Burro Program

in collaboration with

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PREFACE

The Bureau of Land Management (BLM) estimates that 58,150 wild horses and burros (WH&Bs) are roaming on BLM-managed rangelands in 10 Western states, based on the latest data available, compiled as of March 1, 2015. Wild horses and burros have virtually no natural predators and their herd sizes can double about every four years. As a result, the agency must remove thousands of animals from the range each year to control herd sizes.

The Bureau of Land Management manages many off-range corral facilities throughout the U.S. The primary mission of the off-range corral facilities is to act as a holding and preparation facility that accepts WH&Bs from gather/removal operations and prepares them for adoption to the public or placement into off-range pastures. As of November 2015, there are 16,182 WH&Bs in off-range corral facilities.

The design of each facility is organized to handle large numbers of WH&Bs with pens, corrals, alleys, and loading/unloading areas that facilitate animal movement. There are multiple pens and corrals to sort animals for compatibility and care upon arrival to the facility. Each pen or corral offers all animals continuous water accessibility and quality feed on a daily basis.

The BLM strives to place horses removed from the range into private homes that provide quality care. Horses placed in off-range corral facilities are made available to the public for adoption or sale at adoption events held throughout the U.S. and through the BLM's Adopt or Sales Program (http://www.blm.gov/wo/st/en/prog/whbprogram/adoption_program/schedule.html). The off-range corral facility transitions WH&Bs to hay diets, performs necessary vaccinations and deworming procedures, provides hoof care and may train WH&Bs. Other WH&Bs, due to age, temperament, or other factors, may not be adopted or sold and subsequently are placed in off-range pastures. These facilities are designed to provide unadoptable wild horses with humane life-long care in a natural setting off the public rangelands. There are approximately 46,016 WH&Bs being cared for in off-range pastures (November 2015). All WH&Bs residing in both off-range corral facilities and off-range pastures, like those roaming Western public rangelands, are protected by the BLM under the 1971 Wild Free-Roaming Horses and Burros Act, as amended.

The BLM has been criticized by the public and animal protection organizations on their handling and care of wild horses and burros especially during the gathering activities and transitioning of the horses from public lands to off-range facilities. Some of the issues include the transportation conditions of the horses, facility design, environmental conditions, handling practices, and nutrition. Agricultural and research animal industries have developed assessment or auditing programs to verify humane care and handling of their industry's animals. These industries are performing both internal and 3rd-party audits for animal welfare to assure their stakeholders and provide transparency on how these animals are provided care and proper handling. Assessment programs based on standards have multifaceted benefits in providing education to employees and assurance to societal entities that their programs are responsible for properly handling and providing care for the animals. An assessment welfare program reported routinely to the public will increase transparency concerning the humane treatment of BLM's WH&Bs, as recommended by the 2008 US Government Accountability Office.

STANDARDS

Deficiency Definitions

Major Deficiency: impacts welfare of WH&Bs; usually is a procedure. Appropriate wording is "must," "unacceptable," "prohibited."

Minor Deficiency: a reporting deficiency (lack of, not enough detail) or involves an uncontrollable situation. Appropriate wording is "should."

WH&Bs = Wild horses and burros

SECTION 1.

OFF-RANGE CORRAL FACILITY STANDARDS

I. FACILITY PERSONNEL

A. Facility management establishes and implements standards of care, treatment, and handling of WH&Bs, and communicates expectations to all personnel to ensure the humane care and treatment of all WH&Bs at the facility. (**major**)

B. The facility must have employees with training, skills, and experience to observe, move, and handle the WH&Bs on the facility. (**major**)

C. The facility must have personnel that can properly maintain the working chute systems and facility infrastructure to provide for the safe housing, movement, and processing of the WH&Bs. (**major**)

D. The facility should be staffed by appropriate office staff for record maintenance and recording. (minor)

II. FACILITY DESIGN

A. Facilities must be operated in a manner to provide a safe, clean and supportive environment for all WH&Bs. (major)

B. WH&Bs must be allowed to exist in an undisturbed environment unless being prepared for health procedures, identification, adoption events, or transportation. (major)
C. All WH&Bs must have adequate space to move freely within a pen enclosure. (major)
D. The facility must have a sufficient number of pens available to sort WH&Bs according to sex, age, temperament, health status, or physical condition as needed. (major)
E. Facility fences, gates, alleys, tubs, and working chutes must be constructed of stout materials and must be maintained in proper working condition. (major)
F. Fences in pens, alleys, and working chute systems must be not less than 6 feet high for horses, 5 feet high for burros, and the bottom rail must not be more than 12 inches from ground level. (major)
G. Fences must be of stout design and be maintained in proper condition with no holes, gaps, or sharp edges which could result in WH&Bs being injured. (major)
H. All WH&Bs within a pen must have adequate dry space to rest. (major)
I. Ground surfaces in pens must be maintained to promote drainage, reduce wet ground conditions, and allow for routine manure removal. (major)
J. Watering systems in WH&B holding pens must provide unlimited access to clean water appropriate for livestock at all times. (major)
K. Feeding areas must be accessible to all WH&Bs in the enclosure and maintained as a dry area without excessive manure accumulation. (major)
L. An appropriate squeeze chute maintained in proper working order must be available for safely restraining WH&Bs for necessary procedures at the facility including hoof trimming. (major)
M. Facilities must provide access to shade and shelter (wind breaks) in pens designated for compromised animals needing special care (i.e., injured or weak animals). Additional provisions for shade and shelter (wind breaks) will be evaluated and determined by managers as appropriate for their region, the function of their facility and the condition of the animals under their care. (major)

N. Shelter structures should be designed or constructed to reduce the risk for injury of the WH&Bs and maintained to avoid excessive manure and mud. (minor)

III. RECEIVING WILD HORSES AND BURROS

A. Loading and Unloading Facilities

1. Facilities in areas for loading and unloading WH&Bs must be maintained in a safe and proper working condition, including gates and doors that swing freely and latch or tie easily as designed. (**major**)
2. The side panels of the loading chute must be a minimum of 6 feet high and covered with materials such as plywood or metal without holes that may cause injury. (**major**)
3. There must be no holes, gaps or openings, protruding surfaces, or sharp edges present in fence panels or other structures that may cause escape or possible injury. (**major**)
4. Loading and unloading ramps must have a non-slip surface and be maintained in a safe and proper working condition to prevent slips and falls. Examples of non-slip floors would include, but not be limited to, rubber mats, sand, shavings, and steel reinforcement rods or rough surfaces built into the ramp. There must be no holes in flooring or items that cause an animal to trip. (**major**)
5. Trailers must be properly aligned with loading and unloading chutes and panels with no gaps between the chute/panel and floor or sides of the trailer creating a situation where a WH&B could injure itself. (**major**)
6. Stock trailers should be positioned for loading and unloading such that there is no more than 12" clearance between the ground and floor of the trailer for burros and 18" for horses. (minor)

B. Receiving Procedures

1. All unloading of WH&Bs must be performed during daylight hours except when unforeseen circumstances develop and the Authorized Officer approves of the use of supplemental light. (**major**)

2. At the time of unloading, WH&Bs must be inspected by facility personnel to look for signs of infectious disease, sickness or injury and take appropriate steps if these conditions are observed. (**major**)
3. Any WH&B needing immediate veterinary attention must be identified and separated as necessary for examination, and a consultation with a veterinarian must be conducted within 4 hours. (**major**)
4. An authorized, properly trained, and experienced person, as well as euthanasia equipment and supplies, must be available immediately following unloading in the event that the emergency euthanasia of an animal is required. Euthanasia must be done in compliance with BLM Euthanasia policy. (**major**)
5. The receiving Authorized Officer must document any WH&B that is recumbent or dead upon arrival at the destination. (**major**)
6. Reporting of animals received from gather operations or from another BLM facility must be done in compliance with BLM policy. (**major**)
7. WH&Bs received from a gather must remain segregated from resident animals at the facility until a negative test for Equine Infectious Anemia (EIA) can be confirmed. (**major**)
8. Newly arrived WH&Bs must immediately be provided hay and water upon unloading. (**major**)
9. When WH&Bs are received from gather operations or from another facility, the receiving facility should unload them in a manner to minimize stress. (minor)
10. WH&Bs should be penned with WH&Bs of like age, sex, and temperament. (minor)
11. Newly arrived WH&Bs should be observed for signs that they may have difficulty transitioning to hay in a domestic setting. (minor)

IV. CARE OF WILD HORSE AND BURROS

A. Veterinarian

1. Routine presence by an on-site or on-call veterinarian must be provided at each facility with records of those visits maintained at the facility. (**major**)
2. A veterinarian must be available to collect and submit blood samples for Equine Infectious Anemia (EIA) testing and rabies immunization. (**major**)
3. Health care protocols must be in accordance with Program guidelines and accepted by the facility veterinarian for preventive health care procedures (vaccinations, deworming, hoof trimming, freeze marking). Medical treatments will be prescribed by or performed under the supervision of a veterinarian. Surgical procedures will only be performed by a veterinarian. (**major**)
4. WH&B deaths in a facility should be discussed with the facility veterinarian to review the probable causes of death. (minor)
5. If multiple animals die due to a related cause or unknown cause(s), a post-mortem examination or necropsy should be performed by the facility's on-call or on-site veterinarian to identify the cause of death where possible. Laboratory testing should be performed when possible to aid in determining the cause of death or related underlying factors that may be present when these are not readily apparent during the gross examination. (minor)
6. If a series of unexplained deaths occurs, facility quarantine measures must be considered with input from the attending veterinarian until the cause has been determined or when indicated until adequate bio-security measures are in place to prevent the spread of disease. Coordination with State and/or Federal Animal Health Officials in consultation with the attending veterinarian must be done if this occurs. (**major**)

B. Bio-Security

1. Authorized Officers must consult with the on-site or on-call veterinarian(s) to establish and review biosecurity and health care decisions. (**major**)

2. Newly arrived WH&Bs from gather operations must not be co-mingled with resident animals at the facility. (**major**)
3. Pens should be provided to segregate sick, infectious, injured, or weak WH&Bs from other healthy individuals in the facility when possible. (minor)
4. Hazardous or infectious biological waste (i.e., sharps, needles, blood samples, etc.) must be properly disposed in labeled containers. (**major**)
5. Working chute and tub systems should be routinely cleaned and disinfected to reduce the risk of disease transmission, especially after moving contagious WH&Bs through the system. (minor)

C. Feed and Water

1. Quality hay must be provided daily to WH&Bs in the amount of 2-3% of their body weight per day. **(major)**
2. Fresh, clean water appropriate for livestock must be accessible to WH&Bs located in holding pens at all times. (**major**)
3. Water troughs and watering systems must be checked daily to ensure they are clean and operating correctly. (**major**)
4. Feeding sites must allow all WH&Bs within a pen simultaneous access to hay. (**major**)
5. Newly arrived WH&Bs from gather operations may be fed grass hay and transitioned to alfalfa. (minor)
6. Salt and/or mineral blocks should be provided in holding pens at all times. (minor)
7. Supplemental feeds should be provided to address the nutritional needs of the WH&Bs, if needed. (minor)

D. Preparation Procedures

1. Facilities must identify individual WH&Bs and maintain inventories in accordance with BLM policy. This includes unmarked WH&Bs as well as those provided a freeze-mark. **(major)**
2. Facilities must conduct Equine Infectious Anemia (EIA) testing and apply freeze-marks within 30 days of receiving WH&Bs, unless directed by the facility veterinarian when age or physical condition requires a delay. (**major**)

3. WH&Bs receiving a freeze-mark must be recorded on the animal preparation record using the approved Signalment Key. (**major**)
4. Foals born in the facility should be freeze-marked no earlier than 3 months of age. (minor)
5. WH&Bs must be evaluated daily by facility personnel to identify animals in poor body condition, poor hoof condition, injured, or in need of veterinary evaluation/treatment, and/or supplemental feeding. (**major**)
6. Facilities must adhere to the current BLM vaccination policy. (**major**)
7. Foals must be tested for EIA and vaccinated when weaned or at 6 months of age. (**major**)
8. Hoof trimming must be performed twice per year at minimum or as necessary to maintain hooves in a proper condition. (**major**)
9. Castration of stallions and jack burros must be performed by a veterinarian using general anesthesia. If a surgical plane of anesthesia is not reached initially animals must be re-dosed or the procedure postponed until the problem can be resolved. (**major**)
10. Stallions and jack burros should be castrated as soon as approved by the on-site veterinarian for the procedure in accordance with BLM policy. (minor)
11. WH&Bs being prepared for freeze-marking, blood collection, vaccination, hoof trimming, sorting, and other care treatments should be handled to minimize stress and injuries (minor).

E. Euthanasia Procedures

1. The decision to euthanize and method of euthanasia must be directed by the Authorized Officer(s) who may consult with the on-site/on-call veterinarian. (**major)**
2. Euthanasia must be done in compliance with BLM Euthanasia policy. (**major**)
3. An authorized, properly trained, and experienced person, as well as euthanasia equipment and supplies, must be available at off-range corral facilities in the event that the emergency euthanasia of an animal is required. (**major**)

4. Any WH&B that dies or is euthanized must be documented including the circumstances, freeze brand ID if present, a description of the age, sex, color of the animal and the reason the animal was euthanized. A death record must be entered into the WHBPS. (**major**)
5. If an animal is euthanized due to an unknown cause, a post-mortem examination or necropsy should be performed by the facility's on-call or on-site veterinarian to identify the cause of death where possible. Laboratory testing should be performed when possible to aid in determining the cause of death or related underlying factors that may be present when these are not readily apparent during the gross examination. (minor)

F. Carcass Disposal

1. The Authorized Officer must ensure that appropriate procedures are in place for the timely disposal of carcasses when necessary at off-range corral facilities. (**major**)
2. Disposal of carcasses must be in accordance with applicable state and local laws. (**major**)

V. HANDLING WILD HORSES AND BURROS

A. Willful Acts of Abuse

1. Hitting, kicking, or beating any WH&Bs in an abusive manner is prohibited. **(major)**
2. Dragging a recumbent WH&Bs without a sled, side board or slip sheet is prohibited. Ropes used for moving the recumbent animal must be attached to the sled, slide board, or slip sheet. (**major**)
3. There should be no deliberate driving of WH&Bs into other animals, closed gates, panels, or other equipment. (minor)
4. There should be no deliberate slamming of gates and doors on WH&Bs. (minor)
5. There should be no excessive noise (e.g., constant yelling) or sudden activity causing WH&Bs to become unnecessarily flighty, disturbed or agitated. (minor)

B. General Handling

1. All sorting, loading or unloading of WH&Bs must be performed during daylight hours except when unforeseen circumstances develop and the Authorized Officer approves of the use of supplemental light. (**major**)
2. Halters and ropes tied to a WH&B may be used to roll, turn, position, or load a recumbent animal, but a WH&B must not be dragged across the ground by a halter or rope attached to its body while in a recumbent position. (**major**)
3. WH&Bs should be moved into and out of pens in a manner that will minimize stress and injury. (minor)
4. When possible, WH&Bs should be allowed to move at their own pace to new pens or sorting/handling locations. (minor)
5. WH&Bs should be handled to enter runways or chutes in a forward direction. (minor)
6. Any unattended WH&Bs or a single WH&B should not remain in single-file alleyways, runways or chutes longer than 30 minutes. (minor)
7. No equipment should be operated in such a manner as to cause flighty behavior or injury to WH&Bs. (minor)

B. Handling Aids

1. Handling aids such as flags and shaker paddles must be the primary tools for driving and moving WH&Bs during handling and transport procedures. Contact of the flag or paddle end of primary handling aids with a WH&B is allowed. Ropes looped around the hindquarters may be used from horseback or on foot to assist in moving an animal forward or during loading. **(major)**
2. Electric prods must not be used routinely as a driving aid or handling tool. Electric prods may be used in limited circumstances only if the following guidelines are followed:
    a. Electric prods must only be a commercially available make and model that uses DC battery power with batteries fully charged at all times. (**major**)
    b. The electric prod device must never be disguised or concealed. (**major**)

c. Electric prods must only be used after three attempts using other handling aids (flag, shaker paddle, voice or body position) have been tried unsuccessfully to move the WH&Bs. (**major**)
d. Electric prods must only be picked up when intended to deliver a stimulus; these devices are not constantly carried by the handlers. (**major**)
e. Space in front of an animal should be available for the WH&B to move forward prior to application of the electric prod. (**major**)
f. Electric prods must never be applied to the face, genitals, anus, or underside of the tail of a WH&B. (**major**)
g. Electric prods must not be applied to any one WH&B more than three times during a procedure (e.g., sorting, loading) except in extreme cases with the approval of the Authorized Officer. Each exception must be approved at the time by the Authorized Officer. (**major**)

SECTION 2.

TRANSPORTATION STANDARDS TO ANOTHER OFF-RANGE CORRAL FACILITY, OFF-RANGE PASTURE, ECO-SANCTUARY OR ADOPTION EVENT

I. LOADING AND UNLOADING FACILITIES

A. Facilities in areas for loading and unloading WH&Bs must be maintained in a safe and proper working condition, including gates and doors that swing freely and latch or tie easily as designed. (**major**)

B. The side panels of the loading chute must be a minimum of 6 feet high and covered with materials such as plywood or metal without holes that may cause injury. (**major**)

C. There must be no holes, gaps or openings, protruding surfaces, or sharp edges present in fence panels or other structures that may allow escape or cause possible injury. (**major**)

D. Loading and unloading ramps must have a non-slip surface and be maintained in a safe and proper working condition to prevent slips and falls. Examples of non-slip floors would include, but not be limited to, rubber mats, sand, shavings, and steel reinforcement rods or rough surfaces built into the ramp. There must be no holes in flooring or items that cause an animal to trip. (**major**)

E. Trailers must be properly aligned with loading and unloading chutes and panels with no gaps between the chute/panel and floor or sides of the trailer creating a situation where a WH&B could injure itself. (**major**)

F. Stock trailers should be positioned for loading and unloading such that there is no more than 12” clearance between the ground and floor of the trailer for burros and 18” for horses. (minor)

II.CARE OF WILD HORSES AND BURROS DURING TRANSPORT PREPARATION PROCEDURES

A. WH&Bs being transferred to another off-range corral facility, off-range pasture, eco-sanctuary or adoption event must have a current negative EIA test, be in a state of health appropriate for a Certificate of Veterinary Inspection (CVI), and be accompanied by appropriate paperwork as required by the laws of the receiving state. **(major)**

B. WH&Bs being transferred to another off-range corral facility, off-range pasture, eco-sanctuary or adoption event must be fit to endure the travel. (**major**)

    1. WH&Bs that are non-ambulatory, blind in both eyes, or severely injured must not be loaded and shipped unless it is to receive immediate veterinary care or euthanasia (**major**)

    2. WH&Bs that are weak or debilitated must not be transported without the approval of Authorized Officer in consultation with the on-site veterinarian. Appropriate actions for their care during transport must be taken according to the Authorized Officer. (**major**)

C. WH&Bs being transferred to another off-range corral facility, off-range pasture, eco-sanctuary, or adoption event must be sorted prior to shipping to ensure compatibility and minimize aggressive behavior that may cause injury during transport. (**major**)

D. Except for exceptional circumstances including but not limited to trap site adoptions, WH&Bs being offered for adoption should have received primary and booster vaccinations as well as deworming medications prior to adoption. (minor)

II. VEHICLES

A. Straight deck trailers or stock trailers must be used for transporting WH&Bs to another off-range corral facility, off-range pasture, eco-sanctuary or adoption event. **(major)**

    1. Two-tiered or double deck trailers are prohibited. **(major)**
    2. Transport vehicles for WH&Bs must have a covered roof containing them such that WH&Bs cannot escape. **(major)**

B. WH&Bs must have adequate headroom during loading and unloading and must be able to maintain a normal posture with all four feet on the floor during transport without contacting the roof. **(major)**

C. The width and height of all gates and doors must allow WH&Bs to move through freely. **(major)**

D. All gates and doors must open and close easily and be able to be secured in a closed position. **(major)**

E. Loading and unloading ramps of vehicles must have a non-slip surface and be maintained in a safe and proper working condition to prevent slips and falls. Examples of non-slip flooring would include, but not be limited to, rubber mats, sand, shavings, and steel reinforcement rods built into ramp. There must be no holes in the flooring or items that can cause an animal to trip. **(major)**

F. Transport vehicles more than 18 feet and less than 40 feet in length must have a minimum of one partition gate providing two compartments; transport vehicles 40 feet or longer must have at least two partition gates to provide a minimum of three compartments. **(major)**

G. Partition gates in transport vehicles should be used to distribute the load into compartments during travel. (minor)

H. All partitions and panels inside of trailers must be free of sharp edges or holes that could cause injury to WH&Bs. **(major)**

I. The inner lining of all trailers must be strong enough to withstand failure by kicking that would lead to injuries. **(major)**

J. Surfaces and floors of trailers must be cleaned of dirt, manure and other organic matter prior to the beginning of a shipping event, and must have non-skid material on the trailer floor, such as, wood shavings, rubber non-skid mats etc. **(major)**

III. TRANSPORT PROCEDURES

A. WH&Bs must be loaded at the following rates: **(major)**

1. 12 square feet per adult horse.
2. 6.0 square feet per dependent horse foal.
3. 8.0 square feet per adult burro or yearling horse.

4. 4.0 square feet per dependent burro foal

B. Planned drive time from off-range corral facility to another off-range corral facility, off-range pasture, eco-sanctuary, or adoption must not exceed 24 hours without unloading. (**major**)

C. Trucking companies or haulers must be provided directions and contact phone numbers for the facility or adoption location. **(major**)

D. A transportation event that is longer than 24 hours will require unloading and a minimum rest period of 8 hours with access to hay and water prior to being re-loaded and sent to the final destination. **(major**)

E. While in transit, WH&Bs must be observed by the transport driver a minimum of once every 8 hours. **(major)**

F. Non-ambulatory or recumbent WH&Bs must be evaluated on the trailer and either euthanized or removed from the trailers using a sled, slide board or slip sheet. (**major**)

G. WH&Bs should not be allowed to remain standing on straight-deck and stock trailers while not in transport for a combined period of greater than three (3) hours. (minor)

IV. RECEIVING PROCEDURES

See Section 1. Off-range Corral Standards, Part III. B. 1-5 and 8-11.

SECTION 3.

ADOPTION EVENT STANDARDS

I. ADOPTION EVENT PERSONNEL

A. BLM establishes and implements standards of care, treatment, and handling of WH&Bs, and communicates expectations to all personnel to ensure the humane care and treatment of all WH&Bs at the adoption event. **(major)**

B. The adoption event must have employees with training, skills, and experience to observe, move, and handle the WH&Bs at the event. **(major)**

C. The adoption event must have maintenance staff that can properly maintain the facilities to provide for the safe housing, movement, and processing of the WH&Bs. **(major)**

II. SATELLITE FACILITY DESIGN

A. All satellite facilities must be operated in a manner to provide a safe, clean and supportive environment for all WH&Bs. **(major)**

B. The satellite facility must have a sufficient number of pens available to sort WH&Bs according to sex, temperament, or physical condition as needed. (**major**)

C. The satellite facility's fences, gates, alleys, and working chutes must be constructed of stout materials and must be maintained in proper working condition. (**major**)

D. Fences in adoption pens, alleys, and working chute systems must not be less than 6 feet high for horses and 5 feet high for burros. (**major**)

E. Adoption pen fences must be of stout design and must be maintained in proper condition with no holes, gaps, or sharp edges that could result in WH&Bs being injured. (**major**)

F. Watering systems in WH&B adoption holding pens must provide unlimited access to clean water appropriate for livestock at all times. (**major**)

G. Adoption pen feeding areas must be accessible to all WH&Bs in the pen at the same time. (**major**)

H. Ground surfaces in adoption pens should promote drainage to reduce wet ground conditions. (minor)

I. WH&Bs in pens at the satellite facility should be maintained at a stocking density such that when at rest all WH&Bs occupy no more than half the pen area. (minor)

III. CARE OF WILD HORSES AND BURROS RECEIVED AT SATELLITE FACILITIES

A. Provisions to provide care by a veterinarian in a timely manner on-site, on call, or by transporting an animal to a veterinarian must be made in advance**. (major)**

B. Provisions for medical care (treatments including euthanasia if necessary) at adoption events will be made in accordance with BLM policy and carried out as described above for preparation facilities (Section 1. Off-range Corral Facility Standards, Part IV. A. 1-6). (**major**)

C. WH&Bs must be sorted upon arrival at adoption events into pens with animals of appropriate age and temperament such that animals can promptly begin a period of rest, eating, and drinking with limited disturbance. **(major)**

D. All WH&Bs must have adequate space to move freely within an adoption facility pen. **(major)**

E. WH&Bs, to the greatest extent possible, must be allowed to exist in an undisturbed environment after arriving at an adoption facility until the adoption event begins. **(major)**

F. Quality hay must be provided to WH&Bs in the amount of 2-3% of their body weight per day upon unloading following transport and daily during the adoption event. **(major)**

G. WH&Bs at adoption events may be supplemented with feed or water supplements to address the stress of transport. (minor)

H. WH&Bs will be sorted during the adoption event in a manner to reduce stress and opportunity for injury. (minor)

I. WH&Bs transported for more than 12 hours to an adoption event should be allowed a rest period of 5 hours or more prior to formal viewing by the adopting public. (minor)

IV. EUTHANASIA PROCEDURES AT SATELLITE FACILITIES

See Section 1. Off-range Corral Facility Standards, Part IV. E. 1-4.

V. CARCASS DISPOSAL AT SATELLITE FACILITIES

See Section 1. Off-range Corral Facility Standards, Part IV. F. 1-2.

VI. HANDLING WILD HORSES AND BURROS AT SATELLITE FACILITIES

A. Willful Actus of Abuse

See Section 1. Off-range Corral Facility Standards, Part V. A. 1-5

B. General Handling

See Section 1. Off-range Corral Facility Standards, Part V. B. 1-7

C. Handling Aids

See Section 1. Off-range Corral Facility Standards, Part V. C. 1-2

REQUIRED DOCUMENTATION AND RESPONSIBILITIES OF AUTHORIZED OFFICERS

REQUIRED DOCUMENTATION

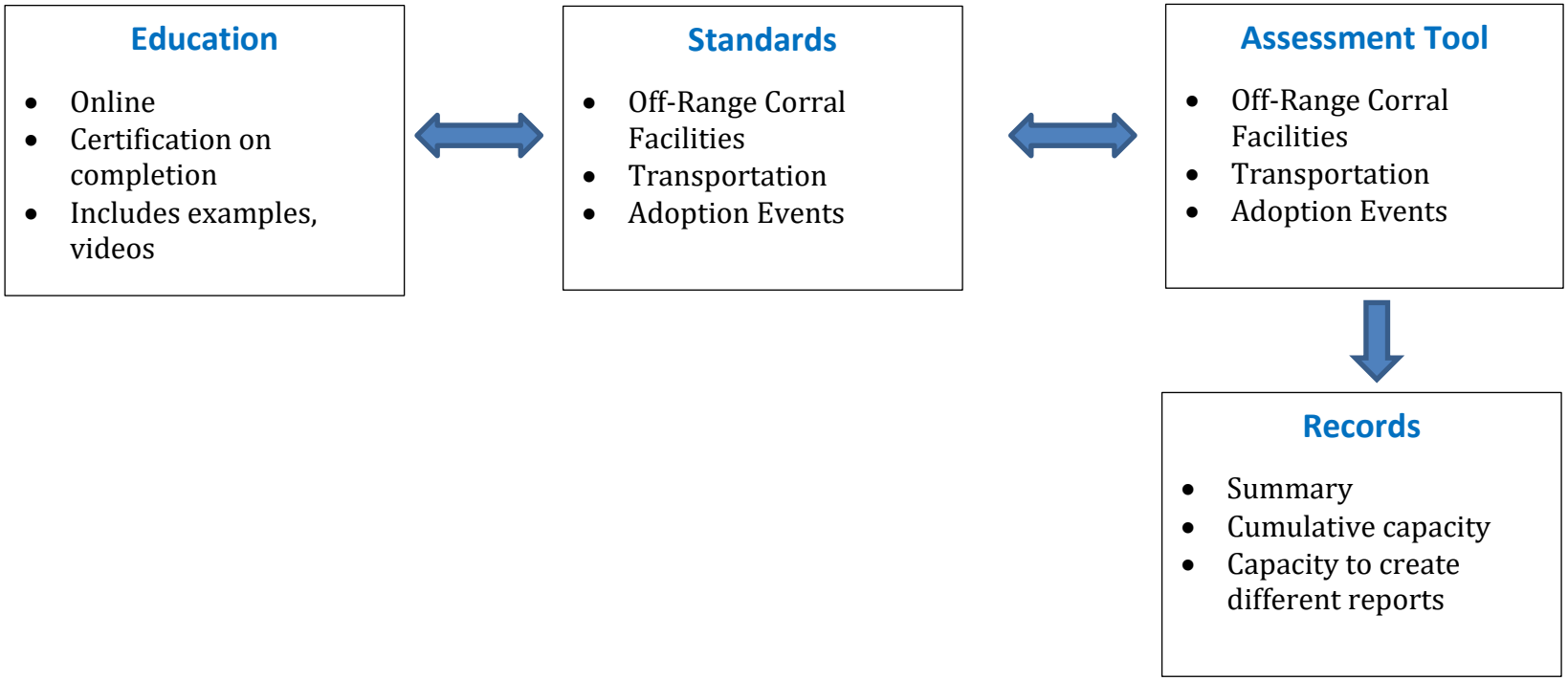
STANDARD	DOCUMENTATION
Section 1	**Off-Range Corral Facility Standards**
Part III. B. 5	Any WH&B that is recumbent or dead upon arrival at the destination
Part IV. A. 1	Record of visits by on-site/on-call veterinarian
Part IV. E. 4	Any WH&B that dies or is euthanized at facility, including the circumstances, freeze brand ID if present, a description of the age, sex, color of the animal and the reason the animal was euthanized. A death record must be entered into the WHBPS.
Section 2	**Transportation Standards**
Part V	Refer to Section 1. Off-range Corral Facility Standards, Part III. B. 5, as above.
Section 3	**Adoption Event Standards**
Part IV	Refer to Section 1. Off-range Corral Facility Standards, Part IV. E. 4, as above

RESPONSIBILITIES

STANDARD	RESPONSIBILITY
Section 1	**Off-Range Corral Facility Standards**
Parts III. B. 1 & V.B.1	Approve use of supplemental lighting when sorting, loading, or unloading WH&Bs
Part III. B. 5	Document any WH&B that is recumbent or dead upon arrival at the destination
Part IV. B. 1	Consult with on-site/on-call veterinarian to establish and review biosecurity and health care decisions
Part IV. E. 1	Direct decision regarding euthanasia and method of euthanasia for any WH&B; may consult with on-site/on-call veterinarian
Part IV. F. 1	Ensure that appropriate procedures are in place for carcass disposal
Part V. C. 2. g	Approve use of electric prod more than three times, for exceptional cases only

STANDARD	RESPONSIBILITY
Section 2	**Transportation Standards**
Part II. D	Approve of transport and care during transport for weak or debilitated WH&B
Section 3	**Adoption Event Standards**
Part VI. B	Refer to Section 1. Off-range Corral Facility Standard, Part IV.B.1, above.
Part VI. C	Refer to Section 1. Off-range Corral Facility Standard, Part V.C.2.g, above.

PROPOSED CAWP COMPONENTS FOR OFF-RANGE CORRAL FACILITIES, TRANSPORTATION, AND ADOPTION EVENTS



United States Government Accountability Office

GAO

Report to the Chairman, Committee on Natural Resources, House of Representatives

October 2008

BUREAU OF LAND MANAGEMENT

Effective Long-Term Options Needed to Manage Unadoptable Wild Horses



GAO-09-77

October 2008

BUREAU OF LAND MANAGEMENT

Effective Long-Term Options Needed to Manage Unadoptable Wild Horses

GAO Accountability • Integrity • Reliability

Highlights

Highlights of GAO-09-77, a report to the Chairman, Committee on Natural Resources, House of Representatives

Why GAO Did This Study

The Department of the Interior's Bureau of Land Management (BLM) manages about 33,100 wild horses and burros on 199 Herd Management Areas (HMA) in 10 western states. Under the Wild Free-Roaming Horses and Burros Act of 1971, as amended, BLM is to protect wild horses and burros, set appropriate management levels (AML), maintain current inventory counts, and remove excess animals to prevent overpopulation and rangeland damage. Over the years, various stakeholders have raised issues about BLM's management of the animals on and off the range.

GAO examined (1) BLM's progress in setting and meeting AML; (2) BLM's management of animals off the range through adoptions, sales, and holding facilities; (3) BLM's controls to help ensure the humane treatment of animals; and (4) what challenges, if any, BLM faces in managing for the long-term sustainability of the program. GAO surveyed and analyzed documents from 26 of the 44 BLM offices that manage wild horses and burros.

What GAO Recommends

To improve the program, GAO is recommending, among other things, that BLM establish a formal policy for setting AML, develop alternatives for long-term holding facilities, and initiate a discussion with Congress and other stakeholders on how best to comply with the act, as amended. The Department of the Interior concurred with GAO's findings and recommendations.

To view the full product, including the scope and methodology, click on GAO-09-77. For more information, contact Robin M. Nazzaro at (202) 512-3841 or nazzaror@gao.gov.

What GAO Found

BLM has made significant progress toward setting and meeting AML (the optimum number of animals which results in a thriving natural ecological balance and avoids range deterioration). BLM has set AML for 197 out of 199 HMAs. Most of the field offices GAO surveyed considered similar factors in determining AML, such as rangeland conditions; however, BLM has not provided specific formal guidance to the field offices on how to set AML. Without clear guidance, BLM cannot ensure that the factors considered in future AML revisions will be consistent across HMAs. At a national level, in 2007, BLM was closer to meeting AML (about 27,200 animals) than in any other year since AMLs were first reported in 1984. The extent to which BLM has actually met AML depends on the accuracy of BLM's population counts. Nineteen of the 26 field officials GAO surveyed used a counting method which, researchers say, consistently undercounts animals and does not provide a statistical range of population estimates. Undercounting can put animals at risk and lead to increased program costs.

The number of animals removed from the range is far greater than the number adopted or sold, which has resulted in the need for increased short-term and long-term holding. Since 2001, over 74,000 animals have been removed from the range, while only about 46,400 have been adopted or sold. Thirty-six percent fewer animals were adopted in 2007 than compared to the average adoption rates in the 1990s. As of June 2008, BLM was holding 30,088 animals in holding facilities, up from 9,807 in 2001. To accommodate the increased removals and declining adoptions and sales, BLM has increased the number of short-term and long-term holding facilities.

BLM has implemented multiple controls to help ensure humane treatment, including random checks on adopted horses and agreements with adopters and buyers to prevent slaughter. Although BLM state offices collect data on the treatment of the animals, BLM does not always compile the information in its central database or report it to the public. Providing additional information to the public on the treatment of these animals could help inform the public about their treatment and improve transparency.

The long-term sustainability of BLM's Wild Horse and Burro Program depends on the resolution of two significant challenges:

- *If not controlled, off-the-range holding costs will continue to overwhelm the program.* The percentage of the program's direct costs for holding animals off the range increased from $7 million in 2000 (46 percent) to $21 million in 2007 (67 percent). In 2008, these costs could account for 74 percent of the program's budget.
- *BLM has limited options for dealing with unadoptable animals.* The act provides that unadopted excess animals shall be humanely destroyed or, under certain circumstances, sold without limitation. However, BLM only manages these animals through sales with limitations. BLM is concerned about the possible reaction to the destruction of healthy animals.

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Abbreviations

AML appropriate management level
BLM Bureau of Land Management
HMA Herd Management Area

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GAO
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United States Government Accountability Office
Washington, DC 20548

October 9, 2008

The Honorable Nick J. Rahall, II
Chairman
Committee on Natural Resources
House of Representatives

Dear Mr. Chairman:

Wild horses have long been a symbol of the independence of the American West, but today, the health of their population depends heavily on government management. At their peak, in the mid-1800s, an estimated 2 million wild horses roamed America's rangelands. Populations decreased as development reduced habitat for wild horses and native grazers and as horses and burros were rounded up to make room for livestock and farming operations. By the early 1900s, most wild horses had disappeared from the Great Plains and those that remained were found primarily in the remote mountains, deserts, and badlands of the West. By 1971, only about 9,500 wild horses were thought to live on public rangelands. Public concerns about abuse and wild horse population declines swelled in the 1950s and 1960s. Subsequently, Congress enacted the Wild Free-Roaming Horses and Burros Act of 1971 to protect wild horses and burros from abuse and death and to manage them to achieve and maintain a thriving natural ecological balance on the public lands.[1] The 1971 act declared these wild animals to be "living symbols of the historic and pioneer spirit of the West; that they contribute to the diversity of life forms within the Nation and enrich the lives of the American people; and that these horses and burros are fast disappearing from the American scene." Since the passage of the act, wild horse and burro populations have increased, but the way they are managed on public lands has been controversial and wild horse advocates continue to voice concerns about horses being slaughtered.

The 1971 act authorized and directed the Secretary of the Interior, on public lands managed by the Bureau of Land Management (BLM), and the Secretary of Agriculture, on public lands managed by the Forest Service, "to protect and manage wild free-roaming horses and burros as

[1]Pub. L. No. 92-195, 85 Stat. 649 (1971) (codified as amended at 16 U.S.C. §§ 1331–1340).

components of public lands."[2] The act also directed the Secretaries to manage them "to achieve and maintain a thriving natural ecological balance on the public lands." BLM field offices are responsible for determining where the animals are to be managed within areas where they were found as of 1971.[3] In fiscal year 2007, the program was funded at $36.4 million under BLM's Management of Lands and Resources appropriation. Forty-four BLM field units manage approximately 33,100 wild horses and burros on 199 Herd Management Areas (HMA) covering over 34 million acres in 10 western states—Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, and Wyoming.[4] BLM's Nevada State Office manages about half of the land and animals in the Wild Horse and Burro Program.

In the mid- to late 1970s, population counts indicated that there was a large increase in wild horses and burros and that they were contributing to overgrazing of the rangeland. Congress amended the 1971 act in 1978 to protect the range from wild horse overpopulation, among other things. The Public Rangelands Improvement Act of 1978 directed the Secretaries of the Interior and Agriculture to determine appropriate management levels (AML), maintain a current inventory of wild horses and burros, and determine whether and where overpopulation exists.[5] AML has been defined as the "optimum number of wild horses which results in a thriving natural ecological balance and avoids deterioration of the range."[6] Each BLM field office is responsible for determining AML for each of the HMAs it manages. The aggregate AML for BLM's 199 HMAs is approximately 27,200. Because wild horse populations can double every 4 years and few

[2]This report focuses solely on BLM's Wild Horse and Burro Program. BLM is responsible for managing over 90 percent of the wild horses and burros on public lands. The Forest Service is responsible for managing 2,200 wild horses and about 300 burros in 37 Wild Horse Territories that cover about 2.5 million acres of Forest Service land.

[3]Shortly after the 1971 act, BLM conducted a wild horse and burro population census and estimated the number of wild horses to be about 17,300 and the number of wild burros to be about 8,000.

[4]The 44 BLM field units include 39 field offices, 4 district offices in Oregon, and 1 field station—the Tonopah Field Station in Nevada. We will refer to these 44 BLM field units collectively as field offices. BLM's count of the number of offices that manage HMAs may differ because the 4 district offices in Oregon manage 7 resource area offices.

[5]Pub. L. No. 95-514, § 14, 92 Stat. 1803, 1808 (1978) (amending 16 U.S.C. §§ 1332–1333).

[6]*Animal Protection Institute of America*, 109 IBLA 112, 119 (1989) (internal quotes omitted).

natural predators remain, managing wild horse and burro populations at AML has become a primary objective of the program. To reach and maintain AML, BLM primarily conducts "gathers" to remove excess animals from the range. From 1971 through 2007, over 267,000 wild horses and burros were removed.[7] In 2001, BLM began implementing its most recent management strategy, to reach AML by increasing removals. Since then, about 10,600 animals have been removed, on average, per year.

Maintaining current and accurate inventories of wild horses and burros is a key component of on-the-range management. BLM has traditionally counted animals using the direct-count method, which involves flying over the HMA and reporting on each individual animal they see. BLM generally conducts this type of animal count or "census" every 4 years or so, leading up to a removal of excess animals. To produce annual population estimates between counts, BLM adjusts these census figures for each HMA based on an estimate of the herd's annual population growth. If the census numbers are inaccurate, particularly if they underestimate the actual population, BLM runs the risk that adequate forage or water may not be available for the wild horses and burros or for livestock and wildlife in the area.

After being removed from the range, excess animals are managed in short-term holding facilities, where they are either prepared for adoption or sale, or in long-term holding facilities, where they will live out the remainder of their lives. The preferred outcome for healthy animals removed from the range is that they be adopted through BLM's Adopt-a-Horse-or-Burro Program. As of 2007, approximately 235,700 animals have been adopted by the public since the start of the program in 1971. On average, about 6,300 wild horses and burros have been adopted annually since 2001. Under the act, as amended, BLM is required to assure that adopters can provide humane treatment and care.[8] When adoption demand is not sufficient to absorb all the animals removed, the act, as amended, directs BLM to either destroy the remaining healthy animals in the most humane and cost-efficient manner possible or, under certain circumstances, sell

[7]This total does not include the number of burros removed from the range in 1981. BLM was not able to verify older data or estimate the number of burro removals for 1981. The total number of wild horses and burros that BLM could verify were removed from the range between 1971 and 2007 was 249,489. Officials verified that the number of animals removed between 1977 and 1980 was 18,009; however, they were unable to further specify this number by year or by species. When added together, this total equals 267,498.

[8]16 U.S.C. § 1333(b)(2)(B).

them without limitation.[9] BLM has not destroyed any animals since January 1982, when a former BLM director issued a moratorium to end the destruction of excess unadoptable animals. To manage for the growing number of unadoptable animals, BLM began opening long-term holding facilities. Unlike the rangelands of the West where the animals normally live, the long-term holding facilities use Midwest grasslands that generally provide the animals with abundant forage and decreased stress. This allows most of the animals to live far longer than they would in the wild. BLM pays the private contractors that operate the long-term holding facilities a fee per horse per day. The sales directive, which was enacted on December 8, 2004, directs BLM to sell excess wild horses and burros without limitation if the animal is more than 10 years of age or has been offered unsuccessfully for adoption at least three times.[10]

Since the passage of the 1971 act, there has been controversy over the number of wild horses and burros that BLM manages in the wild and the amount of public land available for their management. There is concern by some, including wild horse and burro advocacy groups, that the number of animals managed in the wild is too low to protect their genetic integrity; that the numbers are based on insufficient rangeland monitoring data; and that BLM gives preference to other users of the range, primarily livestock and wildlife. For instance, groups often point out that BLM permits far more cattle and sheep to graze on BLM managed lands than horses. Specifically, in fiscal year 2007, approximately 567,000 head of cattle or sheep grazed BLM public lands.[11] However, livestock are managed on 160 million acres of BLM lands, compared to the 29 million BLM acres that

[9]16 U.S.C. § 1333(b)(2)(C) (destroy excess animals for which an adoption demand does not exist) and 16 U.S.C. § 1333(e) (sell without limitation excess animals under certain circumstances).

[10]Pub. L. No. 108-447, Div. E, Title I, § 142, 118 Stat. 2809, 3070 (2004) (amending 16 U.S.C. § 1333). In 2005, shortly after the 2004 sales directive was enacted, legislation was introduced in the 109th Congress that would have prohibited the sale of wild horses and burros for processing into commercial products (H.R. 297 and S. 576). Neither of these bills were enacted. More recently, in the 110th Congress, H.R. 249 was introduced to prohibit the sale of wild horses and burros for processing into commercial products. The bill was passed by the House of Representatives on April 26, 2007. As of August 31, 2008, the Senate had not acted on the bill.

[11]The number 567,000 represents the cattle yearlong equivalent derived by dividing the actual number of animal unit months billed in fiscal year 2007 by 12 months. An animal unit month refers to the amount of forage needed to sustain an adult cow and her calf or horse for 1 month. In reality, few livestock grazing permits are issued for yearlong grazing.

are available for wild horses and burros.[12] Additionally, advocacy groups are concerned that the animals removed from the range are too often adopted into abusive homes or are ultimately sold for slaughter. Some livestock and wildlife groups argue that the population of wild horses and burros has far exceeded the level that provides ecological balance and equitable forage distribution for competing users, such as cattle and sage grouse.

We first reviewed BLM's Wild Horse and Burro Program in 1990.[13] At that time, regarding on-the-range management activities, we found that BLM's decisions on how many wild horses to remove from federal rangelands were not based on direct evidence that wild horse populations exceeded what the range could support and that removals were often not accompanied by reductions in livestock grazing levels or range management to increase the land's capacity. We recommended that BLM develop carrying capacity and range condition data and, in locations where overgrazing was occurring, that BLM implement range management techniques designed to give vegetation more opportunity to grow and, when necessary, remove wild horses and reduce livestock grazing in proportion to the numbers of each species on the range. Regarding off-the-range management activities, we found that "BLM's wild horse sanctuaries [long-term holding facilities] are likely to be much more expensive than originally envisioned and may represent only a temporary solution to the disposal of unadoptable horses.… If horse removals above levels that can be handled by private adoptions are reinstituted, other disposal options will have to be considered." We recommended that BLM consider a variety of disposal options for unadoptable horses and, as necessary, make recommendations for congressional consideration.

To update our 1990 report, we are reporting on (1) BLM's progress in managing wild horses and burros on the range through setting and meeting AML; (2) BLM's management of wild horses and burros off of the range through adoption, sales, and holding facilities; (3) the controls BLM has in place to help ensure humane treatment of wild horses and burros; and (4) what challenges, if any, BLM faces in managing the long-term sustainability of the Wild Horse and Burro Program. We were also asked to

[12]BLM manages wild horses and burros on 199 HMAs that are comprised of 29 million acres of BLM land and an additional 5.35 million acres of non-BLM land.

[13]GAO, *Rangeland Management: Improvements Needed in Federal Wild Horse Program*, GAO/RCED-90-110 (Washington, D.C.: Aug. 20, 1990).

review how and why the acreage available for wild horses and burros had changed since the 1971 act. We did not examine the acreage issue because BLM is in the process of compiling a history of acreage determinations. BLM officials expect their review to be completed by March 2009.

To examine how BLM manages wild horses and burros on and off of the range and to identify the challenges facing BLM, we reviewed relevant laws, regulations, BLM policies, and strategic plans. We also surveyed, and analyzed documents from, 26 of the 44 BLM field offices that manage wild horses and burros.[14] We collected and reviewed relevant resource management decision documents from the surveyed field offices to help corroborate their responses about specific questions, including those about factors used to make AML determinations and gather decisions. In addition, we also conducted follow-up phone calls to clarify ambiguous or incomplete survey responses. We received usable responses from all field offices that we surveyed—a 100 percent response rate. We surveyed field offices in all 10 western states that have HMAs. The field offices we surveyed represented 82 percent of all BLM acres managed for wild horses and burros, 74 percent of all BLM managed wild horses, and 69 percent of burros on the range at the time of our survey. We interviewed BLM Wild Horse and Burro Program managers at the state and national levels and conducted site visits at two field offices that manage HMAs, two adoption events, three short-term holding facilities, and one long-term holding facility. To examine humane treatment, we collected information from BLM's compliance database and interviewed public citizens, advocacy groups, and BLM officials. A more detailed description of our scope and methodology is presented in appendix I.

We conducted this performance audit from September 2007 to October 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[14]We drew our sample of 26 field units from among the 44 field units that manage HMAs, which include 39 field offices, 4 district offices in Oregon, and 1 field station in Nevada. BLM's count of the number of offices that manage HMAs may differ because the 4 district offices in Oregon manage 7 resource area offices.

Results in Brief

BLM has made significant progress in setting and meeting AML for the HMAs. As of February 2008, BLM has set AML for 197 out of 199 HMAs. Most of the field offices we surveyed considered similar factors in determining AML, such as rangeland conditions and climate data; however, BLM has not provided specific formal guidance to the field offices on how to set AML. BLM has been working on revising the program's handbook to provide this guidance since 2006. Without clear guidance, BLM cannot ensure that the factors considered in future AML revisions will be consistent across HMAs, especially since the personnel most familiar with the current, informal practice of determining AML are retiring at an increasing rate. At the national level, BLM was closer to meeting AML in 2007 than in any other year since AMLs were first reported in 1984. Specifically, in February 2007, BLM estimated the population of wild horses and burros to be 28,563, about 1,000 animals over AML. To reach this level, BLM has reduced the nationwide population in the wild by about 40 percent since 2000. Our 1990 report was critical of BLM's decisions on the number of wild horses and burros to remove from the range. At that time we concluded that the decisions were made without adequate information about range carrying capacity or the impact of the animals on range conditions. Since then, in August 2005, BLM updated its formal policy on gathers and removals and specified the key factors that should be considered in the decision making process. The extent to which BLM has actually met AML depends on the accuracy of its population counts. Nineteen of the 26 field officials we surveyed used the direct-count method for their most recent gathers. This method, according to researchers, consistently undercounts animals and does not provide a statistical range of population estimates. Some BLM officials are concerned that other counting methods would require too much additional staff or are too expensive. However, undercounting is also costly since it often leads BLM to remove fewer animals than needed, which leads to overpopulation and costlier gathers in the future. For example, in the summer of 2007, BLM staff on an HMA in Nevada miscalculated the population by approximately 640 wild horses and found that the actual population was about five times greater than what they determined was sustainable. Many of the wild horses subsequently removed from this HMA were in poor condition due to severe drought, and about 150 animals ultimately died from disease in short-term holding as a result.

The number of wild horses and burros removed from the range is far greater than the number adopted or sold, which has resulted in a significant increase in the number of animals in short- and long-term holding and commensurate increases in spending for their care. Since 2001, over 74,000 animals have been removed from the range, while only

about 46,400 have been adopted or sold. Thirty-six percent fewer wild horses and burros were adopted in 2007, compared to average adoption rates in the 1990s. BLM officials attribute the steady adoption decline in recent years to the decreasing demand for horses in general and increasing hay and fuel costs associated with their care. As of June 2008, BLM was holding 30,088 animals in short- and long-term holding facilities, far more than in 2001 when it held 9,807. From 2001 through June 2008, the number of short-term holding facilities increased from 14 to 24 to accommodate more animals, while the average cost per animal increased from $3.00 per day to $5.08 per day. The total cost for short-term holding increased from $6.4 million in 2000 to $11.2 million in 2001. From 2001 through 2007, the cost remained relatively stable, but for 2008, costs are anticipated to increase to $16.2 million. Similarly, BLM has increased the number of long-term holding facilities from 1 in 1988 to 11 as of June 2008, and the average cost per animal has increased to approximately $1.27 per day. Warnings issued in the 1990s by us and the Department of the Interior's Office of Inspector General about the potential for escalating costs for long-term holding have proven accurate, as spending on long-term holding has increased from about $668,000 in 2000 to more than $9.1 million in 2007. In addition, with the long-term holding facilities at full capacity—they held 22,101 wild horses as of June 2008 and had a capacity of 22,100—more wild horses are spending a longer time in the more expensive short-term holding facilities.

BLM has implemented multiple controls to help ensure the humane treatment of wild horses and burros, including standard operating procedures, random checks on adopted horses, and agreements with buyers to help prevent slaughter. For gathers, it has established standard operating procedures and reporting systems to help ensure humane treatment. According to data from 6 of the 10 states that manage wild horses and burros, 1.2 percent of animals removed from 2005 to 2007 were either euthanized or died accidentally. While BLM state offices sometimes collect data on animals that die during gathers, the information is not compiled by BLM headquarters in its centralized database, nor is it reported to the public. For animals held after removal in short- and long-term holding facilities, staff from BLM and veterinarians from the Department of Agriculture's Animal and Plant Health Inspection Service inspect facilities on a regular basis to help ensure adequate care and treatment are provided. For wild horses and burros that have been adopted, BLM guidance directs field offices to make follow-up phone calls or visits for all adopters during the first year of the adoption, physically inspect a random sample of adopted animals, and conduct inspections of adopted animals whenever complaints are received. According to the

results of BLM's random adoption inspections, from 2005 through 2007, on average about 9 percent of adopters did not comply with BLM standards of care for adopted wild horses and burros. The most common violations were failing to report changes in the animals' status or location to BLM and failing to provide adequate facilities or care. For animals that are sold, since the spring of 2005, BLM has required buyers to sign a statement that they do not intend to slaughter the animals. Although BLM tracks information about the treatment of animals in short- and long-term holding and after adoption, it does not regularly report this information to the public. Doing so could help inform the public about the treatment of the animals and improve transparency.

The long-term sustainability of BLM's Wild Horse and Burro Program depends on the resolution of two significant challenges:

- *If not controlled, off-the-range holding costs will continue to overwhelm the program*. The Wild Horse and Burro Program's spending for off-the-range holding increased from $7 million in 2000—46 percent of the program's direct costs—to about $21 million in 2007—67 percent of the program's direct costs. In 2008, BLM anticipates that holding costs will account for about 74 percent of the program's direct costs. As holding costs continue to increase, less funding is available for on-the-range management, which could result in sharp increases to the animal population in the wild. To deal with its long-term holding problem, BLM has primarily sought increased funding to open additional holding facilities. However, funding is not likely to increase in the future, and limited funding is forcing BLM to make the difficult choice among managing the animals on the range to prevent overpopulation, destroying excess unadoptable animals, or selling them without limitation. If funding is not increased or if BLM does not dispose of animals in other ways, BLM projects that the number of wild horses on the range would reach about 50,000, or about 80 percent over AML, by 2012.

- *BLM's options are limited for dealing with unadoptable animals*. The Wild Free-Roaming Horses and Burros Act, as amended, requires that excess animals, for which the adoption demand is not sufficient to absorb all the animals removed from the range, be destroyed in the most humane and cost-efficient manner possible or, under certain circumstances, be sold without limitation. From fiscal year 1988 through fiscal year 2004, Congress prohibited BLM from using its Management of Lands and Resources appropriations to destroy excess healthy, unadopted wild horses and burros, despite the amended act's directive to destroy excess animals. However, since the enactment of

the sales directive in 2004, which provided BLM with another means of disposal for these excess animals, Congress has appropriated funds to BLM without the prohibition. BLM has still chosen not to destroy or sell excess animals without limitation because of concerns about public and congressional reaction to the large-scale slaughter of thousands of healthy horses. However, by not destroying or selling them without limitation, BLM is not in compliance with the requirements of the act. Legislation is pending in the 110th Congress that would repeal the 2004 sales directive but not the requirement to destroy excess horses. As of June 2008, budget constraints have forced BLM to reconsider all of its options, including humane destruction and sales without limitations. BLM has not formally considered other possible solutions to deal with the current number of wild horses in long-term holding other than one pilot project in Wyoming. Some BLM officials suggested that other options are possible, such as placing nonreproducing animals on vacant BLM grazing allotments or on other federal lands, but these actions would require legislative changes.

To improve the management of BLM's Wild Horse and Burro Program, we are recommending that the Secretary of the Interior direct BLM to finalize and issue the new program handbook to ensure that AML determinations are based on consistent factors across HMAs into the future, improve the accuracy of population estimates by continuing to adopt statistically based methods to estimate animal populations, improve public access to data about the welfare of wild horses and burros removed from the range, and develop cost-effective alternatives to caring for wild horses removed from the range in long-term holding facilities. We are also recommending that the Secretary of the Interior direct BLM to initiate discussions with Congress to address BLM's noncompliance with the act. In commenting on a draft of this report, the Department of the Interior concurred with our findings and recommendations and provided several technical clarifications, which we have made as appropriate. Appendix IV presents the Department of the Interior's comment letter.

Background

During the 20th century, tens of thousands of wild horses were either killed or captured for slaughter on America's western ranges. Documented abuses suffered by wild horses led concerned individuals and national humane organizations to push for federal protections in the 1950s. Subsequently, Congress passed legislation in 1959 prohibiting the use of aircraft or motor vehicles to capture or kill wild horses or burros on public lands and polluting watering holes on public lands to trap, kill, wound, or maim wild horses or burros. Despite the 1959 act, wild horse exploitation continued, and some questioned whether the population would eventually be eradicated. To protect wild horses and burros, Congress passed additional legislation in 1971 to require the protection and management of wild free-roaming horses and burros on public lands. The 1971 act was amended in 1976, 1978, 1996, and 2004 (see table 1). The 2004 amendments directed BLM to sell, without limitation, excess animals more than 10 years of age or that have been offered unsuccessfully for adoption at least three times.

Table 1: Major Legislation Governing BLM's Wild Horse and Burro Program

Legislation	Date	Major relevant provisions
Public Law 86-234 (Wild Horse Annie Act of 1959)[a]	Sept. 8, 1959	Establishes criminal penalties for using an aircraft or motor vehicle to hunt wild horses or burros on public lands for capturing or killing and for polluting watering holes on public lands to trap, kill, wound, or maim wild horse or burros.
Public Law 92-195 (Wild Free-Roaming Horses and Burros Act of 1971)[b]	Dec. 15, 1971	Authorizes and directs the Secretaries of the Interior and Agriculture to protect and manage wild horses and burros as components of the public lands to achieve and maintain a thriving natural ecological balance. Authorizes the Secretaries, in areas found to be overpopulated, to order old, sick, or lame animals destroyed in the most humane manner possible and to capture or remove wild horses and burros under humane conditions and care. Authorizes the Secretaries to order wild horses and burros destroyed in the most humane manner possible when such action is deemed necessary to preserve and maintain the habitat in a suitable condition for continued use. The act also establishes criminal penalties for a number of offenses involving wild horses and burros.
Federal Land Policy and Management Act of 1976[c]	Oct. 21, 1976	Directs the Secretary of the Interior to prepare and maintain an inventory of public lands and their resources and other values and to, with public involvement, develop, maintain, and revise land use plans, which provide for the use of public lands. Directs the Secretary to manage the public lands under principles of multiple use and sustained yield. Authorizes the Secretaries of the Interior and Agriculture to contract for the use of helicopters and for using motor vehicles to transport captured animals after a public hearing and in accordance with humane procedures.

Legislation	Date	Major relevant provisions
Public Rangelands Improvement Act of 1978[d]	Oct. 25, 1978	Directs the Secretaries of the Interior and Agriculture to maintain a current inventory of wild horses and burros on given areas of public lands to determine whether and where overpopulation exists and whether to remove excess animals, the appropriate management levels, and whether appropriate management levels could be achieved by removal or destruction of excess animals or through other options. Directs the Secretaries, upon finding that an overpopulation exists and that action is necessary to remove excess wild horses and burros, to restore a thriving ecological balance by first destroying old, sick, and lame animals in the most humane manner possible; then humanely capturing and removing wild horses and burros for private maintenance and care for which an adoption demand exists by qualified individuals; and then destroying additional excess wild horses and burros in the most humane and cost-efficient manner possible. Authorizes the Secretaries, upon application, to grant title to excess wild horses and burros for which an individual provided humane conditions, treatment, and care for a period of 1 year. Provides that a wild horse or burro is no longer a wild horse and burro for purposes of the 1971 act once title has passed to an individual or in a number of other circumstances. No wild horse and burro or its remains may be sold or transferred for consideration for processing into a commercial product.
Omnibus Parks and Public Lands Management Act of 1996[e]	Nov. 12, 1996	Attempts to clarify the effect of the 1976 amendment, which authorized the Secretaries of the Interior and Agriculture to use helicopters and motor vehicles in the capture and transportation of animals.
Department of the Interior and Related Agencies Appropriations Act, 2005[f]	Dec. 8, 2004	Directs the sale, without limitation, of excess wild horses and burros, or their remains, if the animals are more than 10 years of age or have been offered unsuccessfully for adoption at least three times, until all excess animals are sold or until appropriate management levels are attained. It also provides that wild horses and burros, or their remains, once sold, are no longer wild horses and burros for the purposes of the 1971 act. Exempts animals sold under these provisions from the general prohibition under the 1971 act of processing the remains of wild horses and burros into commercial products.

Source: GAO analysis of laws pertinent to BLM's management of the Wild Horse and Burro Program.

[a]Pub. L. No. 86-234, 73 Stat. 470 (1959) (codified as amended at 18 U.S.C. § 47).

[b]Pub. L. No. 92-195, 85 Stat. 649 (1971) (codified as amended at 16 U.S.C. §§ 1331–1340).

[c]Pub. L. No. 94-579, 90 Stat. 2743 (1976). Specifically, section 404 (90 Stat. 2775) amended the 1971 act (codified as amended at 16 U.S.C. § 1338a).

[d]Pub. L. No. 95-514, § 14, 92 Stat. 1803, 1808 (1978) (amending 16 U.S.C. §§ 1332–1333).

[e]Pub. L. No. 104-333, Title VIII, § 803, 110 Stat. 4093, 4186 (1996) (amending 16 U.S.C. § 1338a).

[f]Pub. L. No. 108-447, Div. E, Title I, § 142, 118 Stat. 3039, 3070 (2004) (amending 16 U.S.C. § 1333).

The passage of the 1971 act changed the way BLM managed wild horses and burros on public lands. Rather than considering them as feral species that caused damage to the rangeland, the agencies had to change their mind-set to protect and manage the animals as an integral part of the ecosystem. One of the first tasks in managing the animals was to determine where they lived and their populations. According to the act, BLM is only authorized to manage wild horses and burros in areas where

they were found in 1971.[15] The areas where wild horses and burros were found, largely on public lands managed by the BLM and the Forest Service, as of the date of the act are called herd areas, and they comprise about 53.5 million acres. Once the exact land status and ownership of the herd areas was verified, it was determined that most herd areas were on BLM administered public lands, but some also included private and state-owned in-holdings. The 1971 act states that the Secretaries of the Interior and Agriculture shall arrange for the removal of wild horses and burros that stray onto private land upon notification by the owner.[16]

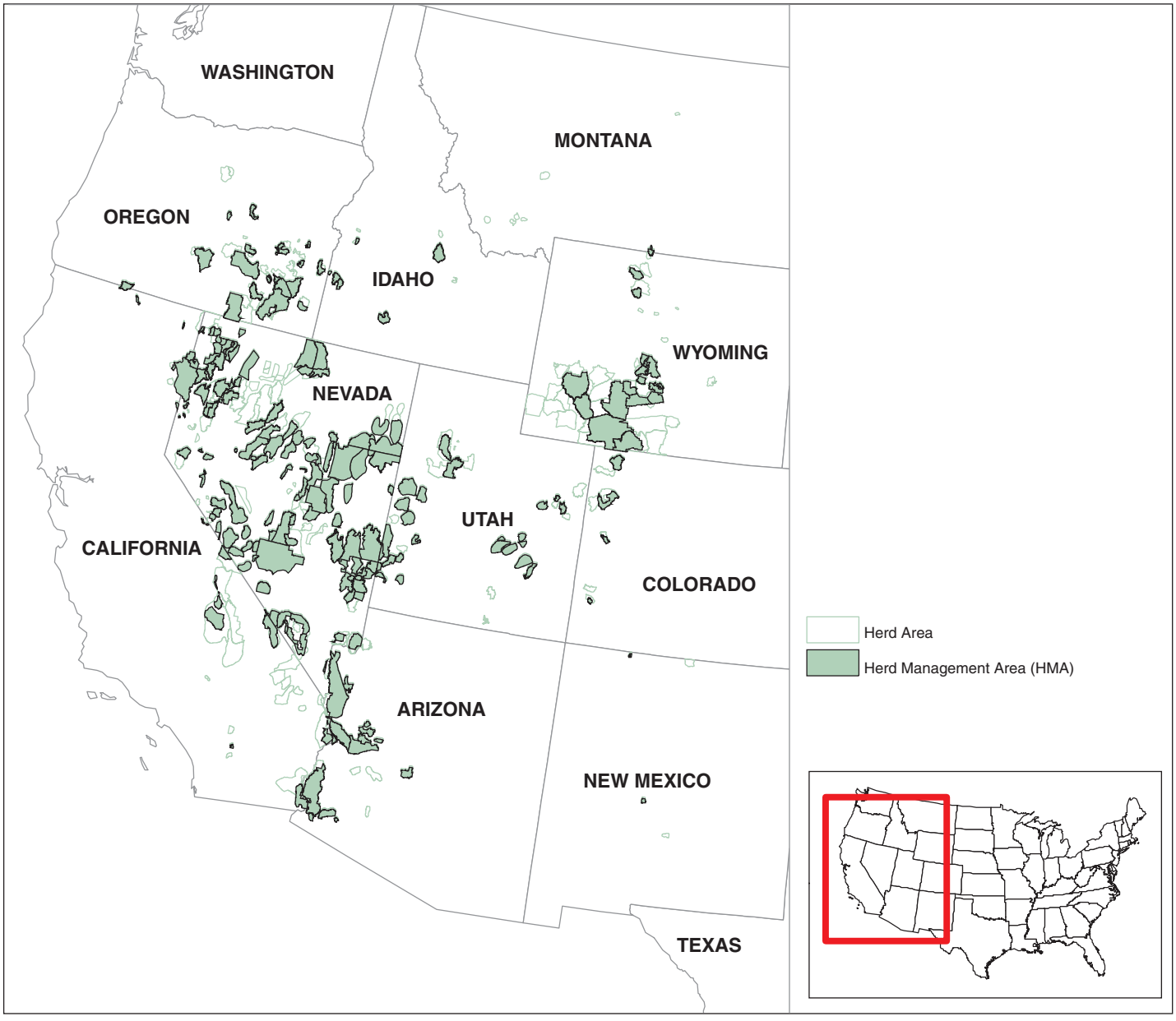
Next, through its land management planning process, BLM designated HMAs within these herd areas. In making HMA designations, BLM determined whether or not the areas where wild horses and burros were found contained adequate forage and water to sustain the herds. BLM also designated some HMAs in such a way as to avoid conflicts with private landowners. Today, BLM is responsible for managing 199 HMAs covering 34.3 million acres across 10 western states (see fig. 1).[17] BLM is currently compiling a history of how BLM field offices made the determination to manage wild horses and burros on the current 34.3 million acres, compared to the 53.5 million acres where they were originally found in 1971. According to BLM officials, they expect the review to be completed by March 2009.

[15]Pub. L. No. 92-196, § 9, 85 Stat. 649, 651 (renumbered as § 10 of the act and codified at 16 U.S.C. § 1339).

[16]Pub. L. No. 92-196, § 4, 85 Stat. 649, 651 (codified at 16 U.S.C. § 1334).

[17]Three of the 199 HMAs are classified as Wild Horse Ranges—the Pryor Mountains Wild Horse Range in Montana, the Little Book Cliffs Wild Horse Range in Colorado, and the Nevada Wild Horse Range of south-central Nevada. One of the HMAs is classified as a Wild Burro Range—the Marietta Wild Burro Range located in Nevada. According to the 1971 act, under certain circumstances, the Secretaries of the Interior and Agriculture may designate and maintain specific ranges on public lands as sanctuaries for the protection and preservation of wild free-roaming horses and burros. 16 U.S.C. § 1333(a). Ranges are to be devoted principally, but not necessarily exclusively, to their welfare in keeping with the multiple-use management concept for the public lands. 16 U.S.C. § 1332(c). BLM can also choose to close appropriate areas of public lands to grazing use by all or a particular kind of livestock, if necessary, to provide habitat for wild horses or burros; to implement herd management actions; or to protect wild horses or burros from disease, harassment, or injury. 43 C.F.R. § 4710.5.

Figure 1: BLM Herd Areas and HMAs in the Western United States



Source: BLM.

The number of HMAs and their acreage has changed over time for many different reasons, including BLM land being redesignated as National Park land and declines in forage or water that make an area unsustainable,

among others. About half the acreage managed under BLM's Wild Horse and Burro Program is located in Nevada (see table 2). While most of BLM's management activities for wild horses and burros occur within HMAs, BLM is responsible for removing populations of animals that stray onto public lands outside of HMAs, as well as those that stray onto private property.

Table 2: Summary Statistics on BLM's Wild Horse and Burro Program, by State, February 2008

				HMA acreage		
State	**Number of HMAs**	**Total AML[a]**	**Population estimate**	**BLM acreage**	**Other acreage**	**Total acreage**
Nevada	102	13,098	16,143	15,772,485	1,695,925	**17,468,410**
Wyoming	16	3,725	3,439	3,638,330	1,137,121	**4,775,451**
Arizona	7	1,676	2,173	1,756,086	1,327,777	**3,083,863**
Oregon	18	2,715	2,473	2,703,409	259,726	**2,963,135**
Utah	21	2,151	3,096	2,379,850	362,817	**2,742,667**
California	22	2,237	3,878	1,946,590	471,855	**2,418,445**
Idaho	6	617	703	377,907	40,287	**418,194**
Colorado	4	812	933	366,098	38,656	**404,754**
Montana	1	105	170	28,282	8,865	**37,147**
New Mexico	2	83	97	24,505	4,107	**28,612**
Total	**199**	**27,219**	**33,105**	**28,993,542**	**5,347,136**	**34,340,678**

Source: BLM.

[a]This column represents the upper limit of AML according to BLM data.

Wild horses and burros are to be managed as self-sustaining populations of healthy animals in balance with other multiple uses and the productive capacity of their habitat. Because wild horses and burros reproduce at an estimated rate of 20 percent annually and no natural predators remain, except for in a very few isolated HMAs, BLM must actively manage the population of the herds. AML has been defined as the "optimum number of wild horses which results in a thriving natural ecological balance and avoids deterioration of the range."[18] AML determinations can be made in a variety of land planning or decision documents, including, but not limited to, resource management plans, Herd Management Area Plans, and multiple use decision documents. The actual number set through an AML determination is predicated, in part, on (1) the number of acres set-aside

[18]*Animal Protection Institute of America*, 109 IBLA at 119 (internal quotes omitted).

for the management of wild horses and burros within a specific resource planning area and (2) the proportion allocation of the available forage allotted for wild horse and burro consumption among other users, such as livestock and wildlife. After these two key multiple use decisions have been made, BLM field offices can then set the actual AML numbers. Available forage is based on range conditions and other data.

BLM's Wild Horse and Burro National Program Office encourages field offices to establish AML as a range with an upper and lower limit.[19] The upper limit of the range equals the maximum number of animals that can be sustained to result in a thriving natural ecological balance and avoid deterioration of the range. The lower limit is generally determined as the number to which a population must be gathered to help ensure the population will not exceed the upper limit of AML within the established gather cycle. For example, if the established gather cycle was 4 years, it would be the number to which a population must be gathered to help ensure the population will not exceed the upper limit of AML within a 4 year time period. BLM strives to maintain a national herd population level that is at the midpoint of AML, where the recently gathered HMAs would be at the lower limit of AML, while those awaiting gathers would be closer to the upper limit of AML. As of February 2008, the upper limit of AML (the cumulative total for each of the 199 HMAs) was approximately 27,219, and the midpoint was about 22,588.[20]

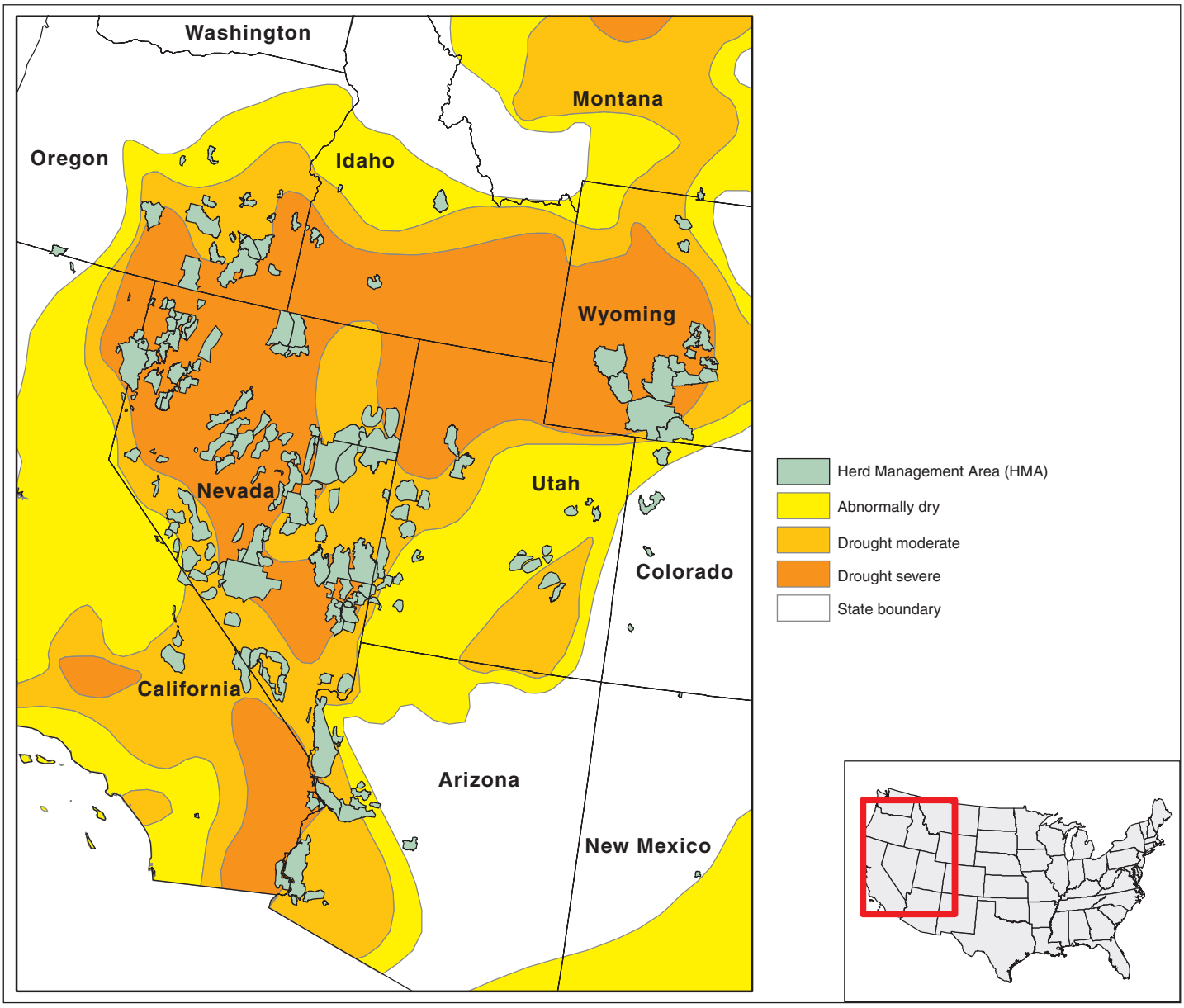
Because AMLs are intended to reflect the population of animals that can be sustainably maintained in an HMA, they are subject to change over time. Changes in AML happen for several reasons, including when acreage is added to or subtracted from an HMA and when changes in rangeland conditions result in improved or reduced forage and water availability sufficient to sustain a certain population level. In the arid ranges where most wild horses and burros are managed, conditions generally do not

[19]Some HMAs report AML as a single number rather than as a range; however, they also calculate an upper and lower limit of AML to determine the level within which to manage herds. BLM is drafting guidance to direct all field offices to identify AML as a range.

[20]According to BLM officials, as of February 2008, the upper limit of AML nationally was approximately 27,219 animals, and the lower limit of AML was approximately 17,957. Based on our calculation, the midpoint between the two limits is approximately 22,588. These numbers are considered approximate because not all HMAs report AML as a range. AML for 7 HMAs are reported as the midpoint of AML, while 29 HMAs report AML as the upper limit. Therefore, to account for the 36 HMAs that report a single AML number, BLM may only approximate the true upper, lower, and midpoint of AML on a nationwide basis.

improve rapidly and have been further degraded by drought conditions that have lasted for over a decade (see fig. 2). The effects of climate change are likely to exacerbate the poor conditions that many HMAs are already experiencing.

Figure 2: Drought Conditions and HMAs, February 2008



Source: BLM.

Determining which type of animal is responsible for rangeland damage is important to properly managing an HMA and in determining the number of animals to permit on the range. BLM can control the number of livestock

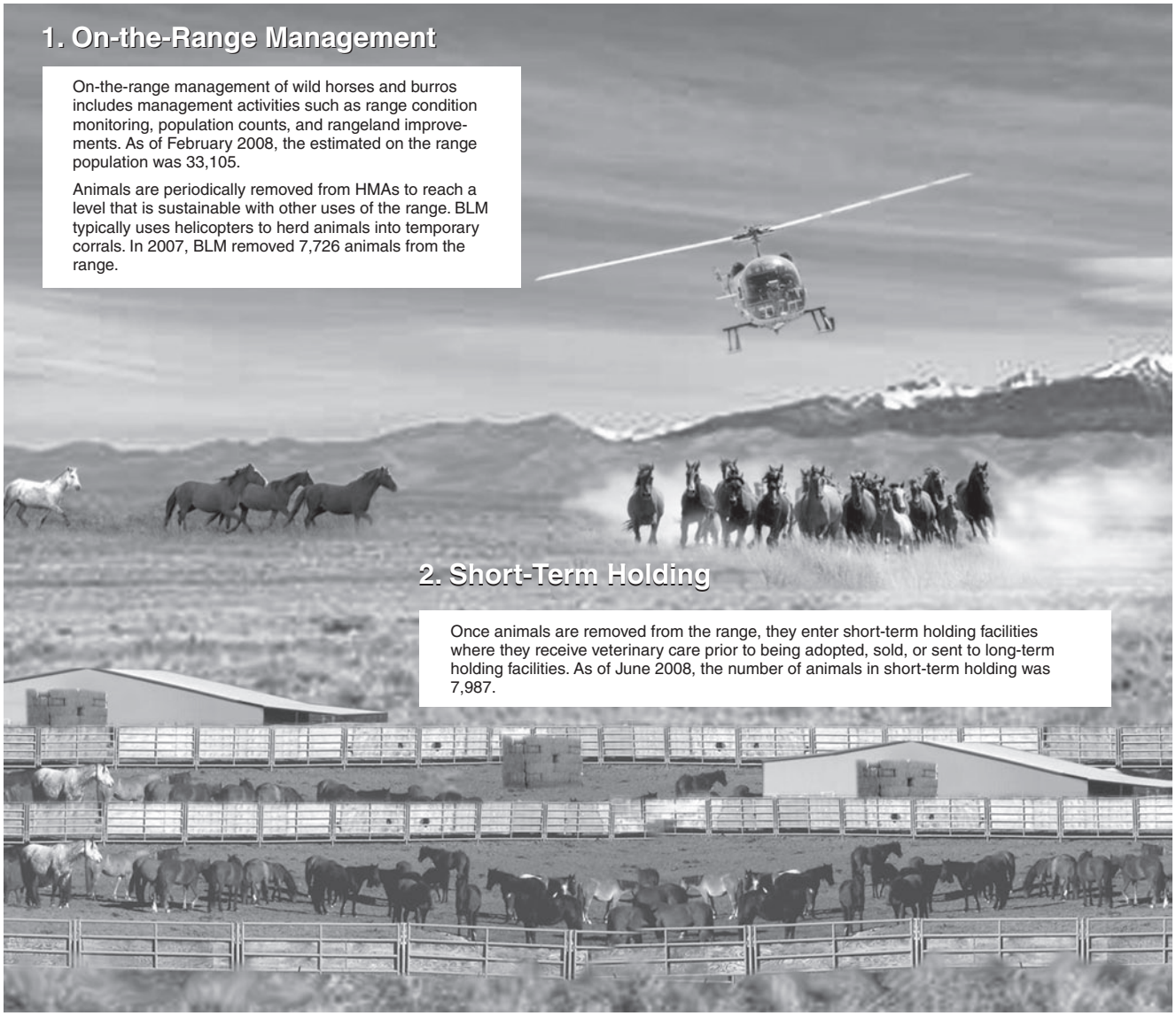
and wild horses and burros to permit on the range, but BLM is not responsible for managing wildlife numbers on the range. Because BLM is not the lead agency responsible for wildlife on public lands, they are to coordinate with state wildlife officials about the forage allocation for wildlife populations. An increase in allocation of any species may cause increased competition for the remaining users of the range, especially under severe conditions. For example, in severe drought conditions, grazing and browsing is concentrated in limited areas near water sources. This intense competition causes heavy use and perhaps depletion of the resources the animals are dependent upon.

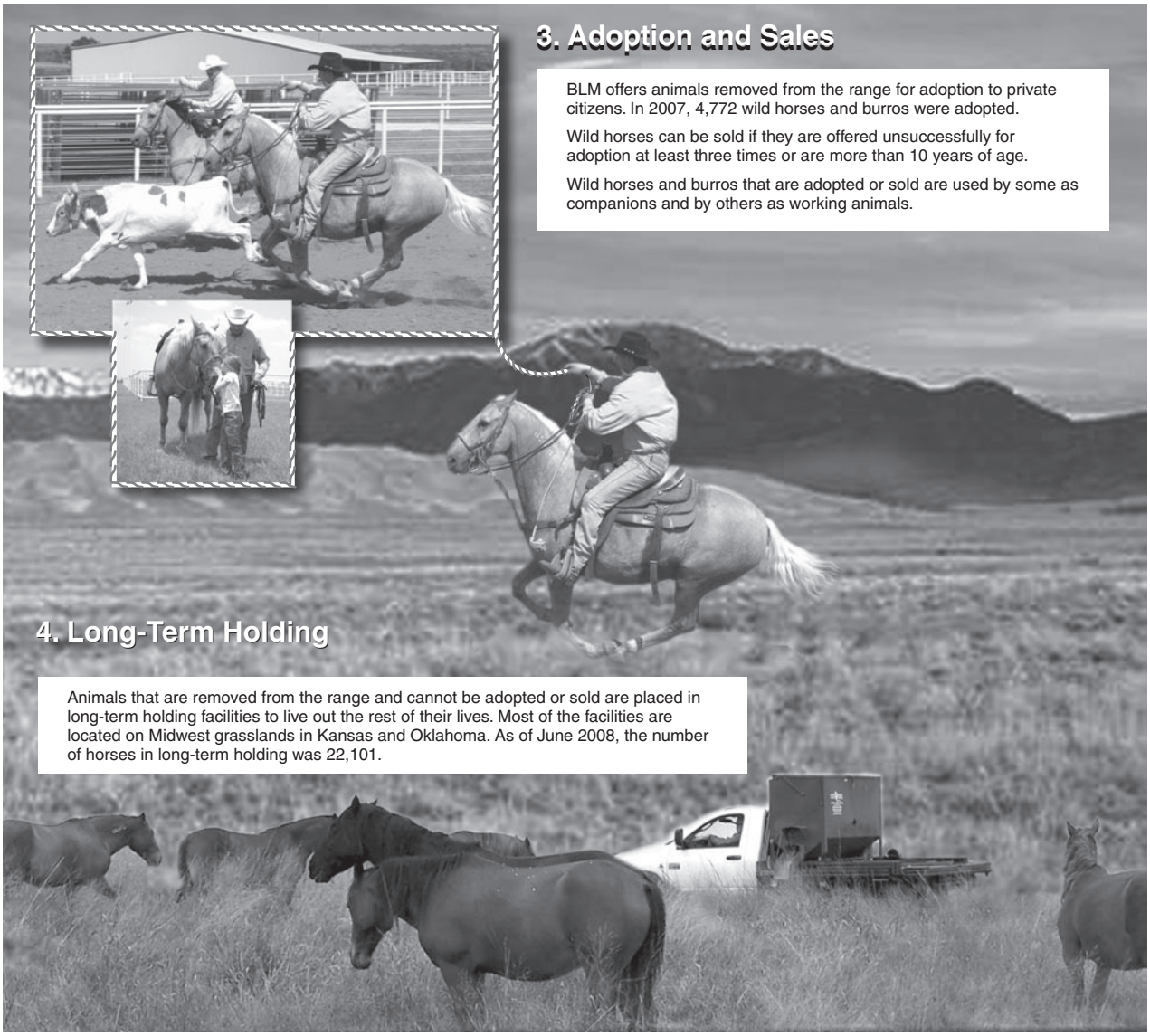
Throughout the life of the program, the population of wild horses and burros on the range has generally far exceeded AML. BLM has used the removal of animals from the range as a primary management tool for managing herd sizes. To gather animals for removal, BLM uses private contractors to herd the animals in an HMA into temporary on-site corrals.[21] The animals are primarily gathered using helicopters. In some cases, when gathering smaller numbers of wild horses and burros, BLM officials or contractors will use other trapping techniques, such as bait trapping, to capture the animals. Once collected into the temporary corrals, BLM officials use a selective removal process to determine which of those gathered animals to remove from the HMA.[22] Animals that are not selected are returned to the wild. When animals are removed from the range, they are taken to short-term holding facilities to receive vaccinations and other treatment prior to either being adopted, sold, or sent to long-term holding. Figure 3 depicts BLM's management of wild horses and burros on and off of the range.

[21]BLM has gather contracts with two private companies.

[22]The selective removal policy is used only for wild horses; it is not applicable to wild burros. When gathers are conducted, an emphasis is placed on removing the younger, more adoptable animals from the range. However, the sex ratio and age structure of the herd must also be considered to assure a healthy population.

Figure 3: BLM Management of Wild Horses and Burros on and off of the Range



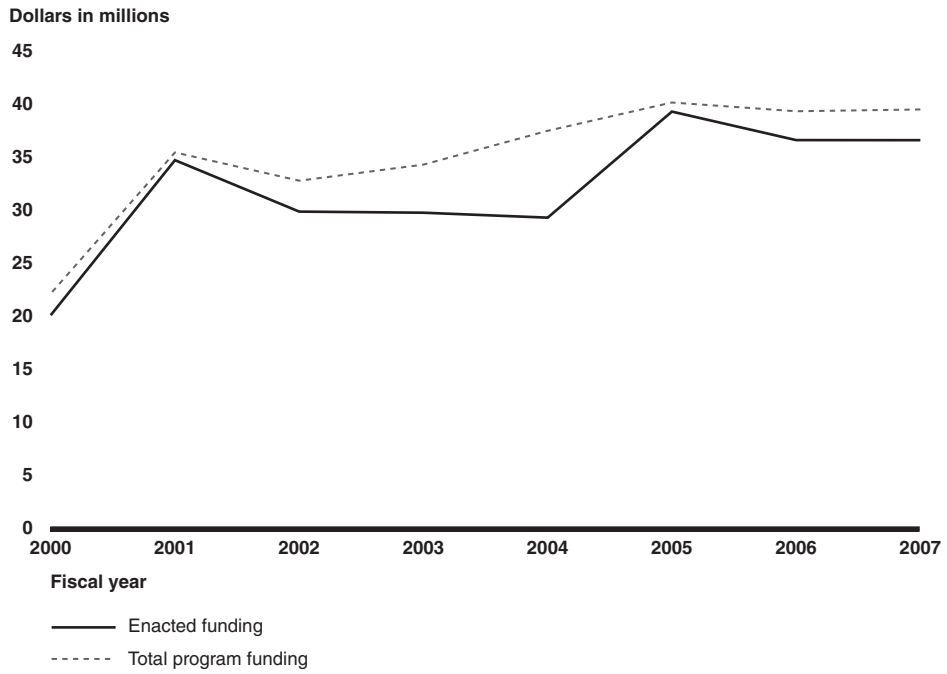


Sources: GAO (photos, photo illustration), BLM (photos).

For fiscal year 2001, BLM requested a budget increase for the program as part of a major initiative to reach the upper limit of AML by 2005.[23] Subsequently, program funding allocated from congressional appropriations—what the agency refers to as "enacted funding"—increased from $19.8 million in fiscal year 2000 to $34.4 million in fiscal year 2001, an increase of $14.6 million. In 2002, enacted funding for the program was $29.6 million, about $10 million over the 2000 congressional funding level. After reassessing the initiative in 2004, BLM estimated it needed an additional $10.5 million on top of their enacted funding level of $29.1 million in fiscal year 2004 to meet its revised goal of meeting the midpoint of AML by 2006. In fiscal year 2005, enacted funding was increased about $10 million for a total of $39 million in fiscal year 2005 (see fig. 4). The President's 2008 budget requested $32 million for the program, about $4 million less than enacted funding for fiscal year 2007.

[23]U.S. Department of the Interior, BLM, *Living Legends in Balance with the Land*, *A Strategy to Achieve Healthy Lands and Viable Herds*, *The Restoration of Threatened Watersheds Initiative* (Washington, D.C., 2000).

Figure 4: BLM's Wild Horse and Burro Program Funding, Fiscal Years 2000 through 2007



Source: BLM.

Note: The enacted funding level, as reported by BLM, is the amount allocated from congressional appropriations minus rescissions for the Wild Horse and Burro Program. Total program funding represents the sum of the enacted funding; reprogrammed funding; and funding from other sources, such as reimbursement for BLM's management of parts of the Forest Service's Wild Horse and Burro Program.

BLM Has Made Progress in Setting and Meeting AML, but Guidance Is Lacking and Meeting AML Has Proven Difficult

BLM has made significant progress in setting and meeting AML for the HMAs. As of February 2008, BLM has set AML for 197 out of 199 HMAs. Most of the field offices we surveyed considered similar factors in determining AML, such as rangeland conditions and climate data; however, BLM has not provided specific formal guidance to the field offices on how to set AML. BLM has been working on revising the program's handbook to provide such guidance since 2006. With increased retirements, field offices reported losing the experienced personnel most familiar with the informal practice of determining AML. Until BLM finalizes the handbook or issues other guidance, it cannot ensure that the factors considered in future revisions of AML determinations are consistent across HMAs. At the national level, BLM reported that it was closer to meeting AML in 2007 than in any other year since AMLs were documented in 1984. Specifically, as of February 2007, BLM estimated the

population at 28,563, which was about 1,000 animals over AML. To reach this level, BLM has reduced the nationwide population in the wild by about 40 percent since 2000. However, the population estimates are higher for 2008, and BLM has not met its goal of meeting AML for each HMA. The fact that not all HMAs have met AML remains a concern because of the damage excessive populations can cause on the range. Twenty of 26 field officials we surveyed told us that conducting gathers to remove excess animals is among their top challenges to maintaining AML because delayed gathers can cause animal populations to quickly exceed AML. In our 1990 report we concluded that BLM's decisions on the number of wild horses and burros to remove were made without adequate information about range carrying capacity or the impact of the animals on range conditions. In August 2005, BLM updated its formal policy on gathers and removals and specified the key factors that should be considered in the decision making process. The extent to which BLM has actually met AML depends on the accuracy of BLM's wild horse and burro population counts. Nineteen of the 26 field officials we surveyed used a method that consistently undercounts animals and does not provide a statistical range of population estimates. Alternative counting methods may be more expensive, but undercounting a population can lead to overpopulation and costlier gathers in future years.

BLM Has Set AML for 197 out of 199 HMAs, but No Formal Guidance Exists on How to Establish AML

BLM has made significant progress in setting AML using rangeland monitoring data for the HMAs. As of February 2008, BLM has set AML for 197 out of 199 HMAs, compared to 2002 when about two-thirds of HMAs had set AML.[24] Prior to 1984, many of the initial AMLs were not based on rangeland data but on factors such as initial herd population counts or administrative convenience. For example, the original AML established for Beaty's Butte HMA in Oregon in 1977 was based on the number of horses found in that area on December 15, 1971. In Wyoming, AMLs for about one-third of the HMAs were based on agreements with local grazing interests because they owned private lands that were interspersed with BLM lands where wild horses were found in 1971. Only 10 out of the 26 field offices we surveyed identified the use of rangeland data to determine their initial AMLs. But since 1984, in accordance with the *Dahl v. Clark* decision, BLM officials told us that field managers have generally

[24]The number of HMAs managed by BLM has changed over time. In 2002, BLM managed 208 HMAs, 142 of which had set AML, or 68 percent.

based AML decisions on monitoring data and an in-depth analysis.[25] Most of the current AMLs for the 199 HMAs were set after 1984 (see table 3). Although some current AMLs were set many years ago, they are generally reviewed every 4 years or so as part of the recurring process to gather and remove excess animals. If during this process, and through monitoring, it is determined that an AML is no longer appropriate, field offices will consider changing it. For example, table 17 in appendix III shows how the current AMLs for the 26 HMAs in our sample have been changed, as applicable, since they were initially set.

Table 3: Years in Which Current AMLs Were Set for BLM's 199 HMAs

Years in which current AMLs were set	Number of HMAs
1975–1979[a]	2
1980–1984	13
1985–1989	13
1990–1994	45
1995–1999	32
2000–2004	68
2005–2008	24
Not yet set	2
Total	**199**

Source: GAO analysis of BLM data.

Note: Although an AML may have been set years ago, they are generally reviewed every 4 years or so as part of the reoccurring process to gather and remove excess animals.

[a]AML determinations were first required by the Public Rangelands Improvement Act of 1978.

Most of the field offices we surveyed considered similar factors in determining AML.[26] According to BLM National Program Office officials, field office staff should consider at least four factors in making AML determinations—climatic data, utilization data, actual use data, and trend data. Climate data measures the amount of precipitation within a specific area. In addition, temperature and wind data may be collected to evaluate

[25]*Dahl v. Clark*, 600 F. Supp. 585 (Dist. Ct. Nev. 1984).

[26]For this report we reviewed BLM's process for making AML determinations and the factors it considers during that process. We are not expressing a legal opinion as to whether any individual AML established through this process would achieve and maintain a "thriving natural ecological balance," as required by the act. 16 U.S.C. § 1333(a), (b)(2); *see also*, *Animal Protection Institute of America*, 109 IBLA 112, 115.

the effect of climate on vegetation; utilization data measures the percent of forage consumed by livestock, wild horses and burros, wildlife, and insects during a specified period; actual use data is the number of grazing animals that used an area within a certain amount of time; and trend data measures the direction of change in ecological status or resource rating observed over time. Our survey results indicate that these four key AML determination factors were considered by some, but not all, of the BLM field offices responsible for setting AML for our sample of 26 HMAs (see table 4).

Table 4: Extent to Which BLM Field Office Staff Considered Each of the Four Key Factors in Making the Most Recent AML Determination for Surveyed Field Offices

Number of the four key factors considered	Number of BLM field offices
4	16
3	6
2	2
1	1
0	1
Total	**26**

Source: GAO survey results.

Almost all of the field offices considered trend (25) and utilization (23) data, but only 19 considered climate and actual use data for livestock, while 14 considered actual use data for wildlife (see table 5).

Table 5: Factors Considered by BLM Field Office Staff in Making the Most Recent AML Determinations for Surveyed Field Offices

Factor	Considered	Not considered	Don't know	Not applicable	Blank
Factors BLM officials told us should be considered					
Trend	25	1	0	0	0
Utilization	23	2	1	0	0
Climate data	19	3	4	0	0
Actual use: livestock	19	2	2	3	0
Actual use: wildlife	14	5	6	1	0
Other factors considered					
Carrying capacity	23	1	2	0	0
Census/inventory	22	2	2	0	0
Water resources	21	3	2	0	0
Stakeholder influence	20	2	4	0	0
Production	19	2	5	0	0
Herd health	19	4	3	0	0
Genetic viability	16	6	3	1	0
Recreational use	14	6	3	3	0
Cultural resources	12	6	5	2	1
Archeological resources	12	6	5	2	1
Livestock agreements	11	4	7	4	0
Human safety issues	8	8	2	8	0
Community expansion	4	8	2	12	0
Court order	2	5	2	17	0
Mineral extraction	3	10	2	11	0
Other factors	7	1	0	1	17

Source: GAO survey results.

In addition to the four factors mentioned by BLM National Program Office officials, field offices considered other factors to help make their AML determinations, including census inventory, water resource availability, herd health, and unique local conditions. For instance, in Arizona, one field office reduced the AML for burros on an HMA because they found

that burros were foraging on the same willows critical to the survival of the endangered Southwestern Willow Flycatcher.[27]

In determining AML, field office staff must also consider rangeland conditions for wild horses and burros in conjunction with other users of the range, including livestock and wildlife. Determining which species is responsible for rangeland damage is an important task to properly managing the HMA and in determining the number of wild horses and burros to permit on the range. For example, if field staff determine that cattle are primarily responsible for damaging an area, they may pursue several management options, including fencing out cattle, reducing the number of cattle, or changing the time of year cattle are allowed to graze in a particular area. BLM lacks similar management techniques to control wild horse and burro use due to their free-roaming nature. BLM's direct management actions are limited to dealing with livestock and wild horses and burros, since individual states are responsible for managing wildlife.

We recognized the difficulty in distinguishing the difference between impacts that wild horses and burros have on the range versus other users in our 1990 report.[28] Some advocacy groups have criticized BLM because they believe that BLM unfairly faults wild horse and burros for damage to the range to justify their removal and reductions in AML. Several BLM officials told us ascribing range impacts can be difficult, but 20 out of the 26 field offices that we surveyed said they had a procedure in place do so. When the damage is caused by all the user groups or when the damage can not be attributed to a specific user group, BLM will generally make across-the-board reductions in the number of animals allowed on the range based on the historic proportion of each user group on the range. For example, if wild horses and burros historically accounted for 10 percent of the forage consumption on the range, then wild horses and burros would bear 10 percent of the necessary reductions.

BLM has also made steady reductions in cattle grazing on BLM land as drought conditions in much of the West have worsened, resulting in the reduction of forage and water availability. For example, in Nevada, the

[27]Under Section 7 of the Endangered Species Act, all federal agencies must ensure that any actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of its designated critical habitat.

[28]GAO/RCED-90-110.

state that manages for the greatest number of wild horses, permitted livestock use was reduced from about 2.5 million animal unit months in 1990 to a little over 2 million in 2006.[29] The actual use during this same period, however, decreased from 1.8 million animal unit months to 1.2 million.

In addition to the factors considered in making AML determinations, the age of the data, or how current it is, can also be important. The meaning of "current" data collection depends on the ecosystem and may vary across HMAs. BLM national program officials explained that data used to support AML decisions should be collected on a frequent basis. In general, they told us climate, utilization, and actual use data should be collected annually and trend data should be analyzed and reviewed within 4 years of setting AML. However, of the respondents who provided the age for data used, fewer than half collected their data for actual use for livestock and wildlife within 1 year of their AML determination; half collected their data for utilization within 1 year of the determination; and more than half collected their data for climate within 1 year of the determination. Fifteen of the 19 respondents who provided the age for data used considered trend data within 4 years of the determination (see table 6).

[29]An animal unit month refers to the amount of forage needed to sustain an adult cow and her calf or horse for 1 month.

Table 6: Age of Data Used to Make Current AML Determinations for Surveyed Field Offices

	Age of the data					
Factor	**1 year**	**2 years**	**3 years**	**4 years**	**5-10 years**	**11 years or older**
Factors BLM officials told us should be considered						
Trend	8	3	1	3	4	0
Utilization	9	2	1	3	3	0
Climate data	9	2	0	2	2	0
Actual use: livestock	6	3	0	2	3	0
Actual use: wildlife	5	1	0	2	2	1
Other factors considered						
Carrying capacity	7	3	0	2	5	1
Census inventory	13	1	1	2	1	0
Water inventory	11	2	0	2	1	0
Production	6	1	0	2	3	2
Herd health	11	1	0	3	1	0
Genetic viability	8	0	0	3	1	0

Source: GAO survey results.

Note: Some field offices that considered the factors listed in this table did not provide a year in which the data was collected.

Although field offices use many factors to make their AML determinations, BLM has no guidance or policy about the specific factors they must consider in determining AML. This is in contrast to the BLM policy that exists for a similar type of analysis that is conducted for removals. According to BLM's 2005 gather policy, the determination to remove animals must be supported by the following factors: climatic data, utilization data, actual use data, trend data, and current census data.[30] While 22 out of 26 BLM field offices responded that the data used to make their AML determination were moderate to very sufficient, several BLM officials told us that with increased retirements, field offices are losing the experienced personnel most familiar with the informal practice of determining AML. Therefore, without clear guidance, BLM cannot ensure

[30]U.S. Department of the Interior, BLM, *Gather Policy and Selective Removal Criteria*, Instruction Memorandum No. 2005-206 (Washington, D.C., Aug. 10, 2005). Although the instruction memorandum had an expiration date of September 30, 2006, according to BLM officials, it is still considered to be in effect until it is reissued.

that the factors considered in future revisions of AML determinations will be consistent across HMAs. To make the informal AML determination process official and to help ensure consistency among BLM field offices, BLM officials have been working on drafting a new handbook for the program since 2006, which specifies the factors field offices should use in making AML determinations.[31] Due to higher priorities and limited resources, the handbook is still in draft form and is undergoing final revision. BLM officials told us they expect the handbook to be completed in fall 2008.

BLM Has Made Significant Progress toward Meeting AML, but Some HMAs Remain Far over AML

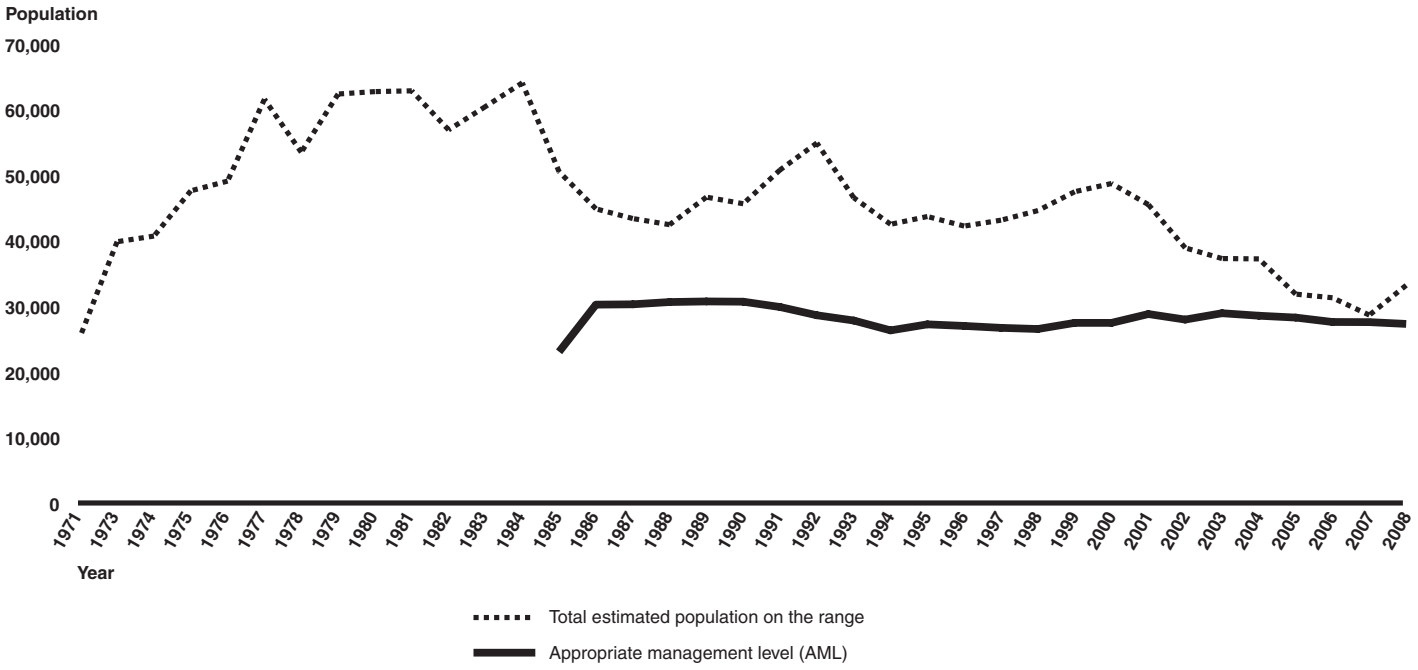
Since 2000, BLM has made significant progress toward meeting AML. At the national level, BLM was closer to meeting AML in 2007 than in any other year since 1984 (when AML levels were first reported by BLM), with a population of 28,563, or about 1,000 animals over the upper limit of AML (see fig. 5). Meeting AML has been a challenge for most of the lifetime of the program. In 1985, in reporting on the Department of the Interior and related agencies' appropriations, the Senate Committee on Appropriations recommended more than tripling the program's funding above the original budgeted amounts to, according to the committee, permit BLM to maintain nearly 14,000 animals in corrals through the end of fiscal year 1986 and to remove 17,000 excess animals during fiscal year 1986.[32] The program's funding was tripled in fiscal year 1986, and with the increased funding, BLM removed 18,959 excess animals. In fiscal year 2001, BLM began implementing a 4-year strategy to aggressively remove animals from the range to reach the upper limit of AML by 2005. However, just before initiating the strategy—which relied heavily on specific assumptions about the number of animals removed, adopted, and held in short-term and long-term holding—emergency drought and fire conditions called for the removal of wild horses and burros in numbers far greater than anticipated. These additional removals and decreases in adoption targets changed BLM's assumptions and made it clear the agency would not be able to meet the targets set forth in their plan. In 2004, BLM again revisited targets and management options that would help them to achieve and maintain the midpoint of AML by 2006. Over the past several years, the program is closer to meeting AML as a result of increases in the number of wild

[31]According to BLM, the effort to revise the *Wild Horse and Burro Program Handbook* was first initiated in 1997. The effort was restarted most recently in 2006 when the draft handbook was significantly rewritten and expanded.

[32]S. Rpt. 99-141, at 6, 121 (1985).

horses and burros removed from the range, but it continues to face challenges in maintaining that level. According to BLM data, the population now exceeds the upper limit of AML by an estimated 5,886 animals. BLM attributes most of the increase in population to more accurate population census counts.

Figure 5: Estimated Population of Wild Horses and Burros on the Range



Source: BLM.

Note: All population levels are estimated based on aerial surveys that likely undercount the number of animals on the range. In 2000, BLM changed the time frame for its population counts from October 1 through September 30 of every year to March 1 through February 28 or 29 of every year. For AML levels prior to 1984, BLM was unable to provide estimated figures. For AML levels from 1984 through 1999, the figures are estimated and they do not necessarily reflect the upper limit of AML; from 2000 onward, the AML figures represent the upper limit of AML.

While the national statistics appear to indicate that BLM is close to meeting its goal, it is important to note that, under the act, BLM is required to maintain HMAs at a level that is at or below the upper limit of AML. To stay below the upper limit of AML, HMAs should be gathered to the lower limit of AML approximately every 3 to 5 years. However, only 7 of the 26 BLM field offices we surveyed said they were typically able to gather to this low level. When animals are not gathered to the low level of AML, a population can quickly rise well above the upper limit of AML. Fewer than

half (10) of the field offices surveyed said they were usually able to manage the population of wild horses and burros on their HMAs within the limits of AML. Fifteen field offices said they managed populations that were typically above AML.

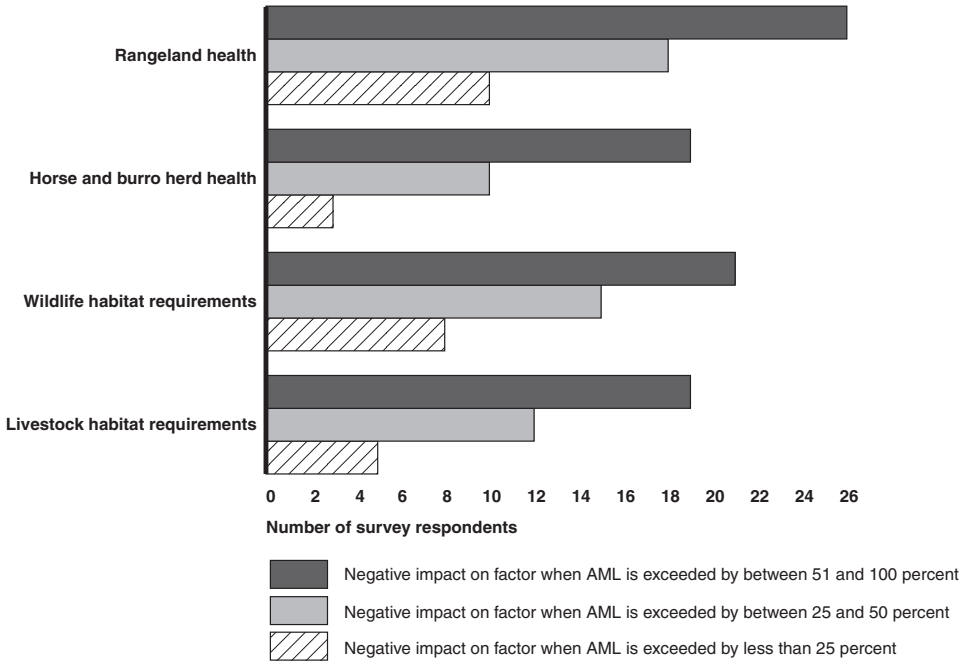
We are not reporting in detail on the extent to which individual HMAs have met AML because we do not believe that BLM's data are precise enough to accurately make such a determination. BLM's estimates of the number of HMAs that are at or below AML may be overstated because, for reporting purposes, BLM considers the HMAs where the population is not more than 10 percent over the upper limit of the AML to be at AML. BLM officials told us that this is done to account for those HMAs that may slightly exceed AML. For example, in 2008, BLM reported that 61 of the 102 HMAs in Nevada were at or below AML. Without the 10 percent adjustment factor, we calculated that 52 HMAs were at or below AML. Because of this adjustment factor and questions about the accuracy of BLM's animal counting methods, we concluded that the data on whether or not individual HMAs had met AML were not sufficiently reliable to report because an error of plus or minus one or two animals could change the status of an HMA from being under or over AML. Aside from the precise issue of whether or not an HMA is within or over AML, it is clear from the data that some HMAs are significantly over AML. For example, as of February 2008, BLM reported that 87 HMAs were over AML. About half of these HMAs were over AML by 50 percent or less, about a quarter were over AML by between 51 and 100 percent, and about another quarter of the HMAs were over AML by more than 100 percent.

Populations that exceed AML can harm the health of the range. For example, in 2004, the Calico HMA in Nevada exceeded AML by about 200 percent. The herds were found to concentrate in sensitive areas, affecting the threatened Lahontan cutthroat trout and contributing to the nonattainment of grazing allotment objectives and standards for rangeland health.[33] As of February 2008, the wild horse population in this HMA exceeded the upper limit of AML by 160 percent. The excess population

[33]Rangeland health standards were developed to be consistent with the fundamentals of rangeland health, including watersheds that are in a properly functioning condition; ecological processes that are maintained in order to support healthy biotic populations and communities; water quality that complies with state water quality standards; and habitats that are being restored or maintained for federal threatened and endangered species, proposed or candidate threatened and endangered species, and other special status species.

levels and continued drought are expected to continue to negatively impact sensitive riparian areas relied upon by the Lahontan cutthroat trout. The overpopulation of wild horses and burros on the range may negatively impact herd health, rangeland health, and livestock and wildlife that depend on the range. An over-obligation of the vegetative resources can result in declines in the healthy vegetative condition that may take years to recover. See figure 6 for our survey results on the possible negative impacts of populations that exceed the upper limits of AML.

Figure 6: Number of Field Offices Who Reported Negative Impacts When Populations Exceed the Upper Limit of AML



Source: GAO analysis of survey data.

Note: We asked survey respondents to identify the impact (positive, slightly positive, no impact, slightly negative, and negative) that populations that exceed the upper limit of AML would have on the four factors above. The figure is a graphic depiction of survey respondents who reported negative impacts when populations exceed AML. See appendix III for the number of survey respondents who reported positive, slightly positive, no impact, or slightly negative impacts when the upper limit of AML is exceeded by a certain percentage.

In addition to the effects on the range, overpopulation in HMAs also results in costlier gathers because a greater number of animals would have to be removed to maintain AML in future years.

Although there has been an increased effort to meet AML, there have been many challenges in meeting and maintaining that level. Twenty of the 26 field officials we surveyed identified limitations to gathers to remove excess animals as one of their top challenges to meeting or maintaining AML. One limitation identified by these respondents included limited funding available to conduct gathers. Another limitation identified by respondents was unplanned gathers that alter the gather schedule as resources are directed to HMAs in critical need. Reasons for unplanned gathers include escalating problems and emergencies. An HMA with an escalating problem is defined as an area where deteriorating rangeland conditions, such as declining availability of forage or water, will negatively affect animal condition and rangeland health. Emergency situations are unexpected situations that threaten the immediate health of wild horses and burros or their habitat, such as fire, disease, or other catastrophic events.

In addition to using gathers and removals to manage the population on the range, BLM may also use fertility treatment to manage the reproductive rates of wild horses. BLM is using this tool on a limited number of HMAs. However, some animal fertility researchers and wild horse advocates believe that this tool should be used more widely. They say that unless the reproductive rate is curtailed, the need to gather a large number of animals from the range will continue. See appendix II for more information about BLM's use of this treatment.

BLM Has Established a Formal Policy on Gathers and Removals that Specifies the Key Factors that Should Be Considered in the Decision Making Process

Removals are used as a primary method for managing wild horse and burro populations on the range; however, the data used to support these removal decisions have been criticized. Specifically, our 1990 report concluded that BLM's decisions on the number of wild horses and burros to remove were made without adequate information about range carrying capacity or the impact of the animals on range conditions.[34] In August 2005, BLM issued an update to their 2002 policy on gathers that determinations to support gathers and removals must be based on a National Environmental Policy Act analysis and a gather plan that consider five key factors—utilization, trend, actual use, climatic data, and

[34] GAO/RCED-90-110.

current census.[35] Eleven of the 26 field offices we surveyed considered all five key factors in their most recent gather plan (see table 7). However, many of these field offices conducted their most recent gathers prior to the issuance of the 2005 policy that specified which factors to consider in their decision making process. Specifically, 11 field offices conducted their most recent gathers between 1990 and 2005. Additionally, some field offices' most recent gathers were conducted as a result of an emergency situation. In those cases, a field office may not have had enough time to consider all five criteria due to the critical time response necessary to remove the animals.[36]

Table 7: Extent to Which BLM Field Office Staff Considered Each of the Five Key Factors in Making Their Most Recent Gather Determination

Number of the five key factors considered	Number of respondents
5	11
4	4
3	5
2	1
1	4
0	1
Total	**26**

Source: GAO survey results.

Regardless of when the most recent gathers were conducted, 25 of the 26 field offices we surveyed considered the data used to support their removals for specific HMAs as moderately to very sufficient. See table 8 for the number of field offices that considered each of the factors we asked about in our survey.

[35]U.S. Department of the Interior, BLM, *Gather Policy and Selective Removal Criteria*, Instruction Memorandum No. 2005-206 (Washington, D.C., Aug. 10, 2005). The 2005 policy updated BLM Instruction Memorandum No. 2002-095, dated February13, 2002. The 2002 policy did not explicitly enumerate the key factors that should be considered as part of the gather and removal analysis.

[36]U.S. Department of the Interior, BLM, *Establishment/Adjustment of Appropriate Management Levels, and Managing Planned Escalating Problem and Emergency Gathers*, Instruction Memorandum No. 2004-151 (Washington, D.C., Mar. 16, 2004). When gathers are conducted as a result of an emergency, such as a fire, a National Environmental Policy Act analysis and gather plans are still required prior to the animal removal, if time permits. If immediate action is required, emergency actions should be documented and a report prepared after resolution of the problem.

Table 8: Factors Considered by Field Offices in Decisions to Gather Wild Horses and Burros from the Range

Factor	Considered	Not considered	Don't know	Not applicable	Blank
Factors that should be considered					
Census/inventory	24	2	0	0	0
Utilization	21	3	1	0	1
Climate data	19	5	1	0	1
Trend	16	6	2	1	1
Actual use: livestock	11	8	2	4	1
Actual use: wildlife	8	10	3	4	1
Other factors considered					
Herd health	21	4	1	0	0
Carrying capacity	17	6	2	0	1
Water resources	16	7	1	0	2
Stakeholder influence	16	3	3	2	2
Production	12	8	4	1	1
Livestock agreements	12	6	1	5	2
Cultural resources	12	7	1	4	2
Archeological resources	12	8	1	3	2
Genetic viability	11	11	2	1	1
Recreational use	8	8	1	7	2
Other factors	8	0	1	3	14
Human safety issues	7	10	1	6	2
Court order	3	5	1	14	3
Mineral extraction	3	9	1	11	2
Community expansion	1	11	1	11	2

Source: GAO survey results.

Unlike our previous report, which stated that data to justify removals was outdated, most respondents who provided the year in which their data was collected indicated that their data was current as of the year of their most recent gather or less than 4 years old (see table 9).

Table 9: Age of Data Used by Field Offices to Determine the Need for Most Recent Gather

	Age of the data					
Factor	**1 year**	**2 years**	**3 years**	**4 years**	**5-10 years**	**11 years or older**
Factors that should be considered						
Census/inventory	14	2	3	0	0	0
Utilization	13	1	0	1	0	0
Climate data	15	0	0	1	0	0
Trend	8	1	1	1	2	0
Actual use: livestock	10	0	0	0	0	0
Actual use: wildlife	7	0	0	0	0	0
Other factors considered						
Herd health	11	2	1	1	0	0
Carrying capacity	6	1	1	0	1	2
Water resources	8	0	0	1	0	0
Production	6	1	0	1	0	0
Genetic viability	1	1	1	2	1	0

Source: GAO survey results.

Half of the survey respondents identified impediments to conducting gathers as a major challenge in managing their HMAs to achieve healthy herd populations that are in balance with the range and other multiple uses. Only 7 of the 26 field offices surveyed said that they were able to typically gather to their lower limits of AML. While several BLM officials explained that gathers can be delayed as a result of funding restrictions or emergency gather priorities, only four of the field offices surveyed indicated that their most recent gather was delayed.

Research and Experience Have Shown That BLM's On-the-Range Population Estimates Are Too Low

Accurate animal population counts are critical to BLM's ability to properly manage wild horse and burro herds and in determining whether AML targets were met. However, many field offices use a population counting method—the direct-count method—that researchers consider inaccurate. This method generally calls for one person to count each animal they spot from an airplane or helicopter. According to researchers, it consistently undercounts animals and does not provide a statistical range of estimates. Nineteen of the 26 field officials we surveyed used the direct-count method for conducting their most recent census.

Regardless of which method is used, counting wild horses and burros can be challenging, particularly when the animals are obscured by trees or when the rangeland is covered with snow. Because counting poses such challenges, researchers are investigating alternative counting methods to assist BLM in collecting accurate population data to form statistically valid population estimates.[37] Each method the researchers are evaluating includes some range of statistical error, whereas direct count only reports the raw number spotted on the ground. Researchers believe that the most effective method will likely be a combination of two or more counting techniques. BLM's population counts of wild horses and burros have long been questioned by managers and advocacy groups alike. By employing alternative methods that account for a range of error, BLM would have a more defensible way of determining population estimates. In the most recent 2008 BLM population estimates, for example, population counts exceeded those in 2007 by approximately 4,500 animals. As a result, on a nationwide level, BLM is once again well over the upper limit of AML, which brings into question earlier population estimates and whether or not those previous years were as close to meeting AML as once thought. BLM is working with the Department of the Interior's U.S. Geological Survey's Fort Collins Science Center and the Colorado State University to develop these methods to achieve greater accuracy in population counts. Some BLM offices have begun to employ some of these methods. For example, in Arizona, managers use the simultaneous double-count method to improve population counts and avoid underestimating burro populations. Some field offices, however, are reluctant to use alternate counting methods because they are concerned that they would require too much

[37]The five methods experts are investigating include the following: (1) Photographic mark-resight involves two or more separate counts. First, an aerial count is conducted, and each group of animals photographed. This is followed soon after by additional aerial counts. The photographs from each survey are compared to determine which animals were seen on each pass and which were missed. A statistical technique to estimate the number missed is based on the number missing on each pass. (2) Simultaneous double-count is a form of mark-resight that uses only one count where two observers in an aircraft independently observe and record a direct count of wild horses or burros. Sighting rates are estimated by comparing sighting records of the two observers, and the number of horses that were missed by both individuals can be estimated. (3) Sightability bias correction involves observers that count animals but also records other factors about each sighting, such as if the groups were large or small, terrain type, weather, and other factors that may have prevented some animals from being seen. (4) Distance sampling estimates the number of animals or herds based on the distance and location of the animals that are seen on the ground. The data enables statisticians to predict the number of animals that are not seen because they are too far away. (5) Combined techniques utilize different combinations of the aforementioned four techniques to mitigate known biases associated with each individual method.

additional staff or would be too expensive. Researchers agree that other methods may be slightly more expensive, given the greater number of staff needed.

When a population is undercounted, BLM is likely to remove fewer animals than is needed to control overpopulation. For example, in 2002, a direct count was used to census the wild horse population located on the Jackson Mountain HMA in northern Nevada, an area that has been affected by severe drought. When a gather was conducted in 2003, staff believed they removed the adequate number of wild horses to reach AML. Funds to conduct their scheduled census in 2006 were not available, and BLM was unable to conduct its population count until the summer of 2007. It was at this point that staff realized that their 2002 census was incorrect and that they miscalculated the population in 2007 by approximately 640 wild horses. They found that the actual population in 2007 was about five times greater than what they determined was sustainable. In the winter of 2007, BLM began to monitor water availability more regularly. The BLM field staff member who managed that HMA told us that although the herd condition was weakened, the horses did not appear to be in extremely poor condition. Nevertheless, more than 150 of the wild horses removed from this HMA died in a short-term holding facility due to disease that was able to overtake the animals in their weakened state.

Declining Adoptions and Sales Have Increased the Need for Short-Term and Long-Term Holding Facilities, and Holding Costs Have Increased

The number of wild horses and burros removed from the range is far greater than the number adopted or sold. Since 2001, about 74,000 animals have been removed from the range, while only about 46,400 have been adopted or sold. This has resulted in significant spending increases due to a greater number of animals in short- and long-term holding. Thirty-six percent fewer wild horses and burros were adopted in 2007, compared to average adoption rates in the 1990s—a trend BLM officials attribute to the decrease in adoption demand and increasing hay and fuel costs. Since 2004, when BLM was directed to sell excess wild horses and burros without limitation, BLM has sold about 2,700 animals—far fewer than expected, despite the low average selling price of $15. As of June 2008, BLM was holding 30,088 animals in short- and long-term holding facilities, compared with the estimated 9,807 held in 2001. To accommodate the increase in animals removed from the range and the decline in adoptions and sales, BLM has increased the number of short- and long-term holding facilities. This has resulted in an increase in spending for short- and long-term holding facilities.

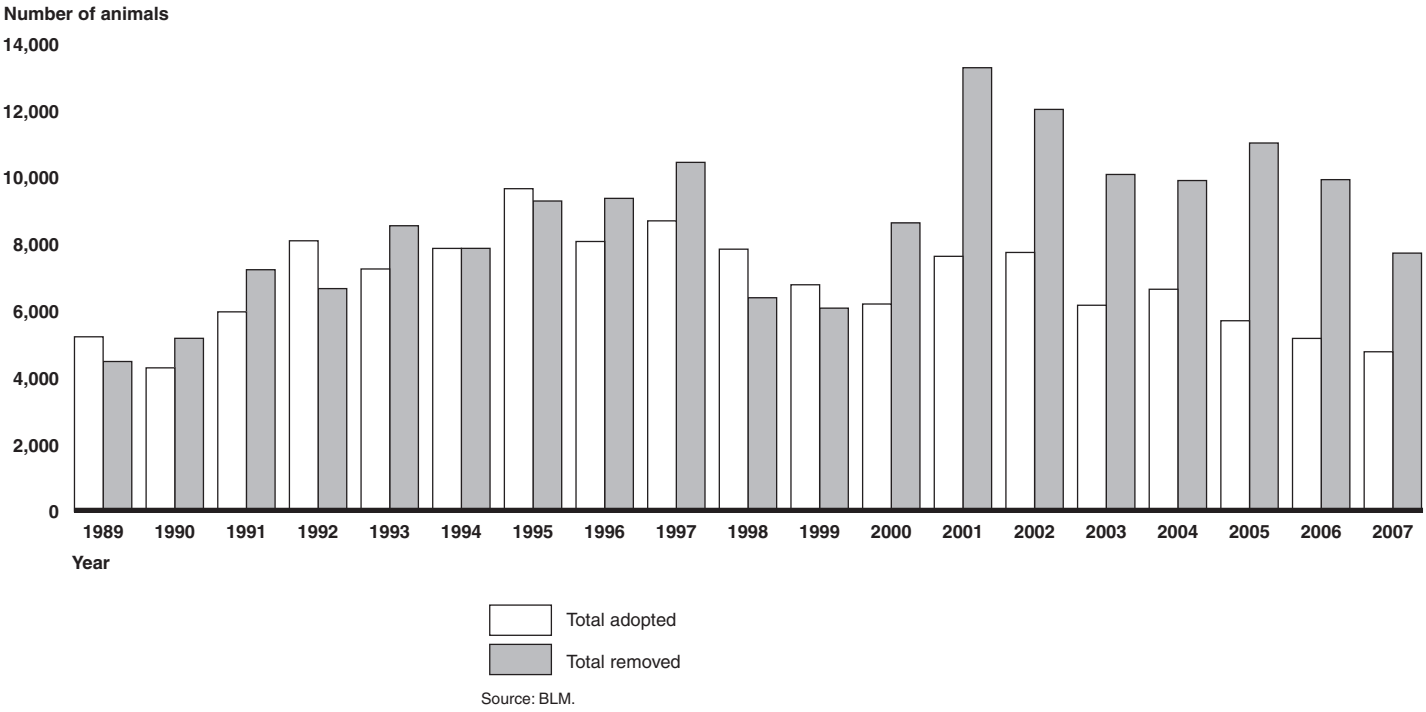
Adoption Rates Have Declined Since the 1990s, and the 2004 Sale Directive Generally Has Not Been Used

BLM has historically managed wild horses and burros removed from the range through adoptions to the general public. Adoption has been regarded as the most economical way to provide humane long-term care to animals that have been removed from the range. In the 1990s, the number of animals removed from the range was about equal to the number of animals adopted. The average number of animals adopted each year in the 1990s was about 7,500. Since 2000, the number of animals removed has outpaced the number of animals adopted or sold due to an increase in removals and a steady decline in adoption demand and sales. Since 2001, about 74,000 animals have been removed from the range, compared to about 46,400 adopted or sold. The average number removed annually from 2001 to 2007 was about 10,600, compared to the average adoption rate of about 6,300 annually. According to BLM's 2004 Report to Congress, at least 7,000 adoptions were needed annually to assist in achieving and maintaining AML. However, only about 4,700 animals were adopted in 2007. Although BLM has increased efforts to market adoptions, demand continues to decline for wild horses, even though the price for adopting them has remained at the minimum fee of $125 since 1997.[38] BLM officials attribute the steady wild horse adoption decline in recent years to increases in hay and fuel costs associated with horse care, the large number of domesticated horses that are currently flooding the adoption market,[39] a general urbanization of rural areas, and a shift toward other forms of recreation. For example, according to one official, individuals who once had corrals with two or three horses may now own one horse and four all-terrain vehicles. Figure 7 compares the number of wild horses and burros removed from the range with the number adopted from 1989 through 2007.

[38]Demand for burros has stayed relatively stable from an annual average of 1,154 burros adopted from 1990 through 1999 and an annual average of 1,092 burros adopted from 2000 through 2007.

[39]The last horse slaughterhouse in the United States closed in fall 2007. The number of domestic horses killed in slaughterhouses from 2000 to 2005 ranged from about 40,000 to 75,000 annually. Without these outlets, more domestic horses are available to the public, causing direct competition with wild horse adoptions and sales.

Figure 7: Comparison of Removed and Adopted Wild Horses and Burros, 1989 through 2007



Source: BLM.

One alternative for managing unadoptable excess wild horses and burros, as provided for by the 2004 amendment to the 1971 act, is to sell the animals "without limitation." The act directs BLM to offer excess animals for sale that are more than 10 years old or that have been offered unsuccessfully for adoption at least three times. At the time of the amendment, BLM estimated that approximately 8,400 animals were eligible for sale. To date, BLM has sold only about 2,700 animals—far fewer than originally expected, despite the low average selling price in 2006 of $15 (see table 10).

Table 10: Number of Wild Horses and Burros Sold under the December 8, 2004, Sales Directive

Year	Number sold
2005	1,468
2006	645
2007	420
2008[a]	211
Total	**2,744**

Source: BLM.

[a]As of June 2008.

In 2005, the first sale was made to a wild horse protection group in Wyoming who purchased 200 horses that would otherwise have likely ended up in long-term holding under BLM's care. A few other animals that were sold, however, ultimately ended up in slaughterhouses. To reduce the likelihood that a buyer would purchase these animals and then sell them for slaughter, BLM changed its sales process to require buyers to sign a "statement of intent" that they do not intend to sell the animals for slaughter. This limitation, as well as a decrease in demand, has contributed to the small number of sales.

BLM Manages 30,088 Animals in an Increasing Number of Short-Term and Long-Term Holding Facilities, and Holding Costs Have Increased

As of June 2008, BLM was holding a combined 30,088 animals in short-term and long-term holding facilities, compared to 9,807 animals in 2001. To accommodate the increase in animals needing care once removed from the range, the number of short-term and long-term holding facilities has increased. Spending on combined short-term and long-term holding has also increased from about $7 million in 2000 to about $20.9 million in 2007. From 2001 through 2008, the number of short-term holding facilities increased from 14 to 24,[40] and the number of animals held in these facilities increased from 6,514 animals to 7,987 by June 2008. These holding facilities provide the animals with vaccinations and other care prior to their being adopted, sold, or sent to long-term holding. The average cost of animals in short-term holding increased from $3.00 per horse per day in 2001 to $5.08 per horse per day in 2008. From 2000 to 2001, the cost for short-term holding increased from $6.4 million to $11.2 million. From

[40]Three of these facilities were added to incorporate horse gentling programs to improve the likelihood of adoption.

2001 through 2007, the cost remained relatively stable, but for 2008, costs are anticipated to increase to $16.2 million. According to several BLM officials, the escalating cost for caring for animals in short-term holding is primarily a result of the dramatic increase in hay and fuel prices from 2007 to 2008. For example, hay prices for one short-term holding facility in Nevada increased from about $160 per ton in 2007 to almost $300 per ton in 2008. Decreases in adoption and sales and a lack of capacity in long-term holding has not only increased the number of animals held in short-term holding, but has also increased the time animals are held there. According to one state official, animals in his state spent 45 to 60 days in short-term holding facilities in the late 1990s. Beginning in 2000, this official told us, it was not uncommon to hold animals for more than a year. Nationwide, according to BLM, the average length of stay in short-term holding in 2008 has been 210 days. This is far longer than the 90 days BLM projected animals would spend in short-term holding in their 2001 initiative to meet AML.

Similarly, the number of long-term holding facilities has increased, as has the cost. The number of facilities increased from 1 in 1988 to 11 as of June 2008, and the number of animals cared for increased from 1,500 in 2000 to 22,101 as of June 2008 (see table 11). These long-term holding facilities have reached their capacity—currently 22,100—despite the increase in numbers of facilities. BLM anticipates it will need greater long-term holding capacity and is working to contract for additional facilities.

Table 11: Number of Wild Horses in Long-Term Holding, by Year, Since 2000

Year	Number of facilities	Capacity	Number of horses in long-term holding
2000	1	2,000	1,500
2001	3	6,000	3,293
2002	5	10,000	7,311
2003	7	14,000	10,122
2004	7	14,000	13,151
2005	9	20,600	15,379
2006	8	19,700	18,198
2007	10	21,800	19,652
2008[a]	11	22,100	22,101

Source: BLM.

[a]As of June 2008.

BLM pays private contractors an average of $1.27 per horse per day to maintain the animals for the remainder of their lifespan, unless removed from long-term holding for adoption or sale. While this fee has increased by only 7 cents since 2000, the number of animals cared for has also increased, resulting in a significant increase in BLM spending on long-term holding.[41] In 2000, BLM spent approximately $668,000 in 2000, compared to more than $9.1 million in 2007 to care for wild horses in long-term holding. The long-term holding facilities are primarily located in Oklahoma and Kansas, where forage is typically more abundant than on HMAs of the West. Table 12 lists the 11 long-term holding facilities.

Table 12: BLM Long-Term Holding Facilities, June 2008

Name of facility	Location	Year(s) animals first held in facility	Capacity	Horses held
Bartlesville	Oklahoma	1989	2,300	2,066
Catoosa	Oklahoma	2001	2,000	2,042
Teterville East	Kansas	2001	2,200	1,913
Teterville West	Kansas	2002	2,200	2,531
Foraker	Oklahoma	2003	2,500	2,507
Pawhuska	Oklahoma	2003–2004	3,400	3,646
Grenola	Kansas	2004	2,200	2,269
Hulah	Oklahoma	2004	2,200	2,203
Herd	Oklahoma	2007	1,000	1,042
Whitehorse	South Dakota	2007	1,100	1,169
Strohm	Oklahoma	2008	1,000	713
Total			**22,100**	**22,101**

Source: BLM.

For at least two decades, BLM's primary strategy to manage excess unadoptable wild horses has been to increase long-term holding, despite warnings in our 1990 report that these facilities were likely to be more expensive than envisioned and to be only a temporary solution to the disposal of unadoptable animals.[42] In 1994, the Department of the Interior's Office of Inspector General also issued a report that strongly discouraged

[41]Long-term holding costs were, on average, $1.20 in 2000, $1.22 in 2001, and $1.25 per horse per day from 2001 through 2004. In 2005, the cost increased to $1.27 per horse per day through 2007 and will increase to $1.28 per horse per day by the end of 2008.

[42]GAO/RCED-90-110.

long-term holding as a solution to managing horses removed from the range due to the large costs.[43] BLM continues to look for more facilities but faces difficulty attracting new contractors that can sustain a large number of animals and that will accept the fee BLM offers, compared to perhaps more profitable land uses.

BLM Has Controls in Place to Help Ensure the Humane Treatment of Wild Horses and Burros, but It Could Better Track and Report These Data to the Public

BLM has implemented multiple controls to help ensure the humane treatment of wild horses and burros, including standard operating procedures and agreements with all three slaughterhouses in the United States before they closed in 2007. A variety of controls are used at various stages in the management of wild horses and burros, including for those animals that are gathered, in short-term holding facilities, in long-term holding facilities, adopted, or sold. BLM's controls for gathers include standard operating procedures, inspections, and data collection. While BLM state offices collect detailed data on animals that die during gathers, the information is not compiled by BLM headquarters in its centralized database, nor is it reported to the public. In addition, BLM does not regularly provide the information it tracks on the treatment of animals in short- and long-term holding and adoption inspections to the public. Making more of this data available to the public may help inform them about the treatment of the animals and improve transparency. Beginning in 1998, until the last horse slaughterhouse in the United States shut down in 2007, BLM sought agreements with all three slaughter facilities to alert BLM of wild horses that entered their facilities. According to BLM data, since 2002, about 2,000 wild horses whose legal titles were obtained by private citizens either through adoption or purchase were slaughtered. During that same period, another 90 wild horses whose title still belonged to BLM were retrieved from slaughterhouses by BLM and by wild horse groups. We reviewed the basic controls BLM has in place, but we did not evaluate their effectiveness. While BLM is required to implement controls to help ensure the humane treatment of wild horses and burros, such

[43]U.S. Department of the Interior, Office of Inspector General, *Selected Aspects of the Wild Horse and Burro Program* (Washington, D.C., May 1994).

controls cannot provide absolute assurance that all agency objectives will be met.[44]

BLM Internal Controls Help Ensure Humane Treatment, but BLM Could Improve Data Gathering and Reporting in Some Areas

A variety of controls are used at various stages in the management of wild horses and burros, including for those animals that are gathered, in short-term holding facilities, in long-term holding facilities, adopted, or sold. BLM's controls for gathers include standard operating procedures, inspections, and data collection. Data collected from 6 of the 10 states from fiscal years 2005 through 2007 indicate that mortality as a result of gathers is about 1.2 percent. Similarly, controls for short- and long-term holding include standard operating procedures, inspections, and data collection. BLM did not report any deaths due to neglect or abuse at holding facilities, aside from one animal that was repossessed by BLM after having been abused by an adopter. BLM has controls over the adoption of wild horses and burros, and data indicate that from 2005 to 2007, about 9 percent of adopters were not in compliance with BLM's standards of care. BLM's controls over humane treatment primarily apply to horses and burros before ownership is passed to private individuals, but BLM has also implemented some controls to protect horses and burros once ownership passes, such as when wild horses and burros are sold. For animals that are sold, since spring 2005, BLM has required buyers to sign a statement that they do not intend to slaughter the animals. BLM does not consistently track information on treatment during gather operations through a central database, nor does it report information about the treatment of animals during gathers, holding, or adoption inspections to the public.

Gathers

BLM has established controls, such as standard operating procedures and tracking systems, to help ensure humane treatment during gather operations. BLM hires contractors to remove wild horses and burros from the range. These contractors generally use helicopters to herd the animals into capture pens on the range (see fig. 8).

[44]Standards for internal control in the federal government describe internal controls as "a series of actions and activities that occur throughout an [agency's] operations and on an ongoing basis" used "to regulate and guide [the agency's] operations." See GAO, *Standards for Internal Control in the Federal Government*, GAO/AIMD-00-21.3.1 (Washington, D.C.: November 1999).

Figure 8: Helicopter Used to Gather Wild Horses Near Ely, Nevada, c. 2006



Source: BLM.

Due to the stress caused to wild animals by gathering them into pens, gather operations have the potential to cause harm to wild horses and burros, such as nervous agitation; conflict between captured animals; or more rarely, animal death. Because of the potential for harm and to help ensure the safe and humane handling of all animals captured, BLM has implemented a range of standard operating procedures for its gather contractors. Prior to the start of gather operations, BLM personnel evaluate the site of the gather to determine whether it is suitable based on environmental and safety concerns. They also approve gather facility plans ensuring, among other things, that they do not present puncture or laceration hazards and that they prevent animals from seeing humans, vehicles, and other perceived threats. During the herding of the animals, BLM sets limitations on the distance and speed the animals will travel, depending on the condition of the animals and other factors. As the animals are herded into the gather site, BLM requires contractors to segregate horses by age and sex to reduce the possibility of conflict and to ensure that very young horses and burros are not left behind to fend for themselves on the range. Finally, as the captured animals are transported from the gather site to short-term holding facilities, contractors are required to follow procedures to ensure animal safety, such as using adequately sized motorized equipment that has been inspected for safety. BLM has managed gathers with standard operating procedures since the passage of the act in 1971.

Although BLM's controls are designed to enhance the safety of wild horses and burros during gather operations, some animals are accidentally killed in the course of gathers or are euthanized because of ill health or prior injury. Six of the 10 BLM state offices reported data about the number of animals that die as a result of their gather operations. Data collected from 6 of the 10 states from fiscal years 2005 through 2007 indicate that, of the 24,855 animals removed from these states during this period, about 1.2 percent were either euthanized or died accidentally (see table 13). Horses and burros sometimes die due to accidents during gather operations on the range or after they are brought to the holding pens. For example, wild horses will sometimes panic and break their necks against capture pens. Animals found with conditions that make it unlikely they will be able to live their life without significant pain, such as lameness or club feet, are euthanized.

Table 13: Number and Percentage of Wild Horses and Burros That Died During Gather Operations, (for 6 of 10 States) Fiscal Years 2005 through 2007

Fiscal year	Number removed	Number of accidental deaths	Percentage	Number euthanized	Percentage
2005	9,830	25	0.25%	46	0.47%
2006	8,081	64	0.79	79	0.98
2007	6,944	28	0.40	60	0.86
Total	**24,855**	**117**	**0.47%**	**185**	**0.74%**

Source: GAO analysis of BLM data.

Note: This chart is based on data reported by 6 of 10 states: California, Colorado, Idaho, Nevada, New Mexico, and Wyoming. The data provided could not be verified for its reliability. We requested this information from the other four states (Arizona, Montana, Oregon, and Utah), but the information was not provided.

Although BLM national and state officials told us that they sometimes record data about the animals accidentally killed or euthanized during gathers at the BLM state office level, BLM does not centrally compile or report these data to the public on a regular basis on a national level. A BLM official told us that although their main tracking database has the capability to record the number of animals that are killed or euthanized during gathers, they generally do not use the database to do so because it was originally intended to track adoptions. Moreover, BLM has not regularly reported to the public how many wild horses and burros are killed in the course of gathers, although BLM officials have cited the data during public hearings. Some advocates and members of the public believe that gathers are held in secret and highlight individual cases of apparent mistreatment as evidence that inhumane treatment is widespread.

However, a BLM official told us that it is BLM's standard practice to allow the public and the media to observe gather operations, and BLM is required to hold public hearings prior to scheduled gathers using helicopters. If BLM does not improve its transparency by presenting reliable data to members of the public, BLM will continue to be vulnerable to accusations that gathers are generally cruel and inhumane.

Short-Term Holding

BLM has issued standard operating procedures to help ensure that wild horses and burros held in short-term holding facilities are well cared for. They include procedures for minimizing the excitement of the animals to prevent injury; separating horses by age, sex, and size; observation of the animals on a regular basis; and recording information about the animals that BLM later uses for tracking the animals in BLM's database. BLM's short-term holding facilities are mostly maintained and directly managed by BLM, either on government property or on leased property. Several are at state prisons, and a few others are maintained by contractors in privately-owned feedlots or ranches that BLM has leased. According to BLM staff, they regularly inspect the short-term holding facilities and the animals they hold. They inspect to see that the corral equipment is up to code and that animals are treated with appropriate veterinary care. For example, staff check to see that the horses' hooves are regularly trimmed so that they do not become too long and cause injury. At two of the short-term holding facilities we visited, we observed specially constructed chutes that hold and rotate horses in place so that horses' hooves can be trimmed more quickly, easily, and with less risk to the animals and the employee than other methods, such as using tranquilizer darts or roping (see fig. 9).

Figure 9: BLM Contractor Trimming Horse Hooves Using a Special Holding Chute at a Contract Short-Term Holding Facility in Fallon, Nevada, October 2007



Source: GAO.

BLM data indicate that the wild horses and burros held in short-term holding facilities from 2003 to 2007 had a mortality rate of about 5 percent. Specifically, for 2007, BLM reported 936 deaths in short-term holding facilities out of a total of 17,363 animals that passed through short-term holding facilities in that year.[45] BLM reported that none of the animals in its care died of neglect or abuse between 2005 and 2007, aside from one case in 2006, where a reclaimed adopted horse died in BLM care due to the effects of abuse suffered while it was in the care of an adopter. BLM data showed that the animals generally died due to sickness, broken limbs, or injuries sustained accidentally during gathers. BLM does not report this information regularly to members of the public who remain concerned that the agency does not adequately care for animals in short-term holding.

Long-Term Holding

BLM has similar controls in place for its long-term holding facilities. BLM staff inspect long-term holding facilities annually to count the number of animals held. Staff also monitor pasture conditions, winter feeding, and

[45]For 2007, BLM also reported 616 births in short-term holding facilities.

animal health throughout the year. According to BLM staff, during these visits they ensure the contractors comply with BLM provisions and discuss possible problems that can be corrected. In addition, veterinary staff from the Department of Agriculture's Animal and Plant Health Inspection Service inspect long-term holding facilities annually; these inspections involve a full count of the horses held there, an inspection of the horses' general health, and written reports. Animal and Plant Health Inspection Service reports from 2007 indicate that the horses kept in long-term holding sanctuaries are generally in "good" or "excellent" condition. These reports, however, highlight some areas for possible improvement. At one facility, one area of improvement included the proper disposal of the remains of animals that have died of natural causes. To help ensure the animals are well cared for, a contract veterinarian provides care when needed at BLM direction and expense. In addition to inspecting the facilities for the well being of wild horses in long-term holding, contractors are required to count and report the number of horses held on a weekly basis for billing and payment purposes. In 2007, long-term holding contractors were paid an average fee of $1.27 per horse per day, or about $460 per horse per year. While this contract fee structure is not in itself a control that guarantees humane treatment, it provides a profit incentive for contractors to ensure the continued health of the horses. According to one BLM official, BLM does not regularly document the results of its inspections. This official told us that the agency would take actions and record them if it found problems, but the official generally has not found problems with the contractors that have warranted action beyond informal conversations to address minor issues.

BLM collects data on how wild horses are cared for in long-term holding, including the number of animals that die in long-term holding. The average mortality rate of wild horses in long-term holding from 2003 through 2007 was about 8 percent, but it fluctuated from a low of 5 percent to a high of 14 percent during that time period. Specifically, for 2007, BLM reported 938 deaths in long-term holding facilities.[46] The number of wild horses in long-term holding in 2007 was 19,652. The animals that die in long-term holding are generally found in the pastures, and unless there is evidence of foul play, BLM does not investigate the cause of death. According to BLM, barring any evidence to the contrary, it is assumed that the animals in

[46]For 2007, BLM also reported 303 births in long-term holding facilities. Although studs are gelded prior to being sent to long-term holding and the wild horses are separated by sex, pregnant mares may be transferred from short-term holding facilities into long-term holding facilities.

long-term holding die of old age. Officially, BLM reported about 95 percent of the animal deaths in long-term holding as "undiagnosed." Some of the other causes of deaths reported included old age and respiratory illness. No animals in long-term holding died from neglect or abuse, according to BLM reports. While BLM collects this data, it does not report this data regularly to the public. In the absence of this data, some members of the public who advocate greater protection for wild horses have repeatedly expressed their concern that BLM does not adequately care for animals in long-term holding.

Adoption

The act requires BLM to determine that adopters have provided humane conditions, treatment, and care for adopted animals for at least 1 year before BLM transfers ownership to the adopter. To implement the act, BLM has established policies for inspecting adopted horses or burros in this first year through telephone calls or personal visits. BLM inspections focus on the condition of the animal; the condition of the facilities; and whether the adopter has notified BLM if the adopted animal has been moved, was stolen, has escaped, or has died. Prior to taking possession of an adopted animal, BLM requires that adopters describe the facility where they will maintain the adopted animal. This is documented in their application, which confers penalties for providing false information.

According to BLM data, from 2005 through 2007, an average of about 9 percent of adopted wild horses and burros that still belong to the government have not been treated in compliance with BLM standards (see table 14). BLM randomly selects a sample from the universe of approximately 5,000 adopters per year who have not yet received title of their adopted animal for inspection. BLM inspects these adopters in order to generate a statistical sample of the likely percentage of adopted animals kept under conditions that do not comply with BLM's policies and standards. The most common conditions in need of improvement included the failure to report changes in the animal's location or status and substandard facilities, such as inadequate fencing or shelter. Less common conditions included lack of care of the animal, such as inadequate feeding or failure to trim the animal's hooves before they grew too long.

Table 14: Results of Random Inspections of Wild Horse and Burro Adoptions, 2005 through 2007

	2005		2006		2007	
Result of random adoption inspections	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
No violation	395	94%	614	91%	805	89%
Failure to notify BLM of change in status	10	2	24	4	36	4
Failure to provide adequate facilities/care	4	1	3	0	30	3
Failure to produce animal	5	1	13	2	19	2
Unauthorized transfer/sale	0	0	6	1	15	2
Commercial exploitation	0	0	0	0	4	0
Inadequate facility	4	1	6	1	0	0
Unauthorized destruction	0	0	5	1	0	0
Inhumane treatment	2	0	0	0	0	0
Total	**420**	**100%**	**671**	**100%**	**909**	**100%**

Source: GAO analysis of BLM data.

In addition, BLM policy directs that officials or certified volunteers conduct personal inspections of all adopted animals whenever BLM receives complaints about mistreatment or when an individual or organization adopts more than four wild horses or burros at one time.

Similar to the data collected on the animals in short- and long-term holding, BLM does not provide information on the results of its adoption inspections to the public. The information regularly provided to the public on the treatment of these animals is in contrast to the comparatively large amount of information BLM provides on the program's Web site regarding information on AML and population estimates for each HMA.

Sales

In the case of animals that were legally sold, BLM has implemented limitations to prevent these animals from being resold to slaughter facilities. In 2004, the act was changed and directed BLM to sell, "without limitation," excess wild horses and burros more than 10 years of age or that had been offered unsuccessfully for adoption at least three times, until all excess animals for sale are sold or until AML is met in all HMAs. However, shortly after BLM began to sell wild horses and burros without limitation, in early 2005, it was discovered that 41 of these wild horses had been slaughtered. In April 2005, BLM suspended its wild horse sales program and resumed sales in May 2005, after adding controls intended to restrict the sale of animals for the purpose of selling them for slaughter. These controls included BLM's requirement that buyers sign a statement

they do not intend to sell the animals for slaughter and verification that potential buyers would provide adequate care for the animals.

BLM Implemented Controls to Prevent Slaughter of Wild Horses in the United States

Although BLM is no longer required to protect animals after ownership has passed to adopters or buyers, BLM implemented controls to help prevent their slaughter beginning in 1998. BLM had negotiated agreements with all three U.S. facilities that operated horse slaughterhouses. The slaughterhouses agreed to alert BLM to all wild horses that entered their facilities and refrain from slaughtering those wild horses whose title still belonged to BLM. According to BLM data, which it was able to provide since 2002, about 2,000 wild horses whose legal titles were obtained by private citizens through adoption or purchase were slaughtered. During that same time period, at least 90 adopted wild horses that were still owned by the government were brought to these slaughterhouses, and all were retrieved by BLM and interested wild horse groups.

As of fall 2007, all horse slaughter facilities in the United States had been shut down following unsuccessful legal challenges to state laws effectively banning the practice. In January 2007, the U.S. Court of Appeals for the Fifth Circuit ruled that a 1949 Texas law banning the sale, possession, or transfer of horsemeat applied to the two slaughterhouses in Texas.[47] In September 2007, the U.S. Court of Appeals for the Seventh Circuit upheld an Illinois ban.[48] These rulings effectively closed the plants and ended horse slaughter in the United States.

Even though all horse slaughter facilities in the United States have been closed, it is still possible for wild horses and burros to be sold to facilities outside the United States.[49] Prior to the closure of all U.S. horse slaughter facilities, about 50,000 domestic horses were brought to slaughter in the United States annually between 2001 and 2004. Generally, exporting horses and burros to other countries for slaughter, such as Canada or Mexico, is not prohibited; for example, about 3,000 horses per month were exported for slaughter in 2007, according to Department of Agriculture

[47]*Empacadora de Carnes de Fresnillo v. Curry*, 476 F.3d 326 (5th Cir. 2007), *cert. denied*, 75 U.S.L.W. 3569 (U.S. May 21, 2007). *See also*, Tex. Agric. Code Ann. §§ 149.001-149.007.

[48]*Cavel Int'l, Inc. v. Madigan*, 500 F.3d 551 (7th Cir. 2007), *cert. denied*, 76 U.S.L.W. 3410 (U.S. June 16, 2008). *See also*, 225 Ill. Comp. Stat. 635/1.5.

[49]Current legislation pending in the 110th Congress (H.R. 503 and S. 311) would prohibit the commercial sale of horses to foreign countries, such as Canada and Mexico, to be slaughtered for human consumption.

information. We attempted to determine how many of these horses were at one time wild, but we were not able to do so. The Department of Agriculture, which certifies the inspections of horses and other livestock exported to other countries, is not required and does not report how many of the horses exported to other countries were once wild horses.

Challenges to the Long-Term Sustainability of the Program Include Growing Holding Costs and Limited Options for Dealing with Unadoptable Animals

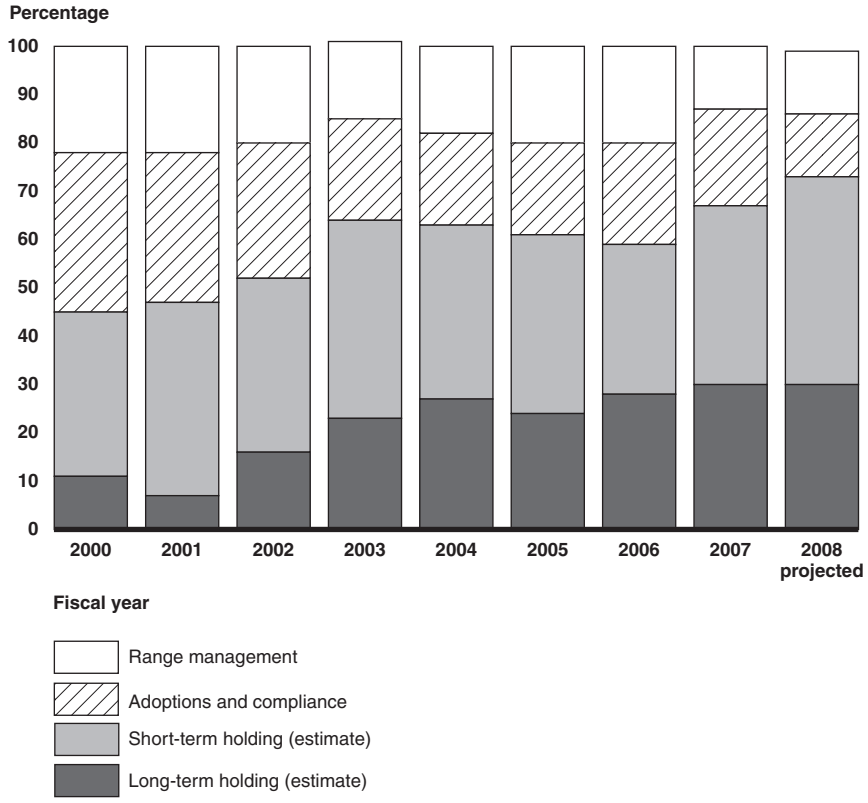
The long-term sustainability of BLM's Wild Horse and Burro Program depends on the resolution of two significant challenges. First, holding costs are overwhelming the program's ability to manage animals on the range and will continue to do so if BLM does not consider alternatives to holding. Second, BLM has limited options for dealing with unadoptable animals off of the range because its alternatives under the act—humane destruction of the animals or selling the animals without limitation—are thought to be unacceptable to the public. As a result, BLM has placed over 30,000 wild horses and burros in holding.

If Not Controlled, Off-the-Range Holding Costs Will Continue to Overwhelm the Program

The portion of the Wild Horse and Burro Program's spending that is directed toward short- and long-term holding has increased from 46 percent of the program's direct costs in 2000 to 67 percent in 2007. This increase leaves a smaller portion of the budget available for on-the-range management activities. Much of the increase has occurred because accelerated removals implemented to reach AML have coincided with a decline in adoption demand. Because long-term holding facilities are at capacity, BLM has had little choice but to hold excess unadoptable horses in more expensive short-term holding. BLM's spending on short- and long-term holding has increased from about $7.0 million in 2000, or 46 percent of the program's direct costs, to about $20.9 million in 2007, or 67 percent of the program's direct costs (see fig. 10). In 2008, BLM anticipates that holding costs will account for about 74 percent of the program's direct costs. To deal with its long-term holding problem, BLM has primarily sought increased funding to open additional long-term holding facilities. However, funding is not likely to increase in the future, and limited funding is forcing BLM to make difficult choices. For example, in January 2008, BLM considered canceling all remaining removals scheduled for the fiscal year because of the amount needed for short- and long-term holding. As of July 2008, BLM was seeking the funds to continue these removals by redirecting money from other BLM activities to the Wild Horse and Burro

Program. As a result, under current funding levels, BLM must now choose between either managing the range to prevent overpopulation or exercise one or both of its other options—destroying animals or selling them without limitation.

Figure 10: BLM Estimated Wild Horse and Burro Direct Program Costs, Fiscal Years 2000 through 2008



Source: GAO analysis of BLM data.

Note: This chart represents direct program spending. It omits spending on overhead items—which average about $7 million per year—such as administrative costs, vehicle costs, and other nondirect program related costs.

To continue to reduce overpopulation on the range by using gathers alone, BLM projects that the program's budget would have to increase to about $77 million by fiscal year 2012, from about $36 million in 2008. If BLM does not receive this increase or exercise its other options to reduce populations off the range, then it will not have sufficient funds to manage wild horses and burros on the range, and populations will sharply

increase. BLM's current projections indicate that caring for unadoptable animals would reduce the agency's ability to gather horses to an average of about 4,500 animals per year, which would only be enough to prevent animals from dying from the effects of overpopulation and drought. At these removal levels, BLM projects that the on-the-range population would reach 50,000 animals by 2012—about 80 percent greater than the upper limit of AML. This on-the-range population level would be greater than the population level prior to the beginning of BLM's 2001 strategic plan.

Since 2004, BLM has had the goal of reducing the total population on the range to the midpoint of AML. If it were to reach this level, which is currently about 22,588 animals, an annual population growth rate of 20 percent would require the annual removal of about 4,500 animals to maintain that level, approximately equal to the recent adoption rate. Assuming that rate remained constant, fewer animals would be sent to long-term holding. However, even if BLM is able to reach a balance between animals removed and those adopted, it still has the challenge of dealing with 30,088 animals that are currently held in short-term and long-term holding facilities across the country. Furthermore the number of animals held in holding would exceed 40,000 animals if BLM were to remove the approximately 11,000 animals necessary to reach the midpoint of AML.

BLM has a number of research projects under way and ideas in development that could slow the increase in the population on the range. These include fertility control efforts, such as the development of a fertility vaccine (see app. II for more information on this vaccine) and releasing sterilized male horses back to the range after capture. Given that many existing HMAs are already over AML, releasing a large number of sterilized male horses or nonreproducing herds back to the range as a means of trying to reduce future holding costs would likely require changing existing land use decisions within BLM's existing authority to increase AMLs, expand existing HMAs or designate new HMAs; or through seeking new legislative authority. Under the 1971 act, the land available for the management of wild horses and burros is limited to the areas where they existed at the time of the act. The originally designated herd areas consisted of 53.5 million acres compared to the existing HMA acreage of 34.3 million, a difference of 19.2 million acres. Specifically, the BLM owned acreage managed for wild horses and burros has changed from 42.2 million acres to 29.0 million acres, a difference of 13.2 million acres. As we mentioned earlier, BLM is in the process of compiling a history of actions that led to these changes. At this point, however, it is not clear how much of the 13.2 million acres is still public land under BLM's control.

While BLM could change AMLs, expand existing HMAs, or designate new HMAs within its existing authority, BLM is a multiple use agency and it weighs the needs of wild horses and burros against other competing uses. Alternatively, should BLM chose to do so, new legislative authority could be pursued to allow nonreproducing herds to be relocated to areas where they were not found at the time of the act. We believe that it is important to consider increasing AML or expanding HMA acreage only as a means to accommodate nonreproducing herds. Increasing the number of reproducing animals on the range without corresponding solutions for fertility control or declining adoption demand will, in the long run, only exacerbate BLM's problems with dealing with excess animals.

Under Current Law BLM's Options Are Limited for Dealing with Unadoptable Animals

Despite these budget problems, BLM has avoided using two options in the act for dealing with unadoptable animals because of concerns over the public and congressional reaction to the large-scale slaughter of thousands of healthy horses. The Wild Free-Roaming Horses and Burros Act, as amended, requires that excess animals, for which the adoption demand is not sufficient to absorb all the animals removed from the range, be destroyed in the most humane and cost-efficient manner possible or, under certain circumstances, be sold without limitation. The 1978 amendments to the original 1971 act directed that "[t]he Secretary shall cause additional excess wild free-roaming horses and burros for which an adoption demand by qualified individuals does not exist to be destroyed in the most humane and cost efficient manner possible."[50] From 1981 to 1982, BLM destroyed at least 47 excess animals. BLM decided not to destroy excess unadoptable animals in 1982 after the Director issued a policy prohibiting the destruction of healthy animals because of public dismay. Furthermore, from fiscal year 1988 through fiscal year 2004, Congress prohibited BLM from using its Management of Lands and Resources appropriations to destroy excess healthy, unadoptable wild horses and burros.

In our 1990 report, we found that keeping excess animals in long-term holding was costly and recommended that BLM examine alternatives, such as sterilizing animals and releasing them back into the wild.[51] Although BLM was prohibited from using its Management of Lands and Resources appropriations for humanely destroying excess animals through

[50] 16 U.S.C. § 1333(b)(2)(C).

[51] GAO/RCED-90-110.

euthanasia at the time of that report, we also recommended that BLM consider this action as a last resort in the event that Congress lifted the prohibition in the future. The recurring prohibition in the annual appropriations bills ended after fiscal year 2004. Since then, BLM has no longer been prohibited from using its Management of Lands and Resources appropriations for carrying out the requirement to destroy excess animals. BLM still has not used this option.

In 2004, Congress provided BLM with an alternative to destroying unadoptable excess animals by amending the act to state that "[a]ny excess animal or the remains of an excess animal shall be sold if—(A) the excess animal is more than 10 years of age; or (B) the excess animal has been offered unsuccessfully for adoption at least 3 times."[52] Furthermore, the amendment stipulated that the excess animals "shall be made available for sale without limitation."[53] BLM has instead imposed limitations on the sales of excess animals in an effort to reduce the risk that animals purchased at a low price would be resold to slaughterhouses for profit.

As a result, BLM is not in compliance with the act. BLM officials told us that they have chosen not to destroy excess animals or sell them without limitation because of concerns about public and congressional reaction to the large-scale slaughter of thousands of healthy horses. Various BLM officials at different levels of responsibility also told us that the agency has not complied with these provisions because doing so would cause an immediate threat to the careers of any officials involved, due to the anticipated negative reaction of the public and Congress. Nevertheless, as of June 2008, budget constraints forced BLM to reconsider all of its options, officials told us. Specifically, for fiscal year 2009, BLM is considering euthanizing about 2,300 horses from short-term holding—about one-third of the animals currently in short-term holding. In addition, they are considering selling without limitation about 8,000 animals from both short- and long-term holding. However, as of August 31, 2008, legislation was pending in the 110th Congress that would repeal the directive for BLM to sell animals without limitation, but not the requirement to destroy unadoptable excess horses.[54]

[52]16 U.S.C. § 1333(e)(1).

[53]16 U.S.C. § 1333(e)(2).

[54]H.R. 249, 110th Cong. (2007). The bill was passed by the House of Representatives on April 26, 2007. As of August 31, 2008, the Senate had not acted on the bill.

Other than one pilot project, BLM has not initiated strategies to reduce the number of horses they currently manage in long-term holding and has not formally considered other possible solutions to indefinitely caring for horses in long-term holding. BLM officials who lead state Wild Horse and Burro Programs suggested several actions that could be taken to alleviate off-the-range costs to the program, but many of these changes would require changes in the law or BLM regulations. The most common suggestion, made by 4 of the 10 state leads, was that the federal government should provide incentives for private individuals or organizations to care for unwanted wild horses, such as monetary incentives or tax deductions. In 2003, BLM initiated a pilot project in Wyoming to pay private ranchers a one-time lump sum to care for unadoptable excess animals. This pilot project ended because of a lack of up-front funds. In addition, a BLM official familiar with the project told us that private ranchers had less interest in the project as the market for cattle grazing improved. Implementing tax deductions would likely require changes in the tax law. Another suggestion made by three of the state leads was that the act should be changed to allow the government to manage unadoptable wild horses and burros on public or private lands outside areas where they were originally found. The act currently does not allow BLM to relocate wild horses and burros to areas of public lands where they were not found when the act was passed. To date, BLM has not sought the legislative changes that would make these suggestions possible.

Conclusions

The management of a program consisting of wild free-roaming animals is unique within BLM, and it presents distinct management challenges. While BLM has made significant progress in increasing the number of HMAs that have set AML and in moving toward meeting AML, its recent removal efforts have resulted in the agency managing almost the same number of animals off of the range as they manage in the wild. By spending an ever increasing amount of funding on caring for animals off the range, little funding is left to conduct important on-the-range management activities, as originally envisioned in the act. Now that BLM is closer to meeting AML, it is important for field offices to have the resources necessary to maintain those levels and to monitor whether those levels indeed create the “thriving natural ecological balance” called for in the act.

Future changes to AML determinations should be based on consistent factors across HMAs. With the turnover of the more experienced senior BLM staff that set the existing AMLs to newer more junior staff, it is important that the newer staff have clear official guidance to follow on making AML determinations. It is also important for the management of

the program that BLM have the most accurate population estimates possible. While counting wild free-roaming animals is an inherently challenging task, the widespread use of statistically based counting methods across more HMAs, as appropriate, would provide a scientifically sound basis for compensating for possible undercounts. BLM provides a great deal of information about the Wild Horse and Burro Program through its Web site, including information on AML and population estimates for each HMA. However, despite public concerns about the humane treatment of these animals, BLM has not provided the public with easily accessible information about their treatment. In some cases, BLM headquarters does not centrally compile information on the treatment of animals during gathers. Providing the public with additional information on the treatment of animals during gathers and once they are removed from the range would help inform the public about their treatment.

In our 1990 report, we noted that given the amount of federal resources needed to maintain unadoptable excess horses in long-term holding, BLM would need to seek alternative options. At the time, we recommended that BLM consider a variety of disposal options for these horses that were not being used, including sterilization and euthanasia. Today, about 20 years after the first long-term holding facility opened, with adoption demand declining and alternative disposal options still not being used, BLM is continuing to open new long-term holding facilities to care for unadoptable wild horses, and the costs continue to escalate. Cost-effective alternatives for long-term holding are still needed.

BLM is faced with a dilemma as it attempts to comply with the act. On one hand, the act directs BLM to protect and preserve wild horses and burros, and on the other hand the act directs BLM to destroy excess animals for which an adoption demand does not exist or, under certain circumstances, to sell them without limitation, which has led to the slaughter of some animals. BLM has committed to caring for these animals, even though the law requires their humane destruction or sale without limitation and the cost for their care off-the-range is now overwhelming the program. The program is at a critical crossroads. Within the program's existing budget, BLM cannot afford to care for all of the animals off the range, while at the same time managing wild horse and burro populations on the range. Resource limitations are forcing BLM to reconsider all available management options, and a workable solution must be developed to bring BLM into compliance with the act.

Recommendations for Executive Action

We make five recommendations to the Secretary of the Interior.

To improve the management of BLM's Wild Horse and Burro Program, we make four recommendations that the Secretary of the Interior direct BLM to:

- finalize and issue the new *Wild Horse and Burro Program Handbook* that establishes a policy for setting AML to ensure that AML is determined based on consistent factors across HMAs into the future;
- continue to adopt and employ statistically based methods to estimate animal populations across HMAs, such as those being evaluated by animal population researchers, to improve the accuracy of population estimates integral to BLM's management of wild horses and burros on the range and in planning for capacity needed for excess animals once they are removed from the range;
- track the number of animals harmed or killed during the gather process in a centralized database system and determine what information on the treatment of gathered animals, short-term and long-term holding animals, and adopted animals could easily be provided to the public to help inform them about the treatment of wild horses and burros; and
- develop cost-effective alternatives to the process of caring for wild horses removed from the range in long-term holding facilities and seek the legislative changes that may be necessary to implement those alternatives.

To address BLM's noncompliance with the act, as amended, we recommend that the Secretary of the Interior direct BLM to discuss with Congress and other stakeholders how best to comply with the act or amend it so that BLM would be able to comply. As part of this discussion, BLM should inform Congress of its concerns with (1) the act's requirement for the humane destruction of excess animals and (2) the possible slaughter of healthy horses if excess animals are sold without limitation, under certain circumstances, as the act requires.

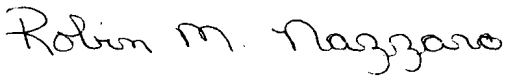
Agency Comments and Our Evaluation

We provided a draft of this report to the Department of the Interior for review and comment. The department concurred with our findings and recommendations and believes they will help to improve the Wild Horse and Burro Program. In addition, the department provided several technical clarifications, which we incorporated as appropriate. Appendix IV contains the Department of the Interior's comment letter.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies of this report to the Secretary of the Interior, the Director of BLM, and other interested parties. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff has any questions about this report, please contact me at (202) 512-3841 or nazzaror@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix V.

Sincerely yours,



Robin M. Nazzaro
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

We examined (1) the Bureau of Land Management's (BLM) progress in managing wild horses and burros on the range through setting and meeting appropriate management levels (AML); (2) BLM's management of wild horses and burros off of the range through adoption, sales, and holding facilities; (3) the controls BLM has in place to help ensure humane treatment of wild horses and burros; and (4) what challenges, if any, BLM faces in managing for the long-term sustainability of the Wild Horse and Burro Program. We were also asked to review how and why the acreage available for wild horses and burros had changed since the 1971 act. We did not examine the acreage issue because BLM is in the process of compiling a history of acreage determinations. BLM officials expect their review to be completed by March 2009.

To examine how BLM manages wild horses and burros on and off of the range and to identify the challenges facing BLM, we reviewed relevant laws, regulations, BLM policy, and BLM strategic plans. We also surveyed, and analyzed documents from, 26 of the 44 BLM field offices that manage wild horses and burros.[1] We collected and reviewed relevant resource management decision documents from the surveyed field offices to help corroborate their responses about specific questions, including those about factors used to make AML determinations and gather decisions. We surveyed field offices in all 10 western states that manage HMAs. The field offices we surveyed represent 82 percent of all BLM acres managed for wild horses and burros, 74 percent of all BLM managed wild horses, and 69 percent of burros on the range at the time of the survey. Our survey sample included 100 percent of the BLM field offices that manage HMAs in Nevada, including the Tonopah Field Station (seven offices); three randomly selected field offices from each of the five states whose field offices or district offices manage a population of wild horses and burros that fall between 1,000 and 10,000 horses (Arizona, California, Oregon, Utah, and Wyoming); and one randomly selected field office from each of the four states whose field offices manage a population of wild horses and burros that is less than 1,000 (Colorado, Idaho, Montana, and New Mexico). Because most of our survey questions focused on the management of a particular HMA, we judgmentally selected an HMA for each field office to consider in responding to our survey. We considered a

[1]We drew our sample of 26 field units from among the 44 field units that manage Herd Management Areas (HMA), which include 39 field offices, 4 district offices in Oregon, and 1 field station in Nevada. We will refer to these 44 BLM field units collectively as field offices. BLM's count of the number of offices that manage HMAs may differ because the 4 district offices in Oregon manage 7 resource area offices.

variety of factors in making these HMA selections, including herd population size and whether the HMA had met or not met AML (according to 2007 BLM Statistics). Table 15 lists the 26 BLM field offices and HMAs we selected as part of our survey.

Table 15: BLM Field Offices and HMAs Included in GAO's Survey

BLM field office by state	HMA
Arizona	
Yuma Field Office	Cibola–Trigo
Hassayampa Field Office	Lake Pleasant
Kingman Field Office	Black Mountain
California	
Surprise Field Office	High Rock
Alturas Field Office	Red Rock Lakes
Ridgecrest Field Office	Centennial
Colorado	
White River Field Office	Piceance–East Douglas Creek
Idaho	
Four Rivers Field Office	Four Mile
Montana	
Billings Field Office	Pryor Mountain Wild Horse Range
Nevada	
Tonopah Field Station	Montezuma Peak
Battle Mountain Field Office	South Shoshone
Carson City Field Office	Flanigan
Elko Field Office	Rock Creek
Ely Field Office	Dry Lake
Las Vegas Field Office	Red Rock
Winnimucca Field Office	Granite Range
New Mexico	
Socorro Field Office	Bordo Atravesado
Oregon	
Prineville District Office	Liggett Table
Lakeview District Office	Beaty's Butte
Vale District Office	Coyote Lake–Alvord Tule Springs

BLM field office by state	HMA
Utah	
Richfield Field Office	Canyon Lands
Vernal Field Office	Hill Creek
Fillmore Field Office	Conger
Wyoming	
Rock Springs Field Office	Divide Basin
Cody Field Office	McCullough Peaks
Lander Field Office	Dishpan Butte

Source: GAO.

The survey included several open-ended responses aimed at determining the primary challenges associated with meeting and maintaining AML, the primary challenges facing the Wild Horse and Burro Program as a whole, and suggestions for ways to improve the program. Two GAO analysts independently reviewed these open-ended survey responses, agreed upon the categories for coding each response, and resolved any disagreements in coding to determine what the respondents as a whole thought about these issues.

The practical difficulties of conducting any survey may introduce errors, commonly referred to as nonsampling errors. For example, difficulties in how a particular question is interpreted, in the sources of information that are available to the respondents, or in how the data are entered into a database or were analyzed can introduce unwanted variability into the survey results. We took steps in the development of the questionnaire, the data collection, and the data analysis to minimize these nonsampling errors. For example, survey specialists designed the questionnaire in collaboration with GAO staff with subject matter expertise. Then, the draft questionnaire was pretested with officials from five BLM field offices in four different states to ensure that the questions were relevant, clearly stated, and easy to comprehend. We also conducted follow-up phone calls to clarify ambiguous or incomplete responses. We received usable responses from all field offices that we surveyed—a 100 percent response rate. See appendix III for a summary of the survey responses not presented elsewhere in the report.

We also interviewed agency officials at BLM Headquarters; the National Program Office in Reno, Nevada; and Wild Horse and Burro Program State Leads from each of the 10 states that manage wild horses and burros. In addition, we conducted site visits at two field offices that manage HMAs in Nevada and Colorado; one long-term holding facility in Oklahoma; three

short-term holding facilities in Colorado, Nevada, and Wyoming; and attended two adoption events in Arizona and Colorado.

To examine humane treatment, we reviewed relevant laws, regulations, and BLM policies. We collected and analyzed reports from BLM Headquarters, state offices, and data from BLM's compliance database. We also interviewed BLM compliance officials from two states, a veterinarian from the Department of Agriculture's Animal and Plant Health Inspection Service, and public citizens and advocacy groups that work to promote the well being of wild horses and burros.

As part of our overall methodology, we interviewed a range of stakeholders interested in BLM's management of the Wild Horse and Burro Program, including, but not limited to, the American Wild Horse Preservation Campaign, the Animal Welfare Institute, the Cloud Foundation, the Humane Society of the United States, the National Cattlemen's Beef Association, and Nevada Bighorns Unlimited.

We conducted this performance audit from September 2007 to October 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Fertility Control and Genetic Variability

In addition to the information provided in this report to answer our primary objectives, we encountered two other issues related to BLM's management of the Wild Horse and Burro Program. The issues primarily relate to BLM's on-the-range management activities, including fertility control and genetic variability.

Fertility Control

BLM has been pursuing a fertility control vaccine called porcine zonae pellucida since 1992 to use as a tool for slowing the reproductive rate in wild horse populations. A slower reproductive rate would reduce the number of animals that would have to be gathered and removed, adopted, and held. BLM officials do not consider this treatment as the best short-term management tool to achieve AML but believe that once HMAs are at AML, fertility treatment can help to maintain that level. Much research has been conducted about the use of the vaccine in domestic and wild horses. The Department of the Interior's National Park Service has used this treatment to successfully manage wild horse populations at two national seashores. BLM field offices have been directed to consider the use of fertility control as an alternative in their gather plans, but they are not required to choose this research tool. The vaccine is considered experimental, and as such, there are barriers to its use. Since 2004, 47 HMAs have used fertility treatments, and a total of about 1,800 wild horses have been injected with the treatment. BLM considers the use of this treatment as a research tool; however, according to a prominent wild horse fertility researcher, BLM should more actively pursue its use as a management tool. According to BLM officials, fertility control may offer the possibility of reducing reproduction rates and costs, but BLM will still need to place horses in long-term holding in the future.

Genetic Variability

Herd health is another important component of BLM's on-the-range management of wild horses and burros. Specifically, it is important to maintain a degree of genetic variability to decrease the likelihood of disease and to maintain the biological fitness of the population. The amount of genetic variability that is sufficient to maintain a healthy population, however, is difficult to discern. Some groups have criticized BLM for setting AMLs at levels that are less than 100 or 150 animals. As of February 2008, 135 of the 199 HMAs had an upper limit of 150 or less for AML (see table 16). Several of these smaller HMAs, however, are part of a complex of HMAs that are managed as one unit where there is regular genetic interchange. For example, 13 complexes in Nevada encompass 45 of their 102 HMAs. According to a leading researcher in the field of wild

horse genetics, however, a herd that has a population of less than 100 can be maintained with the introduction of at least one or two horses every 6 to 7 years, including those whose herd size are as small as 10 to 15 horses.

Table 16: Number of HMAs Managed at Various AMLs, February 2008

Upper limit of AML	Number of HMAs
0	8
1–100	102
101–150	25
151–200	16
201–300	25
301–500	16
501–1,000	5
Not yet determined	2
Total	**199**

Source: BLM.

BLM manages a few herds that show strong evidence of old Spanish heritage which no longer exists outside of the Americas. For example, the Kiger Mustangs of Oregon and the Pryor Mustangs of Montana have some colonial Spanish traits. For most of the HMAs, however, genetic variability is important primarily in maintaining the health of the herd, rather than managing for a specific genetic trait or bloodlines.

Appendix III: Wild Horse and Burro Survey Results

The following tables summarize responses collected through our survey instrument that was sent to 26 BLM field offices that manage HMAs. See appendix I for a complete explanation of which offices were chosen and the methodology used to select those field offices and specific HMAs. Our survey was divided into two sections. The first asked questions specific to the field offices' management of particular HMAs. The second section asked questions related to the field offices' general management of all HMAs.[1]

Section I: Field Office Responses Specific to Selected HMAs

Table 17: Current and Initial AML and Year of Determination per HMA Surveyed

HMA, by state	Initial AML	Year initial AML was set	Current AML	Year current AML was set
Arizona				
Cibola–Trigo	315	1980	[a]	[a]
Lake Pleasant	80	1988	208	2000
Black Mountain	148	1978	478	1996
California				
High Rock	70–100	1981	78–120	2001
Red Rock Lakes	16–25	1981	[a]	[a]
Centennial	168	1980	168	2005
Colorado				
Piceance–East Douglas Creek	90–140	1981	135–235	1999
Idaho				
Four Mile	37–60	2001	[a]	[a]
Montana				
Pryor Mountain Wild Horse Range	121	1984	95	1992

[1]Eight of the 26 field offices surveyed manage only one HMA.

HMA, by state	Initial AML	Year initial AML was set	Current AML	Year current AML was set
Nevada				
Montezuma Peak	161	1974	0	2007
South Shoshone	78	1986	60–100	2005
Flanigan	83–125	1990	[a]	[a]
Rock Creek	119	1987	250	2003
Dry Lake	82	1983	94	2001
Red Rock	116	1982	41–76	2004
Granite Range	155–258	1993	[a]	[a]
New Mexico				
Bordo Atravesado	20–30	1980	50	1991
Oregon				
Liggett Table	10–25	1989	[a]	[a]
Beaty's Butte	234	1971	100–250	1983
Coyote Lake–Alvord Tule Springs	198–390	1978	[a]	[a]
Utah				
Canyon Lands	60–100	2001	[a]	[a]
Hill Creek	195	1985	[a]	[a]
Conger	34	1977	40-80	1987
Wyoming				
Divide Basin	425–588	1979	415–600	1997
McCullough Peaks	70–140	1985	70–140	1990
Dishpan Butte	35–50	1983	50–100	1993

Source: GAO survey results.

[a]At the time of our survey, AML for 9 of the 26 HMAs we selected had not been revised since it was initially set. For those 9 HMAs, the initial AML and the year initial AML was set is also the current AML and the year current AML was set.

Table 18: Level of Data Sufficiency Used to Determine Current AML

Level of sufficiency	Number of respondents
Very sufficient	15
Moderately sufficient	7
Moderately insufficient	2
Very insufficient	1
Unsure/don't know	1

Source: GAO survey results.

Table 19: Respondents' Opinions about Current AML

Current AML	Number of respondents
Too high	3
About right	17
Too low	2
Unsure/don't know	4

Source: GAO survey results.

Table 20: Population Level in Comparison with AML Range

Population level	Number of respondents
Above	15
Within limits	10
Below	0
Unsure/don't know	1

Source: GAO survey results.

Table 21: Primary Challenges in Meeting or Maintaining AML

Challenge	Number of respondents
Impediments to conducting gathers	20
Lack of sufficient removal outlet	12
Inability to conduct range management	9
Limitations to accurate population counts	8
HMA boundary issues	5
Public pressure to not remove animals	4
Multiple use balance	4
Staffing limitations	3
Litigation	2
Habitat limitations	2
High reproductive rates of the animals	2
Other	2

Source: GAO survey results.

Table 22: Impact on Rangeland Resources in HMA When Herd Populations Exceed the Upper Limit of AML by Less Than 25 Percent

	Level of impact					
Rangeland resource	Positive	Slightly positive	No impact	Slightly negative	Negative	Blank
Horse and burro herd health	1	2	10	10	3	0
Rangeland health	0	1	5	10	10	0
Livestock habitat requirements	0	1	10	9	5	1
Wildlife habitat requirements	0	1	8	9	8	0

Source: GAO survey results.

Table 23: Impact on Rangeland Resources in HMA When Herd Populations Exceed the Upper Limit of AML by 25 to 50 Percent

	Level of impact					
Rangeland resource	Positive	Slightly positive	No impact	Slightly negative	Negative	Blank
Horse and burro herd health	1	1	4	10	10	0
Rangeland health	0	0	0	8	18	0
Livestock habitat requirements	0	0	4	9	12	1
Wildlife habitat requirements	0	0	3	8	15	0

Source: GAO survey results.

Table 24: Impact on Rangeland Resources in HMA When Herd Populations Exceed the Upper Limit of AML by 51 to 100 Percent

	Level of impact					
Rangeland resource	Positive	Slightly positive	No impact	Slightly negative	Negative	Blank
Horse and burro herd health	0	1	2	4	19	0
Rangeland health	0	0	0	0	26	0
Livestock habitat requirements	0	0	3	3	19	1
Wildlife habitat requirements	0	0	3	2	21	0

Source: GAO survey results.

Table 25: Number of Field Offices That Have or Do Not Have Procedures in Place to Distinguish Impact of Wild Horses and Burros, Cattle, and Wildlife on Rangeland Condition

Procedure to distinguish impact	Number of respondents
Yes	20
No	6
Unsure/don't know	0

Source: GAO survey results.

Table 26: Actions Taken to Manage HMAs Since 2000

Action taken	Yes	No	Don't know	Not applicable	Blank
Conducted population inventory	24	2	0	0	0
Conducted gathers and removals	23	3	0	0	0
Reduced or modified livestock use	15	7	0	4	0
Increased resource monitoring	14	10	2	0	0
Vegetative/riparian restoration	14	11	1	0	0
Other land management actions	12	2	1	2	9
Changed AML	7	18	1	0	0

Source: GAO survey results.

Table 27: Number of HMAs with a Herd Management Area Plan

Plan	Yes	No	Unsure/don't know
Herd Management Area Plan	16	9	1
Plan to develop a Herd Management Area Plan	8	2	5

Source: GAO survey results.

Table 28: Primary Physical Method Used in Most Recent Census/Inventory

Primary method	Number of respondents
Fixed-wing aircraft	3
Helicopter	20
Horseback/on foot	2
Don't know	1

Source: GAO survey results.

Table 29: Primary Statistical Method Used in Most Recent Census/Inventory

Primary method	Number of respondents
Direct count (single number)	17
Direct count (range)	2
Simultaneous double-count	3
Sightability bias correction model	2
Other	2

Source: GAO survey results.

Table 30: Level of Accuracy of Most Recent Census/Inventory

Level of accuracy	Number of respondents
Greatly over counted	0
Over counted	0
Counted about right	15
Undercounted	10
Greatly undercounted	0
Unsure/don't know	1

Source: GAO survey results.

Table 31: Level of Data Sufficiency Used to Support Most Recent Gather

Level of sufficiency	Number of respondents
Very sufficient	21
Moderately sufficient	4
Moderately insufficient	0
Very insufficient	0
Unsure/don't know	1

Source: GAO survey results.

Table 32: Timing of Gather in Relation to Scheduled Date of Gather

Timing of gather	Number of respondents
Conducted earlier	2
Neither earlier nor delayed	18
Delayed	4
Unsure/don't know	2

Source: GAO survey results.

Table 33: Level of AML to Which HMA Is Typically Gathered

Level of AML	Number of respondents
Upper	7
Middle	7
Lower	7
Unsure/don't know	5

Source: GAO survey results.

Section II: Field Offices' Responses to General Questions Regarding All of the HMAs They Manage

Table 34: Actions Taken to Manage HMA's Since 2000

Action taken	Yes	No	Don't know	Not applicable	Blank
Conducted population inventory	19	0	0	0	0
Conducted gathers and removals	18	1	0	0	0
Reduced or modified livestock use	14	2	1	2	0
Vegetative/riparian restoration	14	5	0	0	0
Increased resource monitoring	12	7	0	0	0
Changed AML	11	8	0	0	0
Other land management actions	6	2	1	0	10

Source: GAO survey results.

Table 35: Field Offices Whose HMAs Have Herd Management Area Plans

Plan	All	Some	None	Unsure/don't know
Herd Management Area Plan	11	6	8	1

Source: GAO survey results.

Table 36: Field Offices Working to Develop Herd Management Area Plans for All of Their HMAs

Response	Number of respondents
Yes	6
No	8

Source: GAO survey results.

Table 37: Actions to Help Field Offices Achieve Healthy Herd Populations in Balance with the Range and Other Multiple Uses

Actions	Number of respondents
Increase range management activities	15
Reach and maintain AML	9
Improve staff capacity	7
Improve census/inventory	7
Increase funding	6
Improve adoption outlet	3
Improve coordination in management	3
Improve access to HMAs	2
Solve long-term holding situation	2

Source: GAO survey results.

Table 38: Major Challenges Facing Field Offices in Managing HMAs to Achieve Healthy Herd Populations That Are in Balance with the Range and Other Multiple Uses

Major challenges	Number of respondents
Impediments to conducting gathers	13
Staffing limitations	11
Limitations to accurate population counts	8
Inability to conduct range management	8
Multiple use balance	7
Lack of sufficient removal outlet	6
Ability to maintain AML	4
Habitat limitations	4
Other	4
Planning process	3
Public pressure	3
HMA boundary issues	3

Source: GAO survey results.

Table 39: Major Challenges Facing BLM's Wild Horse and Burro Program As a Whole

Major challenges	Number of respondents
Lack of sufficient removal outlet[a]	18
Staffing limitations	11
Inability to conduct range management	8
Public pressure	7
Impediments to conducting gathers	5
Unwanted horses released to BLM lands	5
Funding	3
Lack of support	3
Limitations to accurate population counts	2
Habitat limitations	2
Lack of management flexibility	2
Multiple use balance	2
Poor public perception	2

Source: GAO survey results.

[a]Removal outlet limitations include decreased options for animals once removed from the range, such as decreased adoptions, expense of caring for animals removed from the range, and limited capacity in long-term holding facilities.

Appendix IV: Comments from the Department of the Interior

United States Department of the Interior
BUREAU OF LAND MANAGEMENT
Washington, DC 20240
http://www.blm.gov

SEP 0 5 2008

Robin M. Nazzaro
Director, Natural Resources and Environment
Government Accountability Office
441 G Street, N.W.
Washington, D.C. 20548-0001

Dear Ms. Nazzaro:

Thank you for the opportunity to review and comment on the Government Accountability Office draft report entitled, *"Bureau of Land Management: Effective Long-Term Options Needed to Manage Unadoptable Wild Horses,* (GAO-08-989).

The Department of the Interior concurs with the findings and recommendations for executive action and believes these will help us improve the Wild Horses and Burro Program. The Bureau of Land Management will work to develop cost effective alternatives to long term holding. BLM will seek advice from the National Wild Horse and Burro Advisory Board and other partners and stakeholders to find acceptable solutions, and will discuss any helpful legislative proposals with Congress.

The enclosure provides technical comments on the draft report.

If you have any questions, please contact Don Glenn, Chief, Division of Wild Horses and Burros at (202) 452-5082 or LaVanna Stevenson-Harris, BLM Audit Liaison Officer, at (202) 785-6580.

Sincerely,

James L. Caswell
Director

Enclosure

Appendix V: GAO Contact and Staff Acknowledgments

GAO Contact

Robin M. Nazzaro, (202) 512-3841 or nazzaror@gao.gov

Staff Acknowledgments

In addition to the individual named above, Jeffery D. Malcolm, Assistant Director; Ulana Bihun; Kevin Bray; Lee Carroll; Benjamin Shouse; Gregory Wilmoth; and Elizabeth Wood made key contributions to this report. Also contributing to the report were Beverly Ross and Monica Wolford.

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Academic Assessment of Equine Welfare During the Gather Process of the Bureau of Land Management's Wild Horse and Burro Program

E.A. Greene, C.R. Heleski, S.L. Ralston, C.L. Stull

PlumX Metrics

DOI: https://doi.org/10.1016/j.jevs.2011.03.198

The American Horse Protection Association (AHPA) has a mission to protect and preserve America's wild horses and burros on US public range lands [1]. The Bureau of Land Management (BLM) has a priority to ensure that America's public lands are healthy and productive so that all species dependent on them can thrive. This includes a mandate to maintain wild life populations, including the wild horses and burros, to sustainable levels. The means by which the BLM had traditionally managed the equid populations was by conducting periodic "gathers" to remove excess animals and maintain genetic diversity.

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53: 479–482 September 2000

Effects of roundups on behavior and reproduction of feral horses

KYLE V. HANSEN AND JEFFREY C. MOSLEY

Abstract

Roundups are used to maintain feral horse populations in balance with rangeland grazing capacity, but little is known about short-term and long-term effects of roundups on horses. We evaluated the effects of roundups on behavior and reproduction of feral horses. The study was conducted near Challis, Ida. during 1994–1995, and repeated near Lander, Wyo. during 1995–1996. Horses were randomly assigned to 3 different treatment groups. One group (ADOPTED) was gathered by a Bureau of Land Management roundup crew using a helicopter. These horses were removed and placed in the Adopt-A-Horse Program. The second group (SIMULATED) consisted of horses that were gathered by helicopter, but these horses evaded capture and remained in the study area after the roundup. Horses in the third group (CONTROL) were not herded by helicopter. Horse behavior was monitored in the SIMULATED and CONTROL groups before and after roundups. Behavioral variables analyzed were the percentage of time spent resting, feeding, vigilant, traveling, and engaged in agonistic encounters. Neither foraging or social behavior of feral horses was affected by roundups in either study area ($P > 0.10$). Reproduction was monitored within the SIMULATED, CONTROL, and ADOPTED groups during the year following roundups. The percentages of mares with live foals did not differ ($P > 0.10$) among the 3 treatment groups in Idaho or Wyoming. Foaling success rates in Idaho were 29%, 31%, and 43% for CONTROL, ADOPTED, and SIMULATED mares, respectively. In Wyoming, foaling success rates were 29%, 42%, and 48% for CONTROL, ADOPTED, and SIMULATED groups, respectively. We found no evidence that roundups had deleterious effects on behavior or reproduction of feral horses.

Key Words: wild horses, *Equus caballus*, Adopt-A-Horse Program, foraging behavior, social behavior

Resumen

Las redadas se utilizan para mantener las poblaciones de caballos silvestres en balance con la capacidad de apacentamiento, pero poco se sabe acerca de los efectos a corto y largo plazo de las redadas en los caballos. Evaluamos el efecto de las redada en el comportamiento y reproducción de los caballos silvestres. El estudio se condujo cerca de Challis, Ida. durante 1994 y 1995 y se repitió cerca de Lander Wyo. durante 1995 y 1996. Los caballos se asignaron aleatoriamente a tres grupos de tratamiento. Un grupo (ADOPTADO) fue reunido y removido por una cuadrilla de redadas del Buro de Manejo de Tierras la cual utilizó un helicóptero. Estos caballos fueron después colocados en el programa "Adopta un Caballo". El segundo grupo, (SIMULADO) consistio de caballos que fueron reunidos con helicóptero, pero estos caballos evadieron la captura y permanecieron en el área de estudio después de la redada. El tercer grupo (CONTROL), fueron caballos que no se pastorearon con helicóptero. El comportamiento de los caballos se monitoreo en los grupos SIMULADO y CONTROL antes y después de las redadas. Las variables de comportamiento se analizadas fueron el porcentaje de tiempo utilizado en descanso, alimentación, vigilancia, viajar, y encuentros agonísticos. Las redadas no afectaron ni el comportamiento de alimentación ni el comportamiento social de los caballos salvajes en el área de studio ($P > 0.01$). Al año siguiente de las redadas se monitoreo la reproducción dentro de los grupos SIMULADO, CONTROL y ADOPTADOS. El porcentaje de yeguas con potros vivos no difirió entre los tres tratamientos ($P>0.10$) y los resultados fueron similares en Idaho y Wyoming. Las tasas de potros vivos en Idaho fueron 29%, 31% y 43% para los tratamientos CONTROL, ADOPTADO y SIMULADO respectivamente. En Wyoming los porcentajes de potros vivos fueron 29%, 42% y 48% para lostratamientos CONTROL, ADOPTADO y SIMULADO respectivamente. No encontramos evidencia de que las redadas tuvieran un efecto nocivo en el comportamiento o la reproducción de los caballos salvajes.

About 46,000 feral horses (*Equus caballus*) live in the western United States (USDI-BLM and USDA-FS 1993). The Wild Free-Roaming Horse and Burro Act, Public Law 92-195 (U.S. Code 1988), obligates the Bureau of Land Management (BLM) and the U.S. Forest Service to protect feral horses on public lands of the western United States from unauthorized capture or killing. These agencies must also maintain these populations in balance with rangeland carrying capacity (USDI-BLM and USDA-FS 1993). Uncontrolled horse populations lead to excessive grazing, in turn causing rangeland degradation (Smith 1986). Roundups remove excess animals, after which horses are placed in private ownership via the Adopt-A-Horse Program. Roundups obviously disturb the daily routine and behavior of feral horses, but little is known about short-term and long-term effects of roundups on horses. When perturbations occur, horses may shift their behavior to minimize the effects. For example, feral horses alter their habitat use to seek refuge from biting insects (Keiper and Berger 1982). Behavioral responses to perturbations also may include increased time spent in agonistic encounters with other horses, such as when mares enter new areas and encounter resident mares (Tyler 1972). Perturbations may also induce stress that decreases

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reproduction. For example, forced copulation by invading males may induce abortion in females unprotected by their resident stallion (Berger 1983), and abortions may occur in response to male harassment or other stresses imposed by changes in a herd's social structure (Berger 1983). The purpose of this study was to document the effects of roundups on the foraging behavior, social behavior, and reproductive success of feral horses. Our specific null hypotheses were: 1) behavior does not differ between horses rounded up and horses not rounded up; and 2) reproductive success does not differ among horses rounded up, horses not rounded up, and horses placed in the Adopt-A-Horse Program.

Study Area

The study was conducted in 2 separate areas, one in central Idaho about 3 km southwest of Challis, Ida., and one in central Wyoming about 32 km north of Jeffrey City, Wyo.

Idaho Study Area

The Idaho study area was 150-km^2 of public land administered by the BLM, located north of Spar Canyon Road, east of State Highway 75, and west of U.S. Highway 93. Elevations ranged from 1,675–2,745 m. Annual precipitation averages 18 cm, with about 50% occurring as snow during November through March (Perrich 1992). Major plant species present were bluebunch wheatgrass (*Agropyron spicatum* (Pursh.) Scribn. & Smith), western wheatgrass (*Agropyron smithii* Rydb.), Sandberg bluegrass (*Poa sandbergii* Vasey), Idaho fescue (*Festuca idahoensis* Elmer), and Wyoming big sagebrush (*Artemesia tridentata wyomingensis* Beetle & Young). Limber pine (*Pinus flexilus* James), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and curlleaf mountain mahogany (*Cercocarpus ledifolius* Nutt. ex. Torr. & Gray) occurred at higher elevations within the study area.

Soils ranged from a loamy-skeletal, mixed frigid Xerollic Haplargid (Dawtonia) at the lower elevations to a loamy skeletal, mixed Calcic Cryoborol (Gany) at the highest elevations. The dominant range site for the study area was Gravelly Loamy (20–30 cm precipitation) with associated range sites of Gravelly Loam (33–40 cm precipitation) and Flagstone (20–28 cm precipitation). The habitat type was Wyoming big sagebrush/bluebunch wheatgrass at lower elevations and Douglas-fir/Idaho fescue at the highest elevations (BLM-SCS 1979).

Wyoming Study Area

The Wyoming study area was in Muskrat Basin, 202-km^2 of public land administered by the BLM, located between State Highways 789 and 136. Vegetation was dominated by Wyoming big sagebrush, bluebunch wheatgrass, western wheatgrass, Sandberg bluegrass, Idaho fescue, and needle-and-thread grass (*Stipa comata* Trin. & Rupr.). Elevations ranged from 1,820–2,100 m. Annual precipitation averages 25 cm with about 50% occurring during May and June, and 50% occurring during November through March in the form of snow (Perrich 1992). Soils were a loamy-skeletal, mixed (calcareous), frigid, shallow Ustic Torriorthent (Cragosen) in most of the area, and a fine, montmorillonitic Borollic Paleargid (Milren) on the lower sites.

The dominant range site for this study area was Loamy (24–35 cm precipitation) with associated range sites of Shallow Sandy (24–35 cm precipitation) and Sandy (25–35 cm precipitation) (Soil Conservation Service 1988).

Methods

This experiment was conducted in Idaho from July 1994 to July 1995 and in Wyoming from July 1995 to July 1996. Field procedures and statistical methods were identical for both study areas.

Roundups

Horses in each study area were randomly assigned to 3 different treatment groups. One group (ADOPTED) was gathered by a BLM roundup crew using a helicopter. These horses were removed and placed in the Adopt-A-Horse Program. The second group (SIMULATED) consisted of horses that were gathered by helicopter, but these horses evaded capture and remained in the study area after the roundup. Horses in the third group (CONTROL) were not herded by helicopter. In the Idaho study area, the ADOPTED, SIMULATED, and CONTROL groups were composed of 12, 3, and 4 bands (i.e., social subgroups) of horses, respectively. The number of bands in the ADOPTED, SIMULATED and CONTROL groups in Wyoming were 10, 8, and 5, respectively. Bands contained 2 to 10 adult horses, and all bands were photographed to document their membership. Individual members of each band were also photographed, and physical characteristics of each horse were recorded to aid their identification. In Idaho, the SIMULATED, CONTROL, and ADOPTED groups totaled 14, 14, and 39 mares, respectively. In Wyoming, there were 33, 14, and 34 mares, respectively, in the SIMULATED, CONTROL, and ADOPTED groups. In each study area the roundup and simulated roundup occurred the same day, on 27 August 1994 in the Idaho study area and 13 August 1995 in Wyoming.

Horse Behavior

Horse behavior was monitored in the SIMULATED and CONTROL groups for 3 weeks immediately before and 3 weeks after the simulated roundups. Monitoring before the simulated roundup occurred from 25 July through 26 August 1994 on the Idaho study area and 10 July through 12 August 1995 for the Wyoming area. Data following the simulated roundup was collected from 28 August through 20 September 1994 for the Idaho area and 14 August through 28 August 1995 for the Wyoming area. Behavioral observations spanned more than 600 hours during each year of the study.

We recorded the percentage of time that a band of horses spent in the following activities: feeding (primarily grazing with little or no travel other than to move to a new feeding station); resting (both recumbent and standing); traveling (including incidental grazing while walking); aggression within the band (defined as threat postures, striking with the feet, or biting); aggression between bands; and vigilance (head and neck erect, ears forward, actively looking around). Data were recorded every 10 minutes during 4-hour observation periods using instantaneous scan sampling (Altmann 1974). Each band of horses was observed 3 times before and 3 times after the simulated roundups, with one of the 3 observation periods each occurring in early morning (0700–1100 hours), mid-day (1100–1500 hours), and early evening (1500–1900 hours).

Reproduction

Adopted Groups. A veterinarian drew 10 ml of blood from each mare in the ADOPTED groups. These 10-ml samples were immediately frozen, and later in the laboratory blood serum was separated from plasma. Blood serum samples were then sent to the Veterinary School at the University of California-Davis for analysis. Mares were considered pregnant if estrogen blood serum levels were 7 ng/ml or greater and progesterone levels were 6 ng/ml or greater. In July of the year fol-

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lowing roundups, each adopter of a mare was sent a questionnaire asking for foaling information. Non-respondents were contacted in a follow-up survey by telephone. A 100% response rate was achieved.

Simulated and Control Groups. Horses in the SIMULATED and CONTROL groups were observed about 10 months after the roundups. The number of mares and foals in each band was counted on 30 June and 1 July 1995 on the Idaho site and 1 July through 5 July 1996 on the Wyoming site.

Table 1. Mean percentage (±SE) of time that bands of feral horses spent in each behavioral activity following simulated roundups.

Activity	Idaho Site		Wyoming Site	
	Simulated	Control	Simulated	Control
	(%)			
Vigilance	12.9 ± 0.8a[1]	8.3 ± 0.4a	1.3 ± 0.7a	1.8 ± 0.9a
Feeding	58.5 ± 17.3a	71.4 ± 9.4a	46.9 ± 5.9a	38.0 ± 5.3a
Traveling	24.0 ± 17.0a	17.4 ± 10.la	5.5 ± 1.7a	18.7 ± 3.8a
Resting	4.6 ± 3.0a	2.9 ± 2.0a	46.1 ± 6.4a	41.3 ± 0.1a
Aggression within bands	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a
Aggression between bands	0.0 ± 0.0a	0.0 ± 0.0a	0.1 ± 0.0a	0.2 ± 0.0a

[1]Within each study area, values within rows followed by the same lowercase letter are not different (P > 0.10).

Statistical Analysis

A completely random experimental design was used. Data from the Idaho and Wyoming sites were analyzed separately. All differences were considered significant at $P \leq 0.10$. For the behavioral data, a band of horses was the experimental unit. Individual horses within the bands were subsamples. Behavioral data were transformed using arcsine transformation to meet conditions for normality. Each behavioral variable (feeding, resting, traveling, aggression within the band, aggression between bands, and vigilance) was analyzed using analysis of covariance (Johnson and Wichern 1992). Observations collected before the simulated roundups were the covariables (e.g., vigilance before the simulated roundups was the covariable when analyzing vigilance after the simulated roundups). Data were then analyzed collectively using multivariate analyses. Data from the Wyoming site were analyzed using multivariate analysis of covariance (MANCOVA). Dependent variables in the MANCOVA were the behavioral variables vigilance, feeding, traveling, resting, and aggression between bands following the simulated roundup. The independent variable used was group (i.e., SIMULATED or CONTROL). Covariables used were vigilance, feeding, traveling, resting and aggression between bands before the simulated roundup. For the Idaho site there were too few degrees of freedom to allow the observations before the simulated roundup to be used as covariables, so these data were analyzed using multivariate analysis of variance. Aggression within the band was not used as a variable or covariable in the multivariate analyses because no agonistic encounters within bands were recorded.

The percentage of mares with live foals in the SIMULATED, CONTROL, and ADOPTED groups was compared with chi-square analysis (Johnson and Wichern 1992).

Results

Horse Behavior

Individually, none of the behavioral variables differed between SIMULATED and CONTROL treatments in either study area (Table 1). Multivariate analyses also found no differences between the SIMULATED and CONTROL groups in either the Idaho study area ($P = 0.67$) or the Wyoming study area ($P = 0.58$).

Reproduction

The percentage of mares with live foals did not differ ($P > 0.10$) among the 3 treatments in either study area. By July 1995 in the Idaho study area, 29%, 31%, and 43% of the mares had live foals in the CONTROL, ADOPTED, and SIMULATED groups, respectively. In the Wyoming study area, by July 1996 the percentage of mares with live foals in the CONTROL, ADOPTED, and SIMULATED groups was 29%, 42%, and 48%, respectively.

At the time of roundup, 27 of 39 mares (69%) were pregnant in the Idaho ADOPTED group, and 18 of 34 mares (53%) were pregnant in the Wyoming ADOPTED group. Successful pregnancies numbered 12 of 27 (44%) and 14 of 18 (77%) for Idaho and Wyoming ADOPTED groups, respectively.

Discussion and Conclusions

Roundups did not increase agonistic behavior among feral horses, nor did roundups cause feral horses to reallocate their time spent in various daily activities. Feral horses in our study allocated their time similarly to undisturbed free-roaming horses in southern France (Duncan 1980), western Alberta (Salter and Hudson 1979), and central Wyoming (Crane et al. 1997). Feeding was the primary activity.

Domestic horses are usually able to maintain their pregnancies despite hormonal changes induced by stressful conditions (Traub-Dargatz et al. 1988, Baucus et al. 1990a, 1990b, Colburn et al. 1991, Ferlazzo et al. 1991, Wong et al. 1992). Similarly, in our study roundups did not decrease reproductive rates of feral horses. Foaling rates of the SIMULATED, CONTROL, and ADOPTED mares all compared favorably with a 10-year average of 35% documented within a feral horse herd in Montana (Garrott and Taylor 1990). The ADOPTED mares experienced the most perturbation but had an overall foaling rate of 33%.

Feral horses in our study apparently adapted easily to any stress caused by roundups. We found no evidence that roundups had deleterious effects on behavior or reproduction of feral horses.

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Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program; Board on Agriculture and Natural Resources; Division on Earth and Life Studies; National Research Council

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Using Science to Improve the BLM Wild Horse and Burro Program
A Way Forward

Committee to Review the Bureau of Land Management
Wild Horse and Burro Management Program

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Preface

千里之行，始于足下
Lao-tzu, *The Way of Lao-tzu*

The above quotation has been translated most commonly as "A journey of a thousand miles begins with a single step" and, alternatively, as "Even the longest journey must begin where you stand." In both interpretations, there is relevance to moving forward to improve management of free-ranging horses and burros on public lands in the western United States. Although there is a broad spectrum of public opinion regarding how horses should be managed on the land, there is also common ground as to the goal of sustaining healthy equid populations managed on healthy rangeland. In light of the charge to our committee and in the course of our public engagement, it is clear that the status quo of continually removing free-ranging horses and then maintaining them in long-term holding facilities, with no foreseeable end in sight, is both economically unsustainable and discordant with public expectations. It is equally evident that the consequences of simply letting horse populations, which increase at a mean annual rate approaching 20 percent, expand to the level of "self-limitation"—bringing suffering and death due to disease, dehydration, and starvation accompanied by degradation of the land—are also unacceptable. Those facts define the point from which we must begin the journey. However, it also provides a direction for the next steps: how can the natality be effectively managed so as to ensure that genetically viable, physically and behaviorally healthy equid populations are maintained on the land while preserving the ecosystem itself?

The committee has endeavored to examine the full array of options to meet that goal by reviewing prior National Research Council reports on the Wild Horse and Burro Program, studying existing data and current program procedures used by the Bureau of Land Management, and inviting experts to present evidence related to equid behavior, genetics, and reproduction as well as management approaches. Importantly, the committee did not limit itself to free-ranging horses and burros in the western United States but incorporated knowledge derived from the study of equid populations as diverse as donkeys in Sicily, zebras in Africa, and horses on Assateague Island and other barrier islands of the eastern United States. In a similar vein, the committee included studies of diverse ecosystems in which multiple species overlap, such as Yellowstone and the Serengeti, and lessons learned in resolution of environmental issues in which different sectors of the public held views that once seemed irreconcilable. The committee

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took seriously the public's valuation of free-ranging horses and burros on public lands, the importance of promoting a healthy multiple-use ecosystem, and the economic consequences of simply continuing the status quo. On behalf of the committee, I want to express my appreciation to each and every person who took the time, effort, and expense of providing public comment and to those who shared their "citizen science" data with the committee.

A study of this magnitude requires a tremendous commitment from the committee members. All have sacrificed evenings, weekends, and vacations—without financial compensation—in this commitment and in their desire to bring the best possible science to bear on a challenging issue. Individually and collectively, they brought a wealth of experience and knowledge and engaged in vigorous intellectual debate to meet the challenge. On behalf of the committee, I express our thanks and appreciation to the study director, Kara Laney; to Robin Schoen, director of the Board on Agriculture and Natural Resources; to Janet Mulligan, senior program associate for research; and to Kati Reimer, senior program assistant. Without their planning, organization, and editing expertise, this report would not have been possible. I also want to recognize the valuable contributions of Dr. Irwin Liu, who provided expertise on equid fertility.

Science alone, even the best science, cannot resolve the divergent viewpoints on how best to manage free-ranging horses and burros on public lands. Evidence-based science can, however, center debate about management options on the basis of confidence in the data, predictable outcomes of specific options, and understanding of both what is known and where uncertainty remains. I am confident that this study provides a centerpoint and hope that it will serve as a guide for the first step in the journey toward ensuring that genetically viable, physically and behaviorally healthy equid populations can be maintained while preserving a thriving, balanced ecosystem on public lands.

Guy Hughes Palmer
Chair, Committee to Review the Bureau of
Land Management Wild Horse and Burro
Management Program

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Acknowledgments

This report is the product of the cooperation and contribution of many people. The members of the committee thank all the speakers who provided briefings to the committee (Appendix C contains a list of presentations to the committee). Members also wish to express gratitude to Dr. Irwin Liu, University of California, Davis, for his time and input.

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following for their review of this report:

Barry Ball, Gluck Equine Research Center, University of Kentucky
David Berman, Ozecological Pty Ltd
Elissa Z. Cameron, University of Tasmania
C. Rex Cleary, Bureau of Land Management (*retired*)
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Oliver A. Ryder, San Diego Zoo Institute for Conservation Research
Donald B. Siniff, University of Minnesota (*Emeritus)*
Thomas Webler, Social and Environmental Research Institute
Gary C. White, Colorado State University (*Emeritus)*

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by coordinator, Dr. Stephen W. Barthold, University of California, Davis, appointed by the Division on Earth and Life Studies, and monitor, Dr. May R. Berenbaum, University of Illinois, Urbana-Champaign, appointed by the NRC's Report Review Committee. The coordinator and monitor

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were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author committee and the institution.

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Summary

Since 1971, the Bureau of Land Management (BLM) of the U.S. Department of the Interior has been responsible for managing the majority of free-ranging horses and burros on arid federal public lands in the western United States. In the Wild Free-Roaming Horses and Burros Act of 1971 (92 P.L. 195), the U.S. Congress charged BLM with the "protection, management, and control of wild free-roaming horses and burros on public lands." However, the agency is also tasked with managing the land for multiple uses. Public lands provide habitat for horses and burros, but they are also used for recreation, mining, forestry, grazing for livestock, and habitat for wild ungulates and other species. Therefore, although the act stipulated that free-ranging horses and burros were "an integral part of the natural system of the public lands," it limited their range to "their known territorial limits" in 1971. The land was to be "devoted principally but not exclusively to their welfare in keeping with the multiple-use management concept of public lands." Horses and burros were to be managed at "the minimal feasible level." In addition, management was to "achieve and maintain a thriving natural ecological balance on the public lands," protect wildlife habitat, and prevent range deterioration.

The goal of managing free-ranging horses and burros to achieve the vaguely defined thriving natural ecological balance within the multiple-use mandate for public lands has challenged BLM's Wild Horse and Burro Program since its inception. When BLM commissioned the National Research Council to conduct a study of the program in 2011, budget costs for managing the animals were mounting. To sustain healthy populations on healthy rangeland and to maintain a thriving natural ecological balance, BLM attempts to manage herds within population-size ranges that it deems appropriate management levels (AMLs) for designated regions known as Herd Management Areas (HMAs). However, because there are human-created barriers to dispersal and movement and no substantial predator pressure, maintaining a herd within an AML requires removing animals in roundups, also known as gathers. Adoption demand does not balance the number of animals removed, and there is no political support for culling unadopted animals. Therefore, BLM pays for animals removed from the range to live in long-term holding pastures for the remainder of their lives. At the time the committee's report was prepared, long-term holding costs consumed about half the Wild Horse and Burro Program's budget.

BLM is subject to ardent criticism from various stakeholders regarding its approach to management of free-ranging equids. Some parties express concern that the health of the range and the condition of other species that inhabit the land are adversely affected by populations of

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horses and burros that often exceed AMLs. Other members of the public think that horses and burros are unfairly restricted and are concerned that AMLs are too low to maintain genetically healthy herds and that horses and burros are confined to too little public land. They are also concerned about the stress placed on animals during gathers and in holding facilities.

To improve the sustainability and public acceptance of the program, BLM asked the National Research Council Committee to Review the Bureau of Land Management Wild Horse and Burro Program to build on previous Research Council reports on the program and to provide BLM with a scientific evaluation of the program's pressing challenges (Box S-1).

BOX S-1
Statement of Task

At the request of the Bureau of Land Management (BLM), the National Research Council (NRC) will conduct an independent, technical evaluation of the science, methodology, and technical decision-making approaches of the Wild Horse and Burro Management Program. In evaluating the program, the study will build on findings of three prior reports prepared by the NRC in 1980, 1982, and 1991 and summarize additional, relevant research completed since the three earlier reports were prepared. Relying on information about the program provided by BLM and on field data collected by BLM and others, the analysis will address the following key scientific challenges and questions:

1. Estimates of the wild horse and burro populations: Given available information and methods, how accurately can wild horse and burro populations on BLM land designed for wild horse and burro use be estimated? What are the most accurate methods to estimate wild horse and burro herd numbers and what is the margin of error in those methods? Are there better techniques than BLM currently uses to estimate population numbers? For example, could genetics or remote sensing using unmanned aircraft be used to estimate wild horse and burro population size and distribution?

2. Population modeling: Evaluate the strengths and limitations of models for predicting impacts on wild horse populations given various stochastic factors and management alternatives. What types of decisions are most appropriately supported using the WinEquus model? Are there additional models BLM should consider for future uses?

3. Genetic diversity in wild horse and burro herds: What does information available on wild horse and burro herds' genetic diversity indicate about long-term herd health, from a biological and genetic perspective? Is there an optimal level of genetic diversity within a herd to manage for? What management actions can be undertaken to achieve an optimal level of genetic diversity if it is too low?

4. Annual rates of wild horse and burro population growth: Evaluate estimates of the annual rates of increase in wild horse and burro herds, including factors affecting the accuracy of and uncertainty related to the estimates. Is there compensatory reproduction as a result of population-size control (e.g., fertility control or removal from herd management areas)? Would wild horse and burro populations self-limit if they were not controlled, and if so, what indicators (rangeland condition, animal condition, health, etc.) would be present at the point of self-limitation?

5. Predator impact on wild horse and burro population growth: Evaluate information relative to the abundance of predators and their impact on wild horse and burro populations. Although predator management is the responsibility of the U.S. Fish and Wildlife Service or State wildlife agencies and given the constraints in existing federal law, is there evidence that predators alone could effectively control wild horse and burro population size on BLM land designed for wild horse and burro use?

6. Population control: What scientific factors should be considered when making population control decisions (roundups, fertility control, sterilization of either males or females, sex ratio adjustments to favor males and other population control measures) relative to the effectiveness of control approach, herd health, genetic diversity, social behavior, and animal well-being?

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7. Fertility control of wild horses: Evaluate information related to the effectiveness of fertility control methods to prevent pregnancies and reduce herd populations.

8. Managing a portion of a population as non-reproducing: What scientific and technical factors should BLM consider when managing for wild horse and burro herds with a reproducing and nonreproducing population of animals (i.e., a portion of the population is a breeding population and the remainder is nonreproducing males or females)? When managing a herd with reproducing and nonreproducing animals, which options should be considered: geldings, vasectomized males, ovariectomized mares, or other interventions? Is there credible evidence to indicate that geldings or vasectomized stallions in a herd would be effective in decreasing annual population growth rates, or are there other methods BLM should consider for managing stallions in a herd that would be effective in tangibly suppressing population growth?

9. Appropriate Management Level (AML) establishment or adjustment: Evaluate BLM's approach to establishing or adjusting AML as described in the 4700-1 Wild Horses and Burros Management Handbook. Based upon scientific and technical considerations, are there other approaches to establishing or adjusting AML BLM should consider? How might BLM improve its ability to validate AML?

10. Societal considerations: What are some options available to BLM to address the widely divergent and conflicting perspectives about wild horse and burro management and to consider stakeholder concerns while using the best available science to protect land and animal health?

11. Additional Research Needs: Identify research needs and opportunities related to the topics listed above. What research should be the highest priority for BLM to fill information and data gaps, reduce uncertainty, and improve decision-making and management?

KEY FINDINGS

FINDING: Management of free-ranging horses and burros is not based on rigorous population-monitoring procedures.

At the time of the committee's review, most HMAs did not use inventory methods or statistical tools common to modern wildlife management. Survey methods used to obtain sequential counts of populations on HMAs were often inconsistent and poorly documented and did not quantify uncertainty related to estimates. The committee concluded that many methodological flaws identified in previous reviews of the program have persisted.

However, improvements in population monitoring have been implemented in recent years, and the committee supports these efforts. Aggregating neighboring HMAs, on which free movement of horses or burros is known or likely, into HMA complexes to coordinate population surveys, removals, and other management actions can improve data quality and interpretation and enhance population management (Figure S-1). The committee commends the partnership between BLM and the U.S. Geological Survey to develop rigorous, practical, and cost-effective survey methods that account for imperfect detection of animals. The committee strongly encourages continuing this collaborative research effort to develop a suite of survey methods effective for the variety of landscapes occupied by free-ranging equids. Transferring this

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knowledge to managers responsible for monitoring populations is essential if the reforms are to be institutionalized.

BLM should develop protocols for how frequently surveys are to be conducted and ensure that the resources are available to field personnel to maintain a standardized survey schedule. Consideration should be given to identifying sentinel populations in a subset of HMAs that represent the diverse ecological settings throughout western rangelands. Detailed, annual demographic studies of sentinel populations could be used to improve assessment of population dynamics and responses to changes in animal density, management interventions, seasonal weather, and climate. **Record-keeping needs to be substantially improved; the committee recommends the development of a uniform relational database that is accessible to and used by all field offices for recording all pertinent population survey data.**

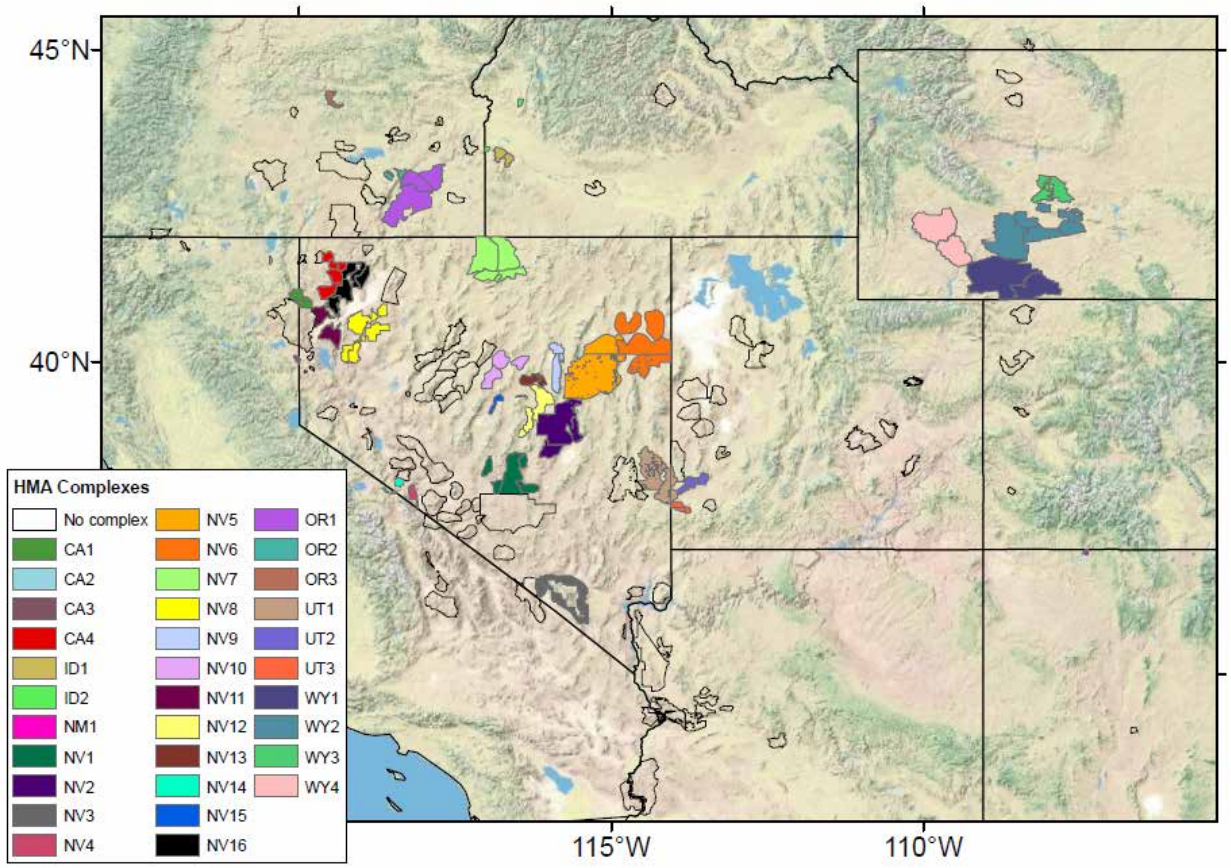


FIGURE S-1 Herd Management Areas managed together or with Wild Horse (or Burro) Territories as complexes.
NOTE: Blank Herd Management Areas are not managed as part of a complex.
DATA SOURCE: Mapping data and complex information provided by the Bureau of Land Management.

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FINDING: On the basis of the information provided to the committee, the statistics on the national population size cannot be considered scientifically rigorous.

The links between the statistics on the national population size and actual population surveys, which are the foundational data of all estimates, are obscure. The procedures used for developing annual HMA population-size estimates from counts are not standardized and often not documented. Therefore, it seems that the national statistics are the product of hundreds of subjective, probably independent, judgments and assumptions by range managers and administrators about the proportion of animals counted during surveys, population growth rates, effects of management interventions, and potential animal movements between HMAs.

Development and use of a uniform and centralized relational database, which captures all inventory and removal data generated at the level of the field offices and animal processing and holding facilities, to generate annual program-wide statistics would provide a clear connection between the data collected and the reported statistics. **The committee also suggests that the survey data at the HMA level and procedures used to modify the survey data to generate population estimates be made readily available to the public to improve transparency and public trust in the management program.**

In the committee's judgment, the reported annual population statistics are probably underestimates of the actual number of equids on the range inasmuch as most of the individual HMA population estimates are based on the assumption that all animals are detected and counted in population surveys. A large body of scientific literature on techniques for inventorying horses and other large mammals clearly refutes that assumption and suggests that the proportion of animals missed on surveys ranges from 10 to 50 percent. An earlier National Research Council committee and the Government Accountability Office also concluded that reported statistics were underestimates.

FINDING: Horse populations are growing at 15-20 percent a year.

The committee concluded that the age-structure data of horses removed from the range can provide a reasonable assessment of the general growth rate of the free-ranging horse populations in the western United States. The population growth-rate index derived from those data is generally consistent with the herd-specific population growth rates reported in the literature. On the basis of the published literature and the additional management data reviewed by the committee, the committee concluded that most free-ranging horse populations managed by BLM are probably growing at 15-20 percent a year.

FINDING: Management practices are facilitating high horse population growth rates.

Free-ranging horse populations are growing at high rates because their numbers are held below levels affected by food limitation and density dependence. In population ecology, density dependence refers to the influence of density on such population processes as population growth, age-specific survival, and natality. Effects of increased population density are manifested through such changes as reductions in pregnancy, fecundity, percentage of females lactating, young-to-female ratios, and survival rates. Regularly removing horses holds population levels below food-limited carrying capacity. Thus, population growth rate could be increased by removals through compensatory population growth from decreased competition for forage. As a

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result, the number of animals processed through holding facilities is probably increased by management.

FINDING: The primary way that equid populations self-limit is through increased competition for forage at higher densities, which results in smaller quantities of forage available per animal, poorer body condition, and decreased natality and survival.

Density dependence, due to food limitation, will reduce population growth rates in equids and other large herbivores through reduced fecundity and survival. Case studies show that animal responses to density dependence will include increased numbers of animals that are in poor body condition and are dying from starvation.

Rangeland health is also affected by density dependence. Equids invariably affect vegetation abundance and composition. Reduced vegetation cover, shifts in species composition, and increased erosion rates often occur on rangelands occupied by equids. However, no case study has reported that the changed vegetation cannot persist over a long period of time or that complete loss of vegetation cover is an inevitable outcome. The results are consistent with theoretical predictions that when a herbivore population is introduced, vegetation cover will initially change and productivity will often be reduced by herbivory. In some environments, however, moderate levels of herbivory have little adverse effect or even have favorable effects on plant production. Vegetation production may decline, but it may stabilize at a lower level as herbivore populations come into quasiequilibrium with the altered vegetation. Whether such a system can persist over the long term is unknown.

FINDING: Predation will not typically control population growth rates of free-ranging horses.

A large predator, when abundant, can influence the dynamics of free-ranging ungulates. However, the potential for predators to affect free-ranging horse populations is limited by the absence of abundance of such predators as mountain lions and wolves on HMAs. Mountain lions are ambush predators and require habitats that have broken topography and tree cover, whereas equids favor habitats that have more extensive viewsheds. Wolves are capable of chasing prey across open, flat topography and have substantial effects on a few horse populations on other continents and certain areas in Canada. Despite evidence that wolves prey on equids elsewhere, the committee was unable to identify any examples of wolf predation on free-ranging equids in the United States. The distribution of wolves in the western United States has been severely reduced by humans, and few habitats of free-ranging horses were occupied by wolves at the time the report was prepared; in addition, there had been little study of the overlap between burros and predators.

FINDING: The most promising fertility-control methods for application to free-ranging horses or burros are porcine zona pellucida (PZP) vaccines, GonaCon™ vaccine, and chemical vasectomy.

The criteria most important in selecting promising fertility-control methods for free-ranging equids are the delivery method, availability, efficacy, duration of effect, and potential physiological and behavioral side effects. Considering those criteria, the methods judged most

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promising are PZP and GonaCon vaccination of females and chemical vasectomy in males. Each method has advantages and disadvantages (Table S-1). Of the PZP vaccines, PZP-22 and SpayVac® seem most appropriate and practical because of their longer duration of effect. GonaCon can be used and has been tested in males, and its effects are similar to those of chemical castration. Preserving natural behaviors is important, so GonaCon seems more appropriate for use in females in that some research has suggested that female sexual behavior continues. However, further studies on behavioral effects of this product are needed. Chemical vasectomy is promising as an alternative to or in combination with treating females. The effects of surgical vasectomy, and presumably of chemical vasectomy, on sexual behavior closely parallel those of the PZP vaccines and possibly of GonaCon.

No method that does not affect physiology or behavior has been developed. The most appropriate comparison in assessing the effects of any fertility-control method is with gathering. That is, to what extent does the prospective method affect health, herd structure, and the expression of natural behaviors compared with the effects of gathering? The selected methods are considered the most promising because they have the fewest and least serious effects on those parameters. Their application requires handling the animals (gathering), but this process is no more disruptive than the current method for controlling numbers and does not entail the further disruption of removal and relocation to long-term holding facilities. Considering all the current options, these three methods, either alone or in combination, offer the most acceptable alternative for managing population numbers.

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TABLE S-1 Advantages and Disadvantages of the Most Promising Fertility-Control Methods

Method	Advantages	Disadvantages
PZP-22 and SpayVac®[a]	Research and application in both captive and free-ranging horses	Capture needed for hand injection of PZP-22
	Allows estrous cycles to continue so natural behaviors are maintained	Extended breeding season requires males to defend females longer
	High efficacy	With repeated use, return to fertility becomes less predictable
	Can be administered during pregnancy or lactation	Out-of-season births are possible
Chemical Vasectomy	Simpler than surgical vasectomy	Requires handling and light anesthesia
	Permanent	Permanent
	No side effects expected	Only surgical vasectomy has been studied in horses, so side effects of the chemical agent are unknown
	Normal male behaviors maintained	Extended breeding season requires males to defend females longer and may result in late-season foals if remaining fertile males mate
	Should have high efficacy	Only surgical vasectomy has been studied in horses, so efficacy rate is unknown
GonaCon™ for Females		Capture may be needed for hand injection of initial vaccine and any boosters
	Effective for multiple years	Lower efficacy than PZP-vaccine products, especially after first year
	Sexual behavior exhibited	Sexual behavior may not be cyclic, inasmuch as ovulation appears to be blocked
	Social behaviors not affected in the single field study	Should not be administered during early pregnancy because abortion could occur
		Few data on horses

[a]PZP-22 and SpayVac® are formulated for longer efficacy and require further documentation of continued efficacy and of rate of unexpected effects.

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FINDING: Management of equids as a metapopulation is necessary for the long-term genetic health of horses and burros at the HMA or HMA-complex level.

The committee reviewed the results of genetic studies of 102 horse HMAs that were based on samples collected during 2000-2012 and found that the reported levels in genetic diversity for most populations were similar to those in healthy mammalian populations, although that could change in time. Little is known about the genetic health of burros; the few studies that have been conducted reported low genetic diversity compared with that in domestic donkeys. Management actions to achieve optimal genetic diversity may involve intensive management of individual animals in HMAs, translocations of free-ranging horses and burros among HMAs or holding areas to effect genetic restoration, or some combination of these. **The committee recommends routine monitoring at all gathers and the collection and analysis of a sufficient number of samples to detect losses of diversity. The committee also recommends that BLM consider at least some animals on different HMAs as a single population and use the principles of metapopulation theory to direct management activities that attain and maintain the level of genetic diversity needed for continued survival, reproduction, and adaptation to changing environmental conditions.** Although there is no minimum viable population size above which a population can be considered forever viable, studies suggest that thousands of animals will be needed for long-term viability and maintenance of genetic diversity. Few HMAs are large enough to buffer the effects of genetic drift and herd sizes must be maintained at prescribed AMLs, so managing HMAs as a metapopulation will reduce the rate of reduction of genetic diversity over the long term. Movement of individual animals among HMAs to maintain genetic diversity will need to be guided by genetic, demographic, behavioral, and logistical factors.

FINDING: Phenotypic data have not been recorded and integrated into genetic management of free-ranging populations. Recording the occurrence of diseases and clinical signs and the ages and sexes of the affected animals would allow BLM to monitor the distribution and prevalence of genetic conditions that have direct effects on population health.

Ten or 11 conditions in horses are known to be caused by genetic mutations. Some are not lethal, so it is possible for the mutations to increase in frequency in HMAs, especially if inbreeding occurs. Few conditions present clinical signs that would be unambiguous and readily discernible during a gather. However, because many of the conditions can be diagnosed via genetic screening of blood or hair samples, surveillance of the genetic mutations underlying them is possible in HMAs. Screening samples from gathered horses could generate frequencies of the alleles involved in the disorders, and the frequencies could be monitored during later gathers to determine whether a particular HMA has a higher occurrence of a given mutation that might affect the fitness of the herd. **Although there are no known clinical issues in burros, the committee recommends that BLM routinely monitor and record any morphological anomalies in burros that may indicate the deleterious effects of inbreeding.**

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FINDING: Input parameters used in the WinEquus model are not transparent, and it is unclear whether or how results are used in management decisions.

BLM includes results of WinEquus population modeling in its gather plans and environmental assessments of horse HMAs. WinEquus uses an individual-based approach (each animal is tracked individually as opposed to the use of aggregated age-sex or life-stage classes) to simulate population dynamics and management of free-ranging horses in the framework of age-structured and sex-structured population models. Given appropriate data, it can incorporate the effects of environmental and demographic stochasticities, density dependence, and management actions and can simulate population dynamics for up to 20 years. There are no similar modeling studies of burros.

The committee found that, given appropriate data, WinEquus can adequately simulate horse population dynamics under alternative management actions (no treatment, removal, female fertility control, and the combination of removal and fertility control). However, the WinEquus results depend heavily on values of input parameters and on the WinEquus options selected by the user when setting up the simulations. Values of input parameters and data used to estimate the values were rarely provided, and the WinEquus options selected often were not described. Most gather plans and environmental assessments simply copied and pasted WinEquus output and gave no explanation or interpretation of the results. Those results cannot be adequately interpreted without knowledge of the input parameter values and WinEquus options selected by the user.

It appeared that one of the default datasets was used to model population dynamics of most or all HMAs or HMA complexes. It is therefore not surprising that most plans and assessments arrived at identical conclusions regarding the potential effects of the management alternatives considered.

The majority of gather plans conveyed nothing about whether or how results of population modeling were used to make management decisions, so the committee could not determine with certitude whether or how BLM uses WinEquus results. Specifically, it was difficult to determine whether results were used to make management decisions or were offered as justification for management decisions that were made independently of modeling results. Furthermore, in the absence of at least some site-specific data and relevant information regarding input parameters and WinEquus options, model results would be difficult for a critical reader to accept as pertinent and meaningful. A clear description of input parameters, including those needed for various management alternatives, and a detailed description of various WinEquus options selected by the user would help the general public to determine the reliability of WinEquus modeling results. In addition, a clear explanation of whether or how results of population modeling were used would improve transparency with the public.

FINDING: A more comprehensive model or suite of models could help BLM to address and adapt to challenges related to management of horses and burros on the range, management of animals in holding facilities, and program costs.

The adequacy of a population model depends on how (and for what purpose) BLM plans to use it, characteristics and processes included in it, management alternatives to be simulated, and availability of data to assign values to parameters of the model. If BLM plans to use a population model for short-term horse population projection and to evaluate potential effects of

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such management alternatives as female fertility control, removal, or a combination of the two, WinEquus is probably sufficient.

However, a suitable modeling framework could inform short-term and long-term management plans. Such a framework would simulate life history, social behavior, mating system, genetics, forage limitation, use of habitat, climate variation, and effects of alternative management actions throughout horse or burro life spans. The usefulness of the information obtained from population modeling is directly related to the reliability of the data used to assign values to parameters and depends on how adequately the model structure reflects life history of the study organisms and whether and to what extent deterministic, stochastic, and management actions that affect the study population are considered. **The committee recognizes that HMA managers often do not have adequate input information to estimate model parameter values for most HMAs. Therefore, efforts should be made to ensure that future modeling exercises use data from the target HMA or HMA complex or a sentinel population that closely resembles the target population being modeled.**

A comprehensive modeling study that evaluates the population dynamics of horses or burros in the western rangelands and in short-term and long-term holding facilities and the costs and consequences of management alternatives, including those not yet available to BLM, would help in evaluating whether and to what extent stated management objectives are achievable under current or projected funding situations. Such a study could help to identify the most effective or cost-effective management options to achieve the objectives or the achievable goals given available funding and policy constraints.

FINDING: The *Wild Horses and Burros Management Handbook* lacks the specificity necessary to guide managers adequately in establishing and adjusting appropriate management levels.

The *Wild Horses and Burros Management Handbook*, issued by BLM in 2010, provides some degree of consistency in goals, forage allocation, and general habitat considerations and should help to improve consistency in how AMLs are set. However, it does not provide detail related to monitoring and assessment methods. The resulting flexibility allows managers to decide what specific approaches fit local environmental conditions and administrative capacity but makes it difficult to review the program's on-the-ground methods. The handbook would be more informative if it provided guidelines on how to conduct various kinds of assessments, even if there were various appropriate methods available, or referenced appropriate sources, linking them to particular settings or situations. The handbook lacks clear protocols for evaluating habitat components other than forage availability. Without clear protocols specific enough to ensure repeatability, the monitoring organization cannot determine whether observed change is due to changes in condition or to changes in methods. **Protocols should also include establishment of controls when the goal is to distinguish treatment or management effects from other causes of change.**

FINDING: The handbook does not clarify the vague legal definitions related to implementing and assessing management strategies for free-ranging equids.

Managing equid populations as free-ranging with the minimal management called for in the legislation entails conceptual challenges associated with defining what constitutes land

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deterioration or health, thriving natural ecological balance, and rangeland condition. For example, the concept of a thriving natural ecological balance does not provide guidance for determining how to allocate forage and other resources among multiple uses, which ecosystem components should be included and monitored in the "balance," or how to decide when a system is out of "balance." It brings up arguments over whether such a balance exists in nature or is even possible. Furthermore, it is easily conflated with the forage allocation process, which is a policy decision. Similarly, rangeland health and setting of land health standards may be seen as a problem of developing specific ecological measurements and standards or as a matter of arriving at a consensus about how rangelands should be maintained. Without precise definitions, those concepts are uninformed by science and open to multiple interpretations. The handbook does not provide assistance in dealing with this dilemma.

An alternative approach for setting AMLs would address the challenge of defining terms used as management criteria, including *appropriate*, *thriving*, *natural*, *in balance*, *healthy*, and *deteriorated*. The approach would involve the development of a conceptual model for ecosystem functioning relative to management objectives and of indicators to measure the degree of departure from a scientifically informed conceptual model of an "appropriately" functioning free-ranging equid ecosystem.

FINDING: How AMLs are established, monitored, and adjusted is not transparent to stakeholders, supported by scientific information, or amenable to adaptation with new information and environmental and social change.

AMLs are a focal point of controversy between BLM and the public. It is therefore necessary to develop and maintain standards for transparency, quality, and equity in AML establishment, adjustment, and monitoring. Research suggests that transparency is an important contributor to the development of trust between agencies and stakeholders. The public should be able to understand the methods used and how they are implemented and should be able to access the data used to make decisions. Transparency will also encourage high quality in data acquisition and use. Data and methods used to inform decisions must be scientifically defensible. Resources are allocated to horses or burros in a context of contending uses for BLM lands, all of which have some standing in the agency's charge for multiple-use management.

Environmental variability and change, changes in social values, and the discovery of new information require that AMLs be adaptable. Adaptive management, an iterative decision-making process, can incorporate development of management objectives, actions to address these objectives, monitoring of results, and repeated adaptation of management to achieve desired results. A key tenet of adaptive management is treating management actions as testable hypotheses. **Maximizing long-term knowledge of the system and thereby improving management hinge on several fundamental tenets of research and monitoring design, including the use of controls and replication and controlling for variability over time. Uncertainty should be explicitly incorporated into estimated measures (such as herd size or utilization rate on an HMA).** The committee concludes that the above principles could be more thoroughly integrated into the Wild Horse and Burro Program to increase the defensibility and scientific validity of management actions.

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FINDING: Resolving conflicts with polarized values and opinions regarding land management rests on the principles of transparency and community-based public participation and engagement in decision-making. Decisions of scientific content will have greater support if they are reached through collaborative, broadly based, integrated, and iterative analytic-deliberative processes that involve both the agency and the public.

There are several well-developed processes for encouraging public participation in public-lands decision-making and management. To reduce conflict and improve the transparency and quality of decisions, the committee suggests using the analytic-deliberative approach to public participation. Participatory decision-making processes foster the development of a shared understanding of the ecosystem, an appreciation for others' viewpoints, and the development of good working relationships. **Thus, BLM should engage with the public in ways that allow public input to influence agency decisions, develop an iterative process between public deliberation and scientific discovery, and codesign the participatory process with representatives of the public.** Finding ways to involve citizens in data-gathering or other scientific practices may help to build relationships and understanding. Because there are also concerns about horses and burros among the national—not just the local and regional—public, it would be appropriate for BLM to support research that uses survey methods that go beyond opinion polls to capture tradeoffs in public concerns to improve understanding of perceptions, values, and preferences regarding horse and burro management, as was recommended by the National Research Council in 1980 and 1982.

FINDING: Tools already exist for BLM to use in addressing challenges faced by its Wild Horse and Burro Program.

The continuation of "business-as-usual" practices will be expensive and unproductive for BLM. Because compelling evidence exists that there are more horses on public rangelands than reported at the national level and that horse population growth rates are high, unmanaged populations would probably double in about 4 years. If populations were not actively managed for even a short time, the abundance of horses on public rangelands would increase until animals became food-limited. Food-limited horse populations would affect forage and water resources for all other animals on shared rangelands and potentially conflict with the multiple-use policy of public rangelands and the legislative mandate to maintain a thriving natural ecological balance. Fertility-control agents have been pursued to enhance efficacy of population management, with the potential to reduce population growth rates and hence the number of animals added to the national population each year. The potential effects of fertility control, however, are limited by the number and proportion of animals that must be effectively treated with contraceptive agents. The committee's conclusions that there are considerably more horses and possibly burros on public lands than reported and that population growth rates are high suggest that the effects of fertility intervention, although potentially substantial, may not completely alleviate the challenges BLM faces in the future in effectively managing the nation's free-ranging equid populations, given legislative and budgetary constraints.

However, the tools already exist for BLM to address many challenges. Given the nature of the situation, a satisfactory resolution will take time, resources, and dedication to a combination of strategies underpinned by science. In the short term, intensive management of free-ranging horses and burros would be expensive, but addressing the problem immediately

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with a long-term view is probably a more affordable and satisfactory answer than continuing to remove animals to long-term holding facilities. Investing in science-based management approaches would not solve the problem instantly, but it could lead the Wild Horse and Burro Program to a more financially sustainable path that manages healthy horses and burros with greater public confidence.

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1

Free-Ranging Horses and Burros in the Western United States

Since 1971, the Bureau of Land Management (BLM) of the U.S. Department of the Interior has been responsible for managing the majority of free-ranging horses and burros on arid federal public lands in the western United States. In the Wild Free-Roaming Horses and Burros Act of 1971 (92 P.L. 195), the U.S. Congress charged BLM[1] with the "protection, management, and control of wild free-roaming horses and burros on public lands." BLM was charged to protect the equids because, the legislation noted, "wild free-roaming horses and burros are living symbols of the historic and pioneer spirit of the West . . . and [they] are fast disappearing from the American scene." In the mid-20th century, horse and burro populations were affected by competing uses for the land, including livestock grazing, and by roundups, from which the animals were often sold for slaughter (GAO, 1990). The protection provided in the 1971 legislation built on the "Wild Horse Annie Act" (86 P.L. 234), passed in 1959, which prohibited the use of motorized vehicles, including aircraft, to hunt free-ranging horses and outlawed the poisoning of watering holes on public lands.

The agency was also tasked with managing and controlling the population because of the multiple uses of public lands. Public lands provide habitat to horses and burros, but they are also used for recreation, mining, forestry, grazing for livestock, and habitat for wildlife, including mule deer, pronghorn, and bighorn sheep. Therefore, although the act stipulated that free-ranging horses and burros were "an integral part of the natural system of the public lands" and were to be managed "as components of the public lands," it limited their range by definition to "their known territorial limits" in 1971. Such public lands were to be "devoted principally but not exclusively to [horse and burro] welfare in keeping with the multiple-use management concept of public lands." In addition, horses and burros were to be managed at "the minimal feasible level." Management should "achieve and maintain a thriving natural ecological balance on the public lands," protect wildlife habitat, and prevent range deterioration.

The goal of protecting free-ranging horses and burros while managing and controlling them to achieve a vaguely defined thriving natural ecological balance within the multiple-use mandate for public lands has challenged BLM's Wild Horse and Burro Program since its

[1]The Wild Free-Roaming Horses and Burros Act of 1971 also pertains to free-ranging horses and burros found on public lands administered by the U.S. Forest Service. This report focuses on animals managed by BLM, which is responsible for over 90 percent of the equid population on public lands in the western United States (GAO, 2008).

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inception. Amendments to the Wild Free-Roaming Horses and Burros Act have not diminished the difficulty. BLM is to monitor the population size to determine where there is an excess of horses and burros; such a situation is to be identified when "a thriving natural ecological balance and multiple-use relationship" is threatened (92 P.L. 195 as amended by the Public Rangelands Improvement Act of 1978, 95 P.L. 514). It is BLM's responsibility to determine when that relationship is under threat and to remove animals to achieve balance. The legislation allows the destruction of old, sick, or lame animals. Excess animals removed from the range may be adopted. Those for which there is no adoption demand are to be "destroyed in the most humane and cost efficient manner possible"; however, the destruction of healthy, unadopted free-ranging horses and burros has been restricted either by a moratorium instituted by the director of BLM or by the annual Congressional appropriations bill for the Department of the Interior in most years. Free-ranging horses and burros have successfully sustained populations in North America for over 300 years, and no large predator widely overlaps with their territory. Since 1989, adoptions have seldom exceeded the number of animals removed from the range; in the 2000s, the discrepancy neared a 2:1 ratio of animals removed to animals adopted (GAO, 2008). Thus, BLM's effort to control horse and burro numbers by removing animals from the range has led to the stockpiling of "excess" horses and burros in holding facilities (Figures 1-1 and 1-2). In fiscal year 2012, more than 45,000 animals were in holding facilities, and their maintenance consumed almost 60 percent of the Wild Horse and Burro Program's budget (BLM, 2012a).

With holding costs in 2010 projected to nearly double those in 2004 (Bolstad, 2011), the U.S. Senate Committee on Appropriations in 2009 instructed BLM to "prepare and publish a new comprehensive long-term plan and policy for management of wild horses and burros" (U.S. Congress, Senate, 2009). BLM responded with a proposed strategy designed around seven topics. With respect to science and research, one method for improving the use of science in its management of horses and burros was to "commission the [National Academy of Sciences] to review earlier reports and make recommendations on how the BLM should proceed in light of the latest scientific research" (BLM, 2011a).

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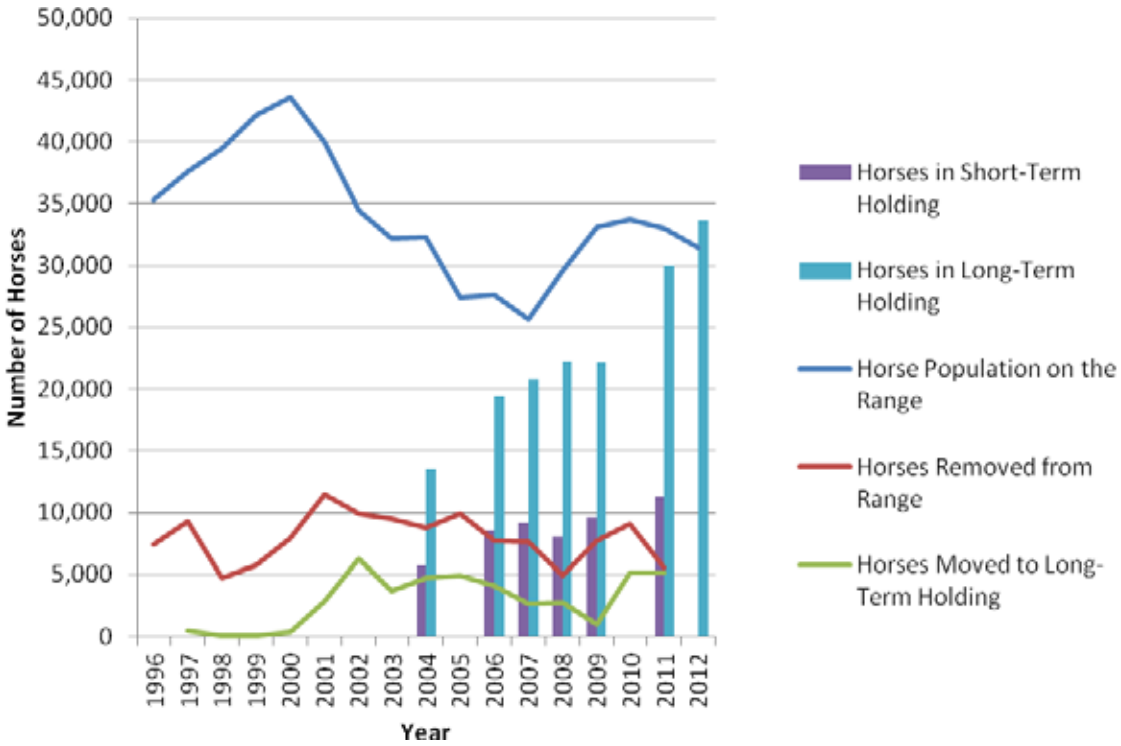


FIGURE 1-1 Horse population reported by the Bureau of Land Management (BLM), horses removed from the range, and horses in holding facilities, 1996-2012 (for years available).

DATA SOURCE: Horse population data from BLM (1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2005a, 2005b, 2006a, 2007a, 2008a, 2009a, 2010, 2011b, 2012b); horse removal data provided by BLM; holding-facilities data from BLM (2004, 2006b, 2007b, 2008b, 2009b, 2011c, 2012c).

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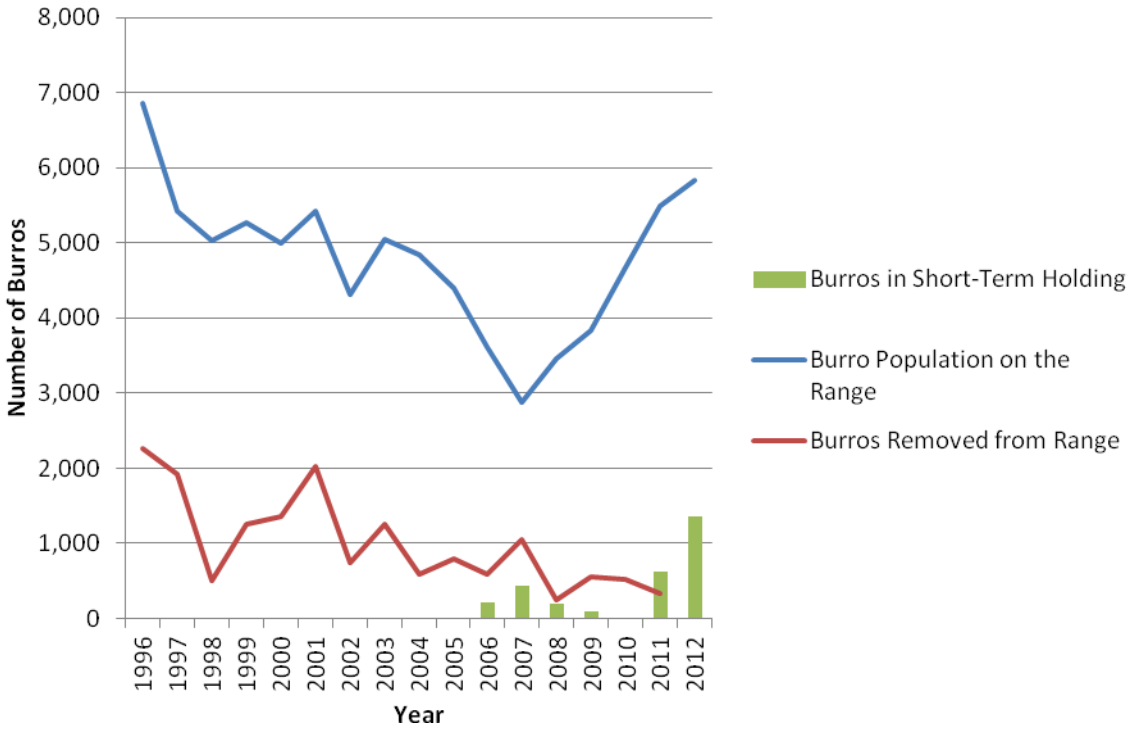


FIGURE 1-2 Burro population reported by the Bureau of Land Management (BLM), burros removed from the range, and burros in short-term holding facilities, 1996-2012 (for years available).

NOTE: There are no long-term holding facilities for burros.
DATA SOURCE: Burro population data from BLM (1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2005a, 2005b, 2006a, 2007a, 2008a, 2009a, 2010, 2011b, 2012b); burro removal data provided by BLM; holding-facilities data from BLM (2004, 2006b, 2007b, 2008b, 2009b, 2011c, 2012c).

COMMITTEE CHARGE AND APPROACH

The committee formed by the National Research Council of the National Academy of Sciences in response to BLM's request was given a long statement of task that required a variety of expertise (Box 1-1). The charge called on the Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program to investigate the annual rates of growth in the animal populations, the implications of genetic diversity for their long-term health, and how they interact with the environment. It also asked the committee to assess the effects of management actions, such as treating animals with contraceptives or removing animals from the range, and to evaluate BLM's tools for measuring the effects. Agency methods for determining the number of animals living on the range and the number of animals appropriate for the range were also to be examined. Finally, the committee was tasked to identify options that could address stakeholder concerns making use of the best available science.

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To accomplish the committee's comprehensive charge, members were appointed on the basis of their scientific research and experience with the questions involved in the statement of task. Experts were selected from the fields of behavioral ecology, conservation biology, genetics, natural-resources management and range ecology, population ecology, reproductive physiology, sociology, veterinary medicine, and wildlife ecology. (The committee members' biographies are in Appendix A.) The committee also retained a consultant who had expertise in equine reproduction.

The committee's study was the first examination of BLM's Wild Horse and Burro Program by the National Research Council in over 20 years. The National Research Council had published three reports on free-ranging horses and burros under BLM's jurisdiction. The first two reports, *Wild and Free-Roaming Horses and Burros: Current Knowledge and Recommended Research, Phase I Final Report* (1980) and *Wild and Free-Roaming Horses and Burros: Final Report* (1982), completed the first and third phases of a three-phase study mandated by Congress in the Public Rangelands Improvement Act of 1978 (95 P.L. 514).[2] Those reports were the product of one study committee, the Committee on Wild and Free-Roaming Horses and Burros, which was convened from 1979 to 1982. The third report, *Wild Horse Populations: Field Studies in Genetics and Fertility* (1991), was undertaken by a separate committee, the Committee on Wild Horse and Burro Research, in accordance with congressional appropriations in fiscal year 1985 to fund another study. The Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program was asked to build on the findings in those three reports. Appendix B contains a summary of findings of the earlier studies that overlap with the statement of task for the Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program.

[2]The second phase of the study consisted of research projects recommended by the committee in its first report.

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BOX 1-1

Statement of Task

At the request of the Bureau of Land Management (BLM), the National Research Council (NRC) will conduct an independent, technical evaluation of the science, methodology, and technical decision-making approaches of the Wild Horse and Burro Management Program. In evaluating the program, the study will build on findings of three prior reports prepared by the NRC in 1980, 1982, and 1991 and summarize additional, relevant research completed since the three earlier reports were prepared. Relying on information about the program provided by BLM and on field data collected by BLM and others, the analysis will address the following key scientific challenges and questions:

1. Estimates of the wild horse and burro populations: Given available information and methods, how accurately can wild horse and burro populations on BLM land designed for wild horse and burro use be estimated? What are the most accurate methods to estimate wild horse and burro herd numbers and what is the margin of error in those methods? Are there better techniques than BLM currently uses to estimate population numbers? For example, could genetics or remote sensing using unmanned aircraft be used to estimate wild horse and burro population size and distribution?

2. Population modeling: Evaluate the strengths and limitations of models for predicting impacts on wild horse populations given various stochastic factors and management alternatives. What types of decisions are most appropriately supported using the WinEquus model? Are there additional models BLM should consider for future uses?

3. Genetic diversity in wild horse and burro herds: What does information available on wild horse and burro herds' genetic diversity indicate about long-term herd health, from a biological and genetic perspective? Is there an optimal level of genetic diversity within a herd to manage for? What management actions can be undertaken to achieve an optimal level of genetic diversity if it is too low?

4. Annual rates of wild horse and burro population growth: Evaluate estimates of the annual rates of increase in wild horse and burro herds, including factors affecting the accuracy of and uncertainty related to the estimates. Is there compensatory reproduction as a result of population-size control (e.g., fertility control or removal from herd management areas)? Would wild horse and burro populations self-limit if they were not controlled, and if so, what indicators (rangeland condition, animal condition, health, etc.) would be present at the point of self-limitation?

5. Predator impact on wild horse and burro population growth: Evaluate information relative to the abundance of predators and their impact on wild horse and burro populations. Although predator management is the responsibility of the U.S. Fish and Wildlife Service or State wildlife agencies and given the constraints in existing federal law, is there evidence that predators alone could effectively control wild horse and burro population size on BLM land designed for wild horse and burro use?

6. Population control: What scientific factors should be considered when making population control decisions (roundups, fertility control, sterilization of either males or females, sex ratio adjustments to favor males and other population control measures) relative to the effectiveness of control approach, herd health, genetic diversity, social behavior, and animal well-being?

7. Fertility control of wild horses: Evaluate information related to the effectiveness of fertility control methods to prevent pregnancies and reduce herd populations.

8. Managing a portion of a population as non-reproducing:[3] What scientific and technical factors should BLM consider when managing for wild horse and burro herds with a reproducing and nonreproducing

[3]A mare is a mature female horse. A stallion is a mature male horse. A gelding is a castrated male horse.

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population of animals (i.e., a portion of the population is a breeding population and the remainder is nonreproducing males or females)? When managing a herd with reproducing and nonreproducing animals, which options should be considered: geldings, vasectomized males, ovariectomized mares, or other interventions? Is there credible evidence to indicate that geldings or vasectomized stallions in a herd would be effective in decreasing annual population growth rates, or are there other methods BLM should consider for managing stallions in a herd that would be effective in tangibly suppressing population growth?

9. Appropriate Management Level (AML) establishment or adjustment: Evaluate BLM's approach to establishing or adjusting AML as described in the 4700-1 Wild Horses and Burros Management Handbook. Based upon scientific and technical considerations, are there other approaches to establishing or adjusting AML BLM should consider? How might BLM improve its ability to validate AML?

10. Societal considerations: What are some options available to BLM to address the widely divergent and conflicting perspectives about wild horse and burro management and to consider stakeholder concerns while using the best available science to protect land and animal health?

11. Additional Research Needs: Identify research needs and opportunities related to the topics listed above. What research should be the highest priority for BLM to fill information and data gaps, reduce uncertainty, and improve decision-making and management?

Six information-gathering meetings took place during the study process (Appendix C). In addition to a presentation from BLM, the committee heard from experts in fertility control, predation, behavioral ecology, and genetics of free-ranging horses and burros. It also received presentations of research on free-ranging horses and burros by the U.S. Geological Survey and the U.S. Fish and Wildlife Service, on the use of adaptive management to address natural-resources issues, on tools for communicating science effectively, and on methods for engaging the public in assessment and decision-making on scientific issues. The committee heard from many interested parties at four public-comment sessions and received numerous written submissions on research and stakeholder concerns related to free-ranging horses and burros and to BLM's management of the animals (Box 1-2).

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BOX 1-2

Divergent Opinions on Appropriate Management of Free-Ranging Horses and Burros

The management of free-ranging horses and burros on public lands is a long-standing source of contention among stakeholder groups. During the course of its review, the committee heard from BLM and from many interested parties about the struggle of managing horses and burros in accordance with a thriving natural ecological balance and the multiple-use mandate. The intent of the Wild Free-Roaming Horses and Burros Act was interpreted differently by various stakeholders, and many critiques of BLM's implementation of the law were offered.

In a presentation to the committee, BLM outlined its mandate under the current law. Among the law's stipulations are that animals are to be managed on land on which they were found in 1971, the land is to be managed for multiple uses, and excess animals are to be removed immediately if appropriate management levels are exceeded.

Some parties who participated in public-comment sessions expressed concern that rangeland health was adversely affected because the population of horses and burros often exceeded appropriate management levels. This perspective considered competition between equids and wildlife to be detrimental to wildlife. It was also pointed out that livestock, which have grazing rights on public lands, do not remain on the land all year, unlike horses.

Other participants in the public sessions of committee meetings communicated that horses and burros were unfairly limited in their range and in their numbers. From that point of view, appropriate management levels were too low to maintain genetically healthy herds, and horses and burros were restricted to too few acres of public land. For example, the number of acres on which livestock are allowed is much greater than that of the Herd Management Areas (the land allocated to horses and burros). Many participants asserted that the horse is a reintroduced wildlife species and fills a niche in its ecosystem. Concern was also expressed about the stress placed on animals during gathers (roundups) and in holding. There were many requests for BLM to provide more robust and transparent evidence to support its management decisions.

Most commenters agreed that the operation of the program was excessively expensive and that management could be improved to reduce costs and increase the welfare of all animals on the range.

The committee based its findings and conclusions on a number of sources. In addition to the information gathered at its meetings, committee members examined peer-reviewed scientific literature on free-ranging horses and burros, particularly literature published since the previous National Research Council reports were completed. The committee analyzed data on free-ranging horse and burro populations and genetics that it received from BLM and from E. Gus Cothran of Texas A&M University, respectively, in response to submitted inquiries (Appendix D). It also synthesized responses from BLM, Stephen Jenkins, and Charles de Seve regarding population modeling and from BLM on establishing herd population levels. When it was relevant, the committee also consulted gray and unpublished literature to inform its analysis.

The committee did not limit itself to research and data on free-ranging horses and burros in the western United States. It also consulted studies on free-ranging horses and burros on the barrier islands off the East Coast of the United States, particularly the herds on Assateague Island and Shackleford Banks.[4] Those populations are not under BLM management and are not subject to the Wild Free-Roaming Horses and Burros Act of 1971, but results of research on the herds,

[4]Several free-ranging horse and burro herds are resident on barrier islands off the East Coast of the United States and Canada. The herds on Assateague Island (Maryland) and Shackleford Banks (North Carolina) are managed by the U.S. Department of the Interior's National Park Service (NPS). There are free-ranging equid populations in the United States that are not under the jurisdiction of BLM. Some are managed by other federal agencies, such as NPS and the U.S. Fish and Wildlife Service; Indian reservations, state agencies, and local entities are also responsible for some herds.

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which in many cases have been studied much more often and thoroughly than BLM herds, were relevant to the conclusions drawn by the committee. Germane studies of the biology, physiology, and behavioral ecology of domestic horses and burros, Przewalski's horses (wild horses native to central Asia), free-ranging horse and burro populations in other countries, native equid species on other continents, and free-ranging ungulates in the United States and elsewhere were also assessed (Box 1-3).

BOX 1-3

Describing Horses and Burros Under Different Management Regimes

In the literature that the committee reviewed, there were many nuances regarding the management regimes of horse and burro populations and other animals. To clarify the differences, the committee defines the terms that are used in the report here.

Free-Ranging. Although the 1971 legislation calls horses and burros in the western United States *free-roaming*, the committee chose to use the term *free-ranging* to reflect the purposeful and spatially adaptive uses of the rangelands that the horses and burros inhabit. Such populations are allowed to use spatially extensive habitats in ways that increase access to forage, improve their physiological condition, and increase the probability of their own and their population's viability. (In many of the contraceptive studies reviewed by the committee, treatments were applied to free-ranging horses that had been gathered from the range and held captive for study.)

Semi–Free-Ranging. The committee uses this term to refer to populations of horses and burros that are confined to limited areas, for example, in fenced reserves or protected areas that are nevertheless expansive enough for the animals to move freely over larger areas than typical farms or ranches.

Domestic. For the purposes of the report, *domestic* describes an animal that is kept by humans, typically as a companion animal or as livestock. This is different from definitions based on presumed inherited effects of domestication in ancestral blood lines. The report terminology distinguishes between domestic donkeys and free-ranging burros.

BOUNDS OF THE STUDY

The committee's statement of task was extensive but did not encompass all issues and challenges pertaining to the Wild Horse and Burro Program. The committee's tasks pertained to management issues related to horses and burros *on the range*. It was not asked to examine BLM procedures and actions related to gathers—the roundups that BLM conducts to administer such management actions as adjusting sex ratios on the range, treating animals with contraceptives, and removing animals from the range. The committee's tasks did not include investigation of the effects of gathers on the welfare of gathered horses and burros. The welfare of animals in holding facilities or of animals that leave the program through adoption or sale was also not part of the study's charge. A critique of the legal framework under which the horses and burros are managed (including the number of acres on which BLM manages the animals), an examination of BLM's legal authority to use euthanasia, and specific recommendations for program budget allocations were similarly not within the scope of the study.

The committee was not tasked with examining issues within BLM that may affect how the Wild Horse and Burro Program functions. One example is related to livestock grazing. The agency's multiple-use mandate includes administering grazing allotments on public lands to private owners of livestock. Whether livestock or equids do or should receive preferential

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treatment by BLM when rangeland is allocated or when the number of animals on the range is adjusted to keep rangelands healthy was not within the study's scope. Another example is BLM's internal organizational structure. The committee was not asked to examine how the organizational hierarchy of national, state, and field offices and the responsibilities of and working relationships between these levels pertain to BLM's effectiveness in managing horses and burros.

In addition, as became evident from public comments at information-gathering sessions and submitted written comments, the statement of task did not include questions that are of concern to many stakeholders. The study did not investigate such topics as the relevance of the evolutionary origin of the horse species in North America and the logistical and economic feasibility of establishing ecosanctuaries for horses and burros. The study did not examine the procedures that BLM uses to gather horses and burros, so it did not explore whether alternative methods of gathering equids could be used. Furthermore, the report does not comment on whether the number of free-ranging horses and burros deemed appropriate by BLM or the area of range available to equids should be increased or decreased.

As a committee established under the auspices of the National Research Council, the Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program was constituted to answer science-based questions. Although the answers to science-based questions inform policy decisions, it is the role of decision-makers to weigh the values associated with the possible outcomes of management actions. National Research Council committees are also not constituted to be bodies of legal review or critique.

Therefore, many of the questions alluded to above were not within the prerogative of the committee. Horses and burros removed from the range by culling or by gathering and moving them to long-term holding are not managed on the range and thus were not within the committee's statement of task. The report's findings on the effects of population control on herd health, genetic diversity, and social behavior (Chapters 4 and 5) would apply to horses and burros remaining on the range if a herd were culled; in contrast, policy decisions to cull on or near the range or to remove animals to long-term holding facilities permanently to control animal populations are value judgments. Similarly, the answers to questions related to the numbers of animals of any species on the range are determined by the public's values, both economic and emotional, concerning not only equids but livestock, wildlife, rangeland conditions, and other natural resources. Science can inform what effects different combinations of species and population levels may have on the range, but science cannot say what decisions *should* be made.

Acts of Congress are policy decisions. The committee recognized that a complicated legal framework affects how free-ranging horses and burros are managed and that the complexity of the framework may create an impediment to effective management. However, it is the role of members of Congress, as representatives of their constituents, to promulgate or amend laws. In the report, the committee commented only by way of description on the legal framework under which horses and burros are managed.

Because of the existing legal framework that protected horses and burros at the time of the study, the committee did not investigate whether the horse should be considered a reintroduced species because of its evolution in North America. Previous National Research Council reports (NRC, 1980, 1982) examined the question and reported that the dearth of information regarding changes in the horse, *Equus caballus*, since domestication, which occurred after the species crossed the land bridge into Eurasia, and changes in the environment and the

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complex of species in North America since the Pleistocene epoch,[5] when *E. caballus* inhabited the continent, made the designation of the horse as a reintroduced species difficult to assess. Discoveries about the evolutionary and genetic history of the horse have been made since those reports (see Weinstock et al., 2005), but uncertainty remains regarding the degree of similarity or change in the morphology and behavior between modern horses and ancestral horses from Pleistocene North America. In the context of the committee's study, free-ranging horses and burros under BLM management, whether or not they are considered a species reintroduced into North America, are protected by the Wild Free-Roaming Horses and Burros Act and therefore have the protection stipulated in the law, that is, to their known territorial limits as of 1971.

Regarding evaluations of gather techniques, the effects of gathers on horses and burros, and the condition of animals placed in long-term holding facilities, such a study would be better conducted by a committee specifically constituted with the expertise to assess animal welfare. The treatment of animals during gathers and in holding facilities has been studied by the Government Accountability Office (2008) and by a task force of the American Association of Equine Practitioners (2011). Investigating the circumstances of animals that leave the program through sale or adoption is more appropriate for a body that has auditing authority. The committee was not asked to assess the viability of ecosanctuaries, so such expertise was not included in the committee's makeup.

Though the committee did not address the aforementioned issues directly, it recognized that increasing costs of gathering animals and holding them indefinitely drove Congress to ask BLM to develop a long-term plan for managing free-ranging horses and burros. The committee was also aware that concerns for animals gathered and placed in holding or released from the program through adoption or sale cause much of the stakeholder frustration with the Wild Horse and Burro Program. In fulfilling its statement of task, which sets forth how BLM can use science to improve management of animals on the range, the committee had the goal in this report to provide BLM with tools that could help the agency to decrease the use of and spending on contentious practices and to manage healthy populations on the range.

STATUS OF FREE-RANGING HORSES AND BURROS UNDER BUREAU OF LAND MANAGEMENT JURISDICTION

At the time the committee conducted its review, BLM reported that 31,453 horses and 5,841 burros were on the range (BLM, 2012b). The animals live on Herd Management Areas (HMAs),[6] rangeland that they inhabited in 1971 and that BLM has found to have adequate forage, water, cover, and space to support them. In 2012, there were 179 HMAs, 171 of which contained equids. Figure 1-3 shows HMAs designated by BLM for use by horses, burros, or both. Recognizing that the proximity of some HMAs to one another allows animals to move from one HMA to another, BLM began to manage some groups of HMAs as complexes, or larger units, in the late 2000s. In 2012, 93 HMAs were parts of complexes (Figure 1-4).

HMAs are in 10 states; almost half the 179 are in Nevada (Table 1-1). BLM reported in 2012 that almost 60 percent of the free-ranging horse population was in Nevada, followed by Wyoming and Utah, at 11 and 10 percent, respectively. Over 50 percent of the burros on the range were in Arizona and 25 percent were in Nevada (Figure 1-5).

[5]The Pleistocene epoch ended 11,700 years before the present.
[6]U.S. Forest Service herd areas are referred to as Wild Horse (or Burro) Territories.

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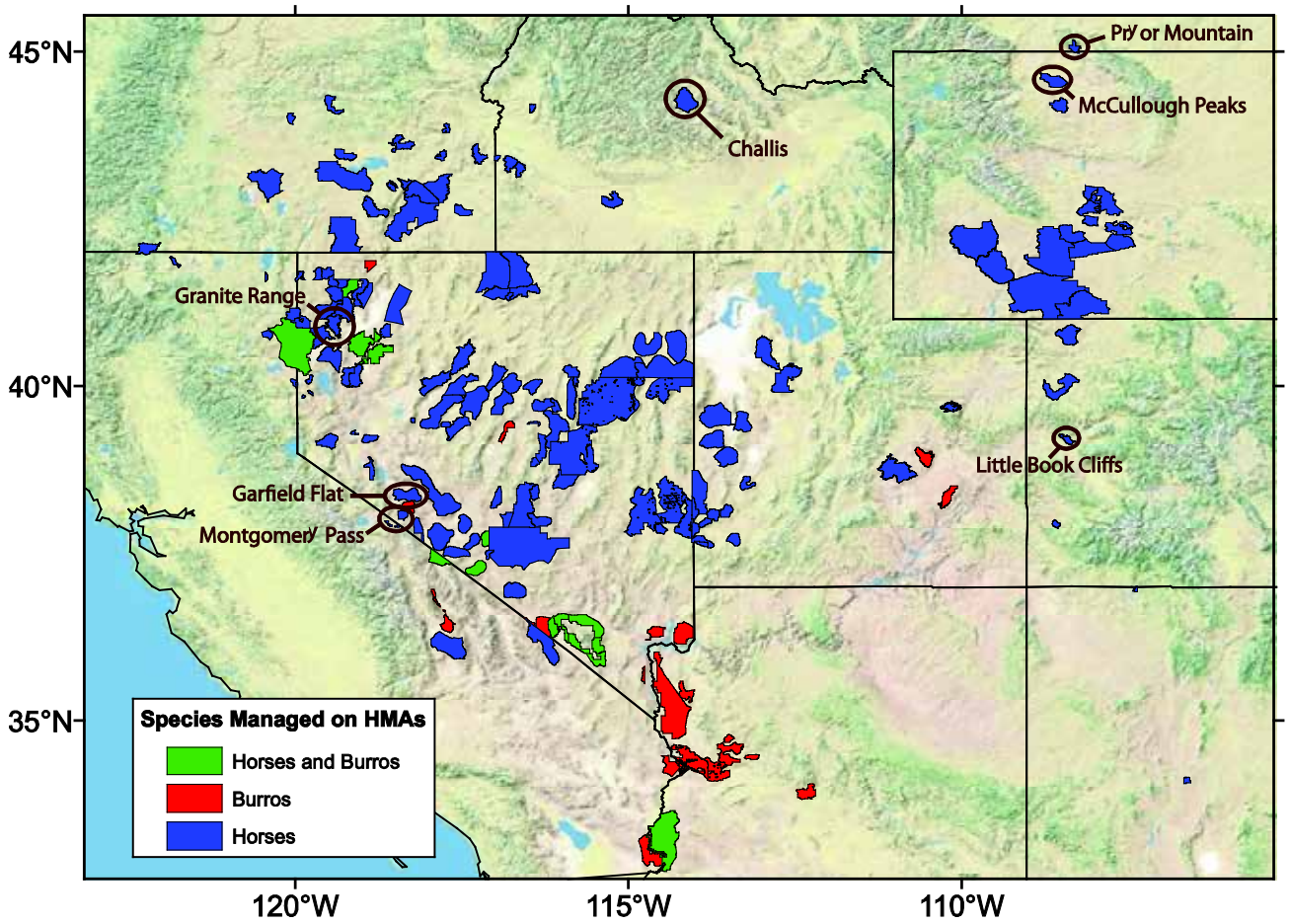


FIGURE 1-3 Herd Management Areas (HMAs) in 2012.
NOTE: The HMAs are categorized by the species that the Bureau of Land Management (BLM) manages in an area. Burros may live in some HMAs that are managed only for horses and vice versa. HMAs discussed often in the report are circled on the map.
DATA SOURCE: Mapping data provided by BLM. Species data from BLM (2012b).

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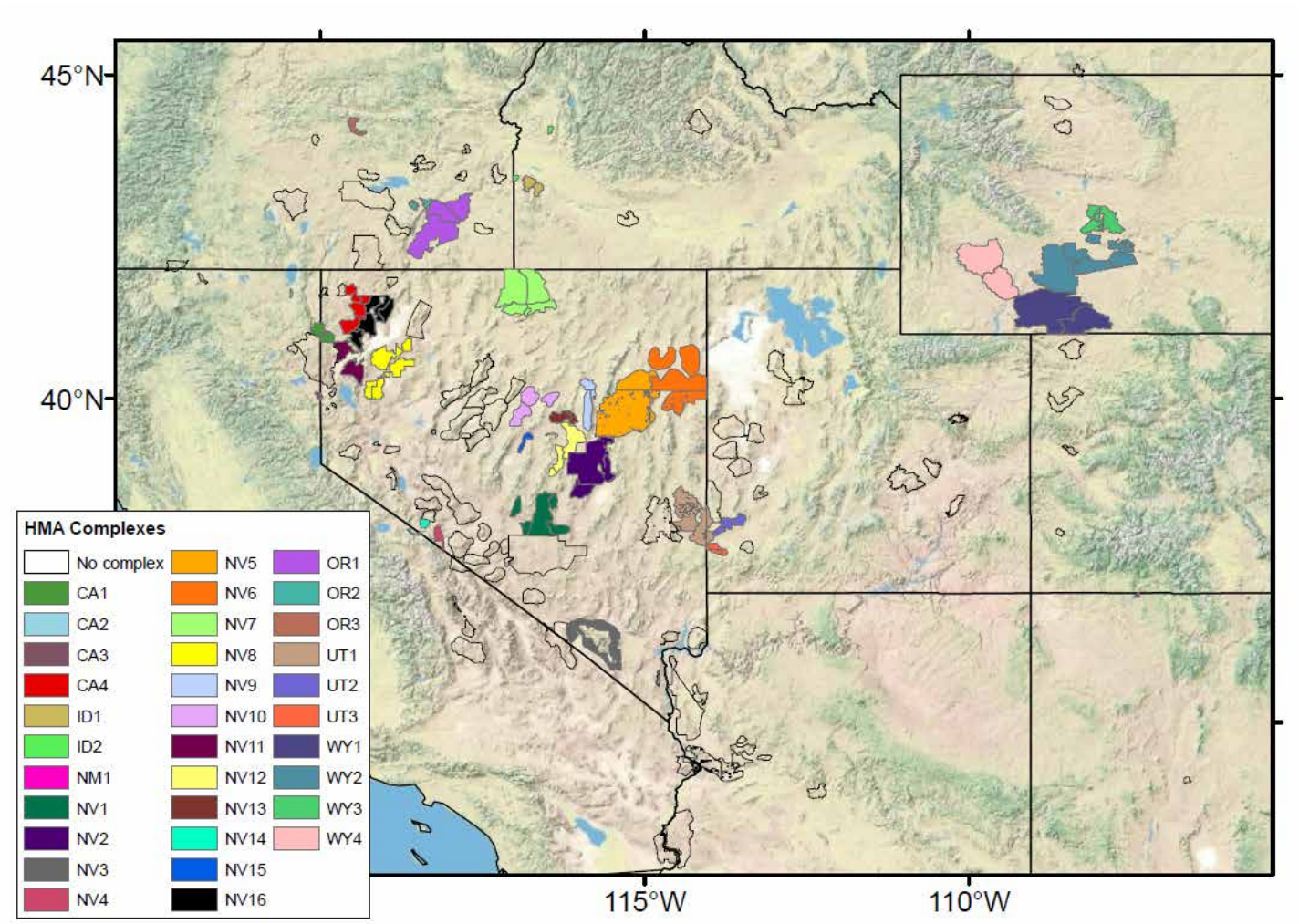


FIGURE 1-4 Herd Management Areas (HMAs) managed together or with Wild Horse or Burro Territories as complexes.
NOTE: Blank HMAs are not managed as part of a complex. The complex codes in the legend correspond to the following HMAs:

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CA1	Buckhorn, Coppersmith
CA2	Round Mountain (managed by the U.S. Forest Service with the Devil's Garden Plateau Wild Horse Territory)
CA3	Fort Sage (California), Fort Sage (Nevada)
CA4	High Rock, Nut Mountain, Wall Canyon, Bitner, Fox Hog
ID1	Black Mountain, Hard Trigger
ID2	Four Mile (Idaho), Sand Basin
NM1	Carracas Mesa (managed by the U.S. Forest Service)
NV1	Stone, Cabin, Saulsbury, Hot Creek, Reveille (managed by the Bureau of Land Management with Monitor Wild Horse Territory)
NV2	Pancake, Sand Springs West (managed by the Bureau of Land Management with Monte Cristo Wild Horse Territory)
NV3	Johnnie, Red Rocks, Wheeler Pass (managed by the Bureau of Land Management with Spring Mountain Wild Horse Territory)
NV4	Fish Lake Valley (managed by the Bureau of Land Management with U.S. Forest Service Wild Horse Territory)
NV5	Triple B, Maverick-Medicine (managed by the Bureau of Land Management with Cherry Springs Wild Horse Territory)
NV6	Antelope, Antelope Valley, Goshute, Spruce-Pequop
NV7	Owyhee, Little Owyhee, Little Humboldt, Rock Creek, Snowstorm Mountain
NV8	Blue Wing Mountains, Seven Troughs, Lava Beds, Nightengale Mountains, Kamma Mountains, Shawave Mountains
NV9	Diamond, Diamond Hills North, Diamond Hills South
NV10	Callaghan, Rocky Hills, Bald Mountain
NV11	Buffalo Hills, Fox-Lake Range
NV12	Seven Mile, Fish Creek, Little Fish Lake, North Monitor (managed with Butler Basin and Little Fish Lake Wild Horse Territories)
NV13	Roberts Mountain, Whistler Mountain
NV14	Montgomery Pass (managed by the U.S. Forest Service)
NV15	Hickison Summit (managed by the U.S. Forest Service with the Hickison Wild Burro Territory)
NV16	Calico Mountains, Black Rock East, Black Rock West, Granite Range, Warm Springs Canyon
OR1	Coyote Lake, Alvord Tule Springs, Sand Springs, Sheepshead/Heath Creek
OR2	Kiger, Riddle Mountain
OR 3	Murderer's Creek (managed by the U.S. Forest Service with Murderer's Creek Wild Horse Territory)
UT1	Choke Cherry (Utah), Mt. Elinor (Utah), Eagle (Nevada)
UT2	Bible Springs, Four Mile (Utah), Tilly Creek
UT3	North Hills (managed by the Bureau of Land Management with the North Hills Wild Horse Territory)
WY1	Adobe Town, Salt Wells Creek
WY2	Divide Basin, Lost Creek, Stewart Creek, Antelope Hills, Green Mountain, Crooks Mountain
WY3	Dishpan Butte, Muskrat Basin, Conant Creek, Rock Creek Mountain
WY4	White Mountain, Little Colorado

DATA SOURCE: Mapping data and complex information provided by the Bureau of Land Management.

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TABLE 1-1 Herd Management Areas, by State, 2012

State	Number of Herd Management Areas	Number of Herd Management Areas with Free-Ranging Equids
Arizona	7	7
California	21	19
Colorado	4	4
Idaho	6	6
Montana	1	1
Nevada	85	79
New Mexico	2	2
Oregon	18	18
Utah	19	19
Wyoming	16	16
Total	179	171

SOURCE: Bureau of Land Management (2012b).

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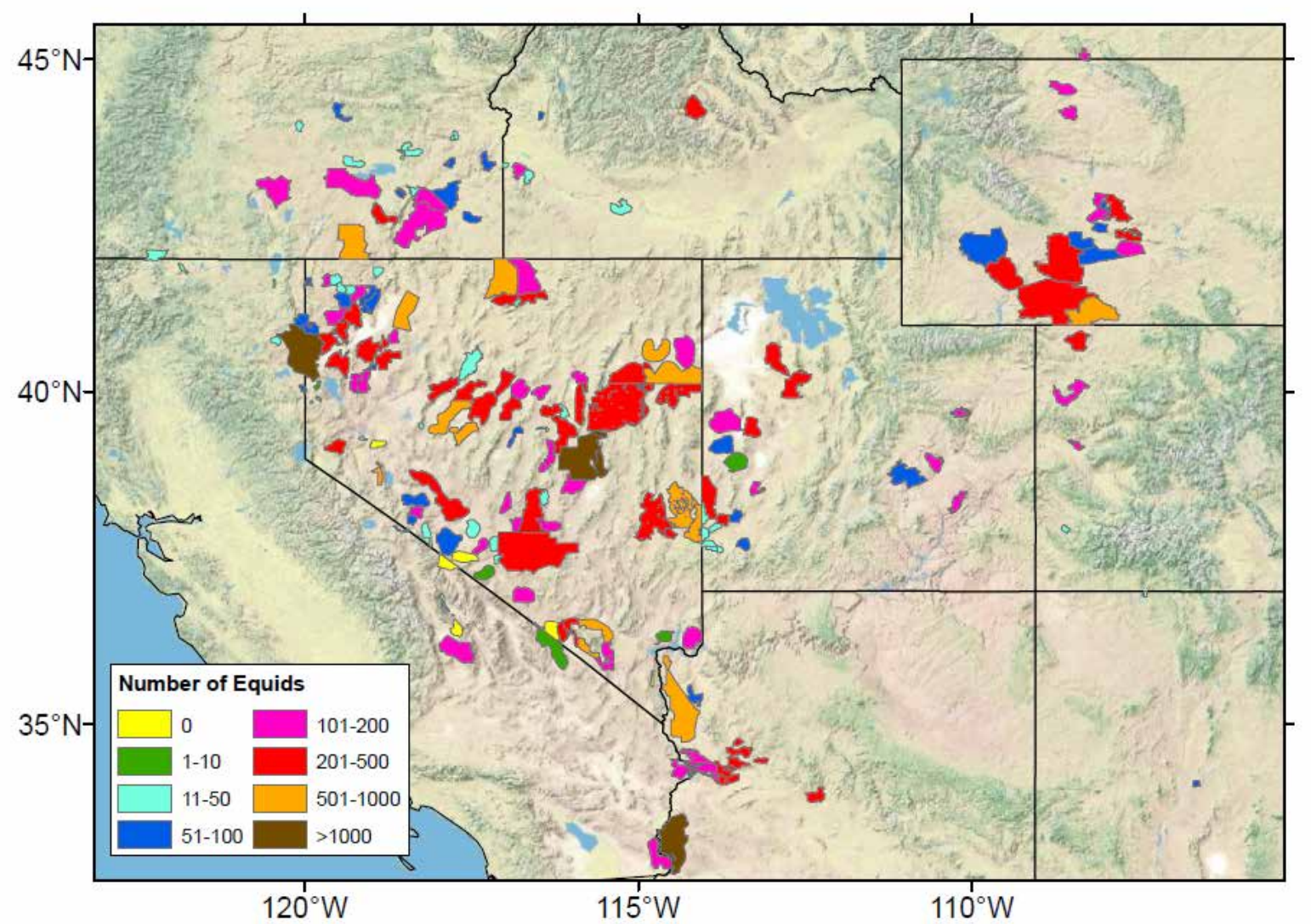


FIGURE 1-5 Number of equids reported by the Bureau of Land Management (BLM) for each Herd Management Area in 2012. DATA SOURCE: Mapping data provided by BLM. Population data from BLM (2012b).

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As required by the Wild Free-Roaming Horses and Burros Act (as amended), BLM sets an appropriate management level (AML) for each HMA, the numeric population range at which the agency has determined a herd can be maintained in healthy condition without adversely affecting a thriving natural ecological balance. When establishing an AML, BLM must also consider other federal acts pertaining to public lands, including the Federal Land Policy and Management Act of 1976 (94 P.L. 579), the Wilderness Act of 1964 (88 P.L. 577), the National Historic Preservation Act of 1966 (89 P.L. 665), the Clean Water Act of 1972 (92 P.L. 500), the Endangered Species Act of 1973 (93 P.L. 205), and the Forest and Rangeland Renewable Resources Planning Act of 1974 (93 P.L. 378). The requirements of these acts as they pertain to free-ranging horse and burro management are discussed in Chapter 7 (see "The History of Appropriate Management Levels").

Table 1-2 shows the upper bounds of AMLs and the estimated population of each species in each state. Often, when populations exceed the upper bound of AML, BLM conducts a gather. After a gather, a healthy animal may be released back to the range, released back to the range after being gelded or treated with a contraceptive, or removed to a short-term holding facility. Animals removed from the range may be put up for adoption.[7] An animal that is not adopted is ultimately moved to a long-term holding facility, where it remains. In 2010, BLM removed 9,042 animals from the range (BLM, email communication, December 11, 2011). As of September 2012, it held 14,238 animals in short-term holding facilities and 33,623 in long-term holding facilities (BLM, 2012c).

TABLE 1-2 Upper Limits of Appropriate Management Levels and Population Estimates of Horses and Burros by State, 2012

State	Appropriate Management Levels		Population Estimates	
	Horse	*Burro*	*Horse*	*Burro*
Arizona	240	1,436	502	3,194
California	1,585	478	1,965	939
Colorado	812	0	967	0
Idaho	617	0	640	0
Montana	120	0	170	0
Nevada	11,964	814	18,425	1,456
New Mexico	83	0	108	0
Oregon	2,690	25	2,093	35
Utah	1,786	170	3,040	217
Wyoming	3,725	0	3,543	0
Total	23,622	2,923	31,453	5,841

SOURCE: Bureau of Land Management (2012b).

[7]At times during the lifetime of the law, BLM has had the authority to sell animals without limitation. During 2005-2010, it sold roughly 650 animals a year (Bolstad, 2011). At the time the study was conducted, BLM had authority to sell animals, although legislation to remove the authority had been proposed.

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ORGANIZATION OF THE REPORT

Because a thorough review of the literature on horse and burro biology was conducted in the 1980 National Research Council report, this report begins with questions pertinent to the statement of task. Information from the 1980 report on the social organization of free-ranging horses and burros is summarized briefly in Box 1-4, and equid life history is explained further in later chapters. Although burros are discussed in this report, the management of horses is featured more comprehensively as more studies have been conducted on free-ranging horses than on burros. Also, at the time this report was published, BLM estimated that it managed over 30,000 horses and fewer than 6,000 burros on the range. Thus, the committee inferred that managing horses was the more pressing issue for BLM and that its review should devote more attention to horses than to burros.

BOX 1-4

Social Organization of Free-Ranging Equids

Equids organize themselves socially in a variety of forms. Two dominant forms are harem organization and territorial organization. A harem, also known as a band, consists of a dominant stallion, subordinate adult males and females, and offspring. The group is strongly bonded, although bands are not entirely stable. Typically, adults in the group are not close genetic relatives. Movement among bands is not uncommon; it often occurs when a stallion is displaced, when a stallion defeats a competitor for a mare, or when females reach maturity. Harem organization is common in free-ranging horses; an average band size is five animals. Occasionally, bands come together to form temporary aggregations or herds. In territorial organization, a male typically defends a territory and mates with females that enter the area. The mother-offspring relationship is the only stable bond. Burros typically display this form of social organization. Temporary groups of bachelor males exist in both organization patterns.

Successful management of horses and burros requires knowing how many animals live on the range. BLM often receives criticism about the validity of the reported number of animals and therefore asked the committee to review its methods for estimating the size of the population of free-ranging horses and burros under its jurisdiction. The committee was also charged with evaluating the estimated population growth rate that BLM uses, another issue that is highly contentious between some stakeholders and BLM. Chapter 2 analyzes data provided to the committee by BLM and reviews the literature on population survey techniques to address this task.

Population processes, such as population growth and self-limitation, affect population size. They can be influenced by the density of a population or by independent factors, such as climate or, in the case of free-ranging horses and burros, management decisions. Chapter 3 examines how density-dependent and density-independent factors and management actions may affect the population processes of free-ranging horses and burros. Changes in the size of a population due to density, climate, predation, and management actions are specifically studied.

BLM has used the contraceptive porcine zona pellucida in mares since 2004, but it has been administered to so few animals that it has had no effect on population size. Since the earlier National Research Council reports were published (NRC, 1980, 1982, 1991), considerable progress has been made in developing and testing fertility control for wild animal populations, both free-ranging and captive. Chapter 4 investigates the fertility-control options for mares and stallions that are available to BLM. The on-the-range feasibility and efficacy of each method is

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assessed, and the effect of potential widespread application of these methods on population processes is evaluated.

Chapter 5 summarizes the research on genetic diversity in free-ranging horse and burro populations in the western United States. Much work has been conducted since the earlier National Research Council reports were published, and genetic-testing capabilities have advanced. The chapter examines the relevance of genetic diversity to long-term herd health of ungulates in general and of free-ranging horses and burros in particular. It presents methods for maintaining healthy levels of genetic diversity. It also reviews the science on the minimum population size needed for viability and explores the different ways in which free-ranging horse and burro populations could be managed for genetic diversity, for example: In terms of genetics, should a population be defined as the animals on an HMA, the animals on an HMA complex, or the entire population of free-ranging horses or burros?

Anticipating the effects of a management action can help decision-makers to select the most efficient and productive course of action when managing animal populations. Chapter 6 reviews population models that are or could be used by BLM to project the effects of management actions (such as removals from the range, contraceptive treatments, and changes in the sex ratio) on the population dynamics of a herd or a larger population. The components necessary for a modeling framework that would comprehensively address the Wild Horse and Burro Program's challenges are detailed.

The Wild Free-Roaming Horses and Burros Act charges BLM with establishing AMLs and managing populations to protect and restore a thriving natural ecological balance of all wildlife species, particularly endangered species, and to protect rangelands from deterioration. The agency must also consider the capacity of an area to support equids in a healthy condition and the multiple-use objective of BLM management when determining AMLs. In Chapter 7, the committee examines the process that BLM has designed for establishing and adjusting AMLs, as published in its *Wild Horses and Burros Management Handbook* in June 2010. The chapter also reviews alternative approaches that BLM might use to set and validate AMLs.

As alluded to in Box 1-2, there are strong and often divergent stakeholder opinions regarding the management of horses and burros, and BLM has often been criticized for its procedures by parties holding conflicting opinions and values. Chapter 8 explores ways in which BLM can use participatory approaches to find greater convergence on management objectives and actions that use the best science available. The issue of the horse as native to North America is also addressed in the chapter.

Chapter 9 uses the report's findings to suggest a sustainable path forward for the Wild Horse and Burro Program built on scientific research.

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2

Estimating Population Size and Growth Rates

Understanding the number and distribution of free-ranging horses and burros on their range is explicitly part of the mandate to the Bureau of Land Management (BLM) in the Wild Free-Roaming Horses and Burros Act of 1971 (92 P.L. 195). That act, as amended by the Public Rangelands Improvement Act of 1978 (95 P.L. 514), states that BLM "shall maintain a current inventory of wild free-roaming horses and burros on given areas of the public lands" to, in part, "make determinations as to whether and where an overpopulation exists and whether action should be taken to remove excess animals."[1] Thus, nearly all the management actions that BLM takes on Herd Management Areas (HMAs) are predicated on the population-size estimates of equids on the range. Population estimates aid in allocation and management of forage and habitat and underlie the establishment of appropriate management levels (AMLs). In addition, data on changing horse and burro abundance provide information that can be used to estimate population growth rates; aid in accruing knowledge to understand population and evolutionary processes (Chapters 3 and 5); assess the effectiveness of such management actions as removals, sex-age class manipulations, and contraceptive treatments to reduce population growth rates (Chapter 4); provide important information for assigning values to parameters of population models (Chapter 6); determine whether AMLs are being maintained and meeting their objectives (Chapters 5 and 7); and inform all those who have an interest in free-ranging horses and burros (Chapter 8). This chapter responds to the BLM request for a review of free-ranging horse and burro population estimates, techniques to improve those estimates, and population growth rates.

In fiscal year 2011, BLM spent about $641,250 to estimate the abundance of horses and burros on HMAs; that is about 1 percent of the Wild Horse and Burro Program's annual budget (BLM, 2011). However, maintaining a current, accurate, and robust inventory of horses and burros living on land under its jurisdiction has been a continuing struggle for BLM. Because accurate estimates of free-ranging horse and burro populations are the foundation of scientifically based management of these animals, third parties have paid considerable attention

[1]"Excess animals" are ones that "must be removed from an area in order to preserve and maintain a thriving natural ecological balance and multiple-use relationship in that area" (95 P.L. 514). Chapter 7 discusses the concept of thriving natural ecological balance and the multiple-use mandate of the act.

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to assessments of BLM's methods for inventorying horses and burros over the history of the program (NRC, 1980, 1982; GAO, 1990, 2008). The committee received unfavorable comments during the study process from many members of the public regarding BLM's reports of equid population estimates and assumed or reported population growth rates.

This chapter focuses initially on estimation of free-ranging horse and burro populations. It first distinguishes the difference between counting animals and estimating population size and discusses why this methodological distinction is important for management and transparency. It then reviews several classes of population-survey methods and their strengths, weaknesses, and applicability to free-ranging horses and burros. The section that follows evaluates information available on the methods used by BLM to inventory equid populations and report the results to the public and Congress when this study was conducted. Recent initiatives to improve BLM's inventory procedures are then described with recommendations for strengthening the scientific validity and accuracy of the inventory program and enhancing communication of these important statistics to stakeholders. The second topic addressed in the chapter deals with population growth rates. A number of data sources that provide insight into growth rates of horse and burro populations are reviewed, and the results critiqued and synthesized. The chapter ends with a summary of the committee's conclusions regarding BLM's horse and burro inventory and reporting procedures and an assessment of typical population growth rates realized on western rangelands. The conclusions are then interpreted in the context of the challenges faced in managing free-ranging equid populations in the future.

ESTIMATING THE SIZE OF FREE-RANGING EQUID POPULATIONS

Since the inception of the Wild Horse and Burro Program, BLM's population inventory program has involved attempting to survey completely the fixed areas occupied by free-ranging equids, known as HMAs, and to count all the animals detected. Those inventory surveys are commonly referred to as censuses in BLM reports; however, a census involves the perfect enumeration of every animal that occupies a given area of interest; that is, every animal is detected and counted. That is ideal, but counting free-ranging animal populations is an imperfect exercise. Topography, the extent of survey areas, vegetation structure, weather, animal behavior and coat color, the size of areas used by individual animals, the performance of aircraft used by observers, the skill and condition of observers, sun angle, cloud cover, and wind speed are some of the major factors that can influence the detectability of animals, which in turn affects the accuracy, efficiency, and effectiveness of survey methods (MacKenzie et al., 2006). For any given set of survey conditions, those factors can result in observers' failure to detect animals that are present in a survey area or their unknowing detection and counting of the same animals on multiple occasions. Although animals can be missed or double-counted during the same survey, a large body of scientific literature on techniques for inventorying large mammals has demonstrated that failure to detect animals is overwhelmingly more common (Caughley, 1974a; Pollock and Kendall, 1987; Samuel et al., 1987). The first studies of probabilities of detection of free-ranging horses on western rangelands reported that in typical surveys only 7 percent of horses were undetected in flat, treeless terrain, but 50-60 percent were undetected in more rugged terrain with tree cover (Frei et al., 1979; Siniff et al., 1982). More recent studies of inventory techniques have reaffirmed those conclusions (Walter and Hone, 2003; Laake et al., 2008;

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Lubow and Ransom, 2009; Ransom, 2012a). Overcounting horses has only been reported for a relatively high-density population in New Zealand where the systematic flight pattern of the helicopter, with closely spaced flight lines and routinely low altitude above ground, resulted in bands of horses unknowingly being counted several times (Linklater and Cameron, 2002).

Thus, the animal counts (the total number of animals tallied in a given survey) derived from BLM's typical inventory procedures do not reflect the true number of animals in an HMA but instead represent what is more appropriately termed a population estimate, that is, an approximation of the true population that is based on the data collected (the count). The counts themselves represent the minimum number of animals occupying the HMA, but how closely the counts approximate the true number of animals occupying a given HMA depends on the proportion of the animals that are undetected and thus are not counted. For example, if a BLM aerial survey counted 180 horses on an HMA and 90 percent of the animals were detected, the count was a reasonably accurate population estimate in that the true number of horses occupying the HMA was 200. However, if only 50 percent of the animals were detected, the count would represent a poor population estimate in that the true population size was actually 360 horses. There is a large body of methodological and statistical literature on the development and testing of techniques for obtaining accurate and precise estimates of animal abundance (Seber, 1982; Pollock et al., 1990; Lancia et al., 1996; Nichols and Conroy, 1996; Krebs, 1999; Williams et al., 2001; Mills, 2007; Conroy and Carrol, 2009). It provides insights on how to detect and count animals better, procedures for estimating detection probability, and techniques for "adjusting" or statistically extrapolating count data collected in various ways to produce more accurate population estimates and measures of the precision of estimates.

Population Survey and Detection Methods

Scientifically robust surveying techniques are essential for obtaining accurate estimates of the abundance of free-ranging horses and burros that are necessary for successful management of herds on BLM-managed rangelands. As detailed above, horses and burros are imperfectly detected for a number of reasons, but ground-based assessments, aerial surveys, remote-sensing imagery, genetic techniques, or some combination of these can be effective for locating animals and estimating the size of a population of equids in a target domain, such as an HMA or an HMA complex. This section reviews selected survey methods that were supported by scientific research and in use as of late 2012. It also describes methods that may have potential for detecting free-ranging equids in a logistically and fiscally feasible manner.

Ground-Based and Aerial Survey Methods

To prevent undercounting or double counting of free-ranging ungulates, especially in heterogeneous or topographically complex landscapes, several techniques have been developed that allow explicit quantification of sampling uncertainty and detectability of animals. The following methods have been applied effectively to estimate detectability and uncertainty in estimating the abundance of free-ranging horses and burros.

Strip and Line Transects. A target domain is sampled by traveling along lines that are often placed systematically across relatively homogeneous landscapes and, in more heterogeneous landscapes, may be distributed in more complex arrangements to ensure adequate coverage (Caughley, 1974a; Buckland and Turnock, 1992). The lines, known as transects, are typically

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traveled by aircraft that carry one or more observers to record animals detected. In strip-transect surveys, the observer constrains recording of animals to a relatively narrow width of the transect to try to fulfill the assumption that all animals in the transect are detected. The resulting data are used to estimate a density of animals in the areas covered by the strip transects, and this density is extrapolated to the entire area that was sampled to obtain an estimate of the number of animals in the sampled area (Burnham et al., 1980; Marsh and Sinclair, 1989).

In line-transect surveys, observers record all animals spotted while they traverse the transect, typically using distance sampling (Buckland et al., 2004, 2005), in which all groups of animals detected are recorded with their perpendicular distance from the transect. Such data aggregated across many transects are then used to estimate a detection probability function, which assumes that all groups of animals on the transect line are perfectly detected, and detectability declines for groups of animals at increasing distances from the transect line. The primary advantage of this technique for free-ranging horses is that distance sampling can accommodate large spatial areas of high topographic and vegetative heterogeneity (J. Ransom, National Park Service, personal communication, August 10, 2012), and detection probability is explicitly modeled and estimated. Assumptions of the approach are that lines are placed randomly with respect to the distribution of the objects (such as equids) sampled, that equids do not move because of the aircraft (that is, they are detected at their initial locations), that perpendicular distances from the transect line to each equid group are measured accurately, and that detections are statistically independent events. U.S. Geological Survey biologists were as yet unable to find a distance-measuring device that worked satisfactorily, but they were developing such a tool (J. Ransom, National Park Service, personal communication, August 10, 2012). Ransom et al. (2012) used distance sampling and minimally trained local observers in Mongolia to estimate the abundance of wild asses (*Equus hemionus*).

Mark-Recapture and Mark-Resight. In mark-recapture studies, animals are uniquely marked (or identified individually on the basis of unique markings or characteristics) and later recaptured (either physically or with visual recapture methods) so that a detection history of each marked animal can be compiled. Population size can be estimated by applying open-population or closed-population mark-recapture models to detection-history data (Schwarz and Arnason, 1996; Williams et al., 2001). Software packages, such as Program MARK (White and Burnham, 1999), provide a flexible framework for implementing closed-population and open-population models in estimating abundance and related parameters.

Whereas conventional capture-recapture methods for estimating population size (e.g., Otis et al., 1978; Williams et al., 2001) generally require animals to be uniquely marked in such a way that a detection history for each marked animal can be compiled, more recent mark-resight approaches can also incorporate sightings of unmarked animals into the estimation framework (McClintock and White, 2009). Mark-resight efforts can often be less expensive and less invasive (Minta and Mangel, 1989; McClintock and White, 2007) than traditional mark-recapture methods (Otis et al., 1978). In particular, animals need to be captured only one time (capture is often the most hazardous, stressful, and expensive aspect of these estimation techniques); after initial marking periods, additional data can be collected with sighting surveys, which do not necessitate physical capture of animals and thus are less invasive (McClintock et al., 2009). However, mark-resight methods assume that animals are sampled and resighted in a closed population (that is, no immigration, emigration, births, or deaths occur) and that the

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number of marked animals available for resighting is known exactly or can be reliably estimated (McClintock et al., 2009). Those assumptions can be approximated by conducting sighting surveys soon after the initial marking (to ensure a closed population), by using radio collars with mortality sensors on all captured animals (McClintock and White, 2007), or by using other mark-resight models that do not require that the number of marked animals be exactly known (Arnason et al.,1991; McClintock et al., 2009). McClintock et al. (2009) provided an estimation framework that addresses both constraints by using Poisson-log (PNE) and zero-truncated Poisson logit-normal (ZPNE) mixed-effects models. Various versions of mark-resight models are available in the freeware Program MARK (White and Burnham, 1999).

Mark-resight techniques using natural distinguishing characteristics of horses have been used in Australia and New Zealand (Linklater and Cameron, 2002; Dawson and Miller, 2008), and Lubow and Ransom (2009) used a photograph-based form of mark-resight methods for enumerating free-ranging horses in the western United States by identifying each group of horses (via such markings as blaze, socks, and coat color) and determining how many groups were resighted on later flights. Transects should be widely spaced so that an HMA can be completely covered multiple times with differently oriented transects (Lubow and Ransom, 2009). Lubow and Ransom (2009) reported that the advantages of the photographic mark-resight technique for free-ranging horses are that it can be performed with only one observer, it does not matter if horses are displaced by the aircraft or if a group is encountered repeatedly on the same survey, the technique works in areas with tree cover and complex terrain, and most covariate data are captured in each photograph, so the need to write them down is eliminated. Lubow and Ransom (2009) suggested that the method is likely to produce negatively biased (but quantified) estimates of abundance, and bias probably would increase as the visibility of the horses decreases (for example, more complex topography or more tree cover). Lubow and Ransom noted that it might take several visits to obtain reliable estimates; validation of photographic mark-resight data suggested that it would take six or more occasions in areas that have complex topography and heavy tree cover. According to data collected by Lubow and Ransom (2009) at McCullough Peaks, Little Owyhee, and Pryor Mountain HMAs, the approach provided consistent and reliable estimates of total horse numbers (within 3-9 percent of exact counts). The limitations are that helicopters (which are more expensive to use than fixed-wing aircraft) are usually needed to observe markings in photographs, a high-resolution digital camera with an image-stabilized lens must be used, and it may be difficult to separate horses that have similar coat colors or that are in HMAs that have large numbers of animals (J. Ransom, National Park Service, personal communication, August 10, 2012). This method will probably perform poorly for burros (J. Ransom, National Park Service, personal communication, August 10, 2012).

Simultaneous-Double Count. Two observers independently record the number of animals seen from a given location at the same time. Records are compared to inform population estimates by assessing how many animals or groups of animals are detected by both observers and how many are detected by only one observer or the other (Caughley, 1974a; Ransom, 2012b). The technique can also be used in combination with distance sampling (Kissling and Garton, 2006). It is assumed that observers do not communicate during the observations, that observations are recorded honestly (i.e., it is not a competition), and that transects traveled are uniform, are predetermined, and cover the entire area of interest. The advantages of this method for free-ranging horses are that it provides an estimate of abundance with quantified error and does not

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require any special equipment. The limitation is that, even with two observers, it is unlikely that it will be sufficient to overcome large biases due to high landscape heterogeneity.

Pre-Gather and Post-Gather Counts. The number of animals captured or removed from the land is used to inform population estimates. This technique can be used when a count has been conducted and is followed soon thereafter by a gather, in which a relatively large proportion of the horses are removed and the quantity is known. Another count is conducted soon after the gather. The difference between the two counts can be used to estimate the detection probability (Eberhardt, 1982).

All the methods except removals or captures can be conducted from the ground or from the air. In ground-based surveys, observers might traverse transects on foot, in vehicles, on horseback, or a combination of the three. Ground-based observers may be in prepositioned, stationary blinds to count animals with the mark-resight or double-observation methods. Cameras can be used to photograph animals at places of common congregation, such as watering holes (Cao et al., 2012; Petersen et al., 2012), and animals can be identified in a series of photographs over time by their markings; this procedure is typically used in a mark-resight analytical framework. Given the sizes of HMAs and their varied topography, it is usually practical and cost-effective to conduct surveys of horses and burros from the air. Helicopters and fixed-wing aircraft are the two aerial survey platforms typically used. In some cases, fixed-wing aerial surveys, which are less expensive than helicopter surveys, are adequate to locate and count animals, especially in areas dominated by sagebrush or other low-growing vegetation. In areas that have higher canopy and cover, however, helicopters may be needed for slower and more careful searching patterns. In aerial surveys, survey methods may be combined. For example, more than one observer may count animals as an aircraft follows a transect pattern by using distance sampling. Transect patterns can also be flown more than once during a survey to increase accuracy of population estimation, assuming that animals do not move substantially relative to flight paths between surveys.

Similarly, the Wild Horse Identification Management System (Osborn, 2004) was established in the Pryor Mountains to enumerate free-ranging horses by using unique coat-color markings and morphological characteristics in photographs. Lubow and Ransom (2009) used this approach in three HMAs (whose horse populations were of known size and were each smaller than 400) that were monitored weekly. Before correcting for detection probability, population size was biased (undercounted) by as much as 32 percent, but estimates accounting for heterogeneity of sighting probability (detection probability) were within 3-29 percent of the true number of animals known to be occupying the areas at the time of the surveys (Lubow and Ransom, 2009). The authors considered the cost of the more accurate models that quantified uncertainty in population-size estimates to be comparable with the costs of raw counts typically used by BLM (Lubow and Ransom, 2009), although the post-processing staff time required can be greater for this technique (Ransom, 2012b).

Remote-Sensing Methods

Remote-sensing technology can be used effectively to locate and count free-ranging horses and burros with a wide variety of sensors on satellites or manned and unmanned aircraft. The sensors can obtain high-resolution images at user-defined times and locations and can

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capture surface-reflectance characteristics at various spatial resolutions. Manned and unmanned aircraft can also take high-resolution videography that can be used to count horses and assess condition. New technology, including videography that detects movement patterns and measures speed of travel, can sense features with tremendous detail and accuracy. These methods will continue to be developed and improved and will allow even higher-resolution information with decreased costs. The development of remote-sensing technology to be used with unmanned (drone) aircraft also reduces the risk associated with flying planes and helicopters.

High-resolution remote-sensing imagery can be used to observe unique coat patterns and to detect identifying marks or scars for horse identification. Aerial images taken from manned and unmanned aircraft can produce images with centimeter-level resolution. In addition to color or color-infrared imagery, forward-looking infrared (FLIR) cameras can detect body heat from more than one-fourth of a mile above the ground (Millette et al., 2011). Those cameras have the potential to distinguish horses from the surrounding environment and provide an accurate method for counting animals. Quickbird and Ikonos are satellite sensors that acquire data with resolution of 0.5 to 1 m. These midlevel resolution sensors may be effective for detecting horses and for monitoring change in population densities. Higher-resolution satellite images have been developed and in time will be more readily available.

There are limitations that should be considered when selecting the appropriate remote-sensing platform with respect to estimating populations of free-ranging horses and burros (Millette et al., 2011). First, the spatial resolution of the data must be fine enough to detect individual animals (especially when animals are moving or in a herd) and reduce misidentification with other animal species. Insufficient resolution can be a problem with many satellite-based sensors. Second, data acquisition may be untimely because some technologies rely on orbiting satellites that pass over a given landscape only at intervals of a few days to a few weeks. Third, many remote-sensing technologies are expensive. Fourth, some cameras have too small a field of view and may need to pan back and forth (such as FLIR and handheld cameras). Fifth, the detectability of animals may depend on weather, time of day, vegetation composition and structure, or local topography in a survey area, and quantification of detection probability can be difficult. For example, radiant heat from the Earth's surface (in particular during the daytime) can camouflage the heat produced from a horse or burro when FLIR sensors are used. Sixth, weather patterns, particularly cloud cover, can preclude data collection with many remote-sensing technologies and can add risk to aircraft operators. Finally, current Federal Aviation Administration restrictions limit the use of unmanned aerial vehicles.

Genetic Techniques

A number of studies have used molecular markers to identify animals in noninvasively collected samples to estimate population size. That approach is particularly effective for populations in which individuals are difficult to detect because of vegetative cover or elusive behavior. Traditionally, such populations were surveyed with indirect methods, or indexes, such as sign counts (e.g., feces and tracks), which were corrected for estimates of the rates at which the signs are deposited and decay. In many cases, however, those estimates have relatively large confidence intervals, which limit their usefulness in managing or monitoring populations (Barnes, 2002). For such populations, multilocus genotypes derived from noninvasively collected samples (e.g., feces, hair, and scent marks) have been used as genetic tags for individuals. With a capture-mark-recapture design, populations have been surveyed and the resulting data have been analyzed to estimate population sizes. Genetic tags have advantages

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over traditional tagging systems in that animals retain their genotypes throughout their lives (thus, tags cannot be lost), and there is no reason to believe that a noninvasively assigned tag will affect the ability to resample the animal (the animals cannot become trap-happy or trap-shy). For dangerous or difficult-to-observe species—such as bears (Woods et al., 1999; Sawaya et al., 2012), mountain lions (Ernest et al., 2000), tigers (Sugimoto et al., 2012), wolves (Stenglein et al., 2010), coyotes (Kohn et al., 1999), and mountain gorillas (Guschanski et al., 2009)—genetic surveys have provided information about not only population sizes but sex ratios, levels of genetic diversity, and relatedness.

Although to the committee's knowledge the genetic-tag method has not been used for free-ranging horses, the necessary preliminary work to develop methods of preserving and genotyping DNA from horse dung has been done. There was no need to estimate population size for the Assateague Island National Seashore herd because individual horses are carefully monitored by park management, but the National Park Service sought information about relatedness among individuals to assess and inform its management regime. In a collaborative study with scientists at the Smithsonian Institution, methods of preserving horse dung were tested, and a representative set of microsatellite loci was optimized (Eggert et al., 2010). Potential disadvantages of this method include the time needed for genotyping and data analysis and the difficulties that may be encountered in finding a laboratory willing to conduct the work at a reasonable cost.

Herd Management Area Survey Information Requested and Received by the Committee

The committee initially requested the most recent 12 years of records (2000-2011) on all HMAs so that it could evaluate the methods and procedures used by BLM to estimate sizes of free-ranging horse and burro populations at the time of its study. Because BLM publishes annual national statistics on the numbers of horses and burros on western public rangelands, the committee assumed that requested records would include an estimate of the population of each HMA for each year. Actual surveys of the number of animals occupying a given HMA are usually not conducted annually (BLM, 2010), so the committee expected only a subset of years for each HMA to include records of actual animals counted on the basis of some survey procedure and estimates for the intervening years to be based on previous inventories. For years when counts were conducted, the committee requested the approximate date of the count, the survey platform used (e.g., ground, fixed-wing aircraft, helicopter), and whether the inventory covered the entire HMA or used some sort of sampling regimen whereby a portion of the HMA was surveyed and the results were extrapolated to obtain a population estimate for the entire HMA.

Previous research on techniques for surveying free-ranging horses and burros (Frei et al., 1979; Siniff et al., 1982; Walter and Hone, 2003; Laake et al., 2008; Lubow and Ransom, 2009) and many other large mammal species (Caughley, 1974a; Pollock and Kendall, 1987; Samuel et al., 1987) has demonstrated that not all animals are detected on surveys. Thus, survey results require the estimation of detection probability and adjustment of the number of animals counted to account for the proportion of animals that were undetected. The committee also asked whether the number of animals counted was adjusted to produce the population estimate for a given year. The committee was informed that populations in years in which no counts were conducted were estimated by multiplying the previous year's population estimate by some assumed population

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growth rate until another count was conducted (Box 2-1; BLM, personal communication, December 2011). If the HMA had experienced a gather and removal of horses in the intervening year, the number of animals removed was incorporated into the later year's population estimate. Thus, for years in which no count was performed for the HMA, the committee requested that BLM report the growth rate that was applied to obtain the population estimate with the removal data provided in a separate master database.

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BOX 2-1

Converting Counts to Population Estimates

BLM biologists obtain counts of free-ranging horses and burros to inform management decisions and to monitor equid populations. Counts can be reported directly as a "population estimate" of the animals occupying a given area, or they may be altered on the basis of other information in an attempt to make the estimate more accurate. Research has consistently shown that not all animals are detected and counted when biologists conduct surveys to count them, whether from the ground or with the use of aircraft. If an estimate of the percentage of animals detected is available, the count can be adjusted by that value to obtain an estimate that is a more accurate reflection of the number of animals in the population. For example, if 80 percent of the horses in an area are assumed to have been detected and counted in an aerial survey, this value can be converted into a proportion (0.80) and the count divided by the proportion to obtain a population estimate. The appropriate calculations for the 2 years depicted in Figure 2-1 in which counts were conducted would be

Year	Count	Estimated Proportion of Animals Detected	Calculation	Population Estimate
2001	422	0.80	422/0.80	528
2004	722	0.80	722/0.80	903

If a count is not conducted in a given year but a population estimate is still needed, an estimate can be obtained by multiplying the previous year's population estimate by an estimate of the growth rate of the population. For example, if the horse population is assumed to be growing by 20 percent a year, this value can be converted into a λ value (finite population multiplier) of 1.20 and multiplied by the previous year's population estimate to project the size of the population in the following year when a count was not conducted. The appropriate calculations for the 2 years depicted in Figure 2-1 in which a count was not conducted would be

Year	Previous Year's Population Estimate	Estimated Population Growth Rate (λ)	Calculation	Projected Population Size
2002	528	1.20	(528)(1.20)	634
2003	634	1.20	(634)(1.20)	761

If a detection probability or growth rate is used to adjust counts without empirically measuring either quantity, the values may simply be assumptions or "best guesses," and the adjusted counts would be reported as population estimates with no associated measure of precision. The accuracy of such estimates depends on how closely the assumed detection probability and growth rate reflect the truth, which is probably unknown. There are, however, statistical procedures for obtaining quantitatively rigorous estimates of detection probability, population size, and growth rate on the basis of data, and there are measures of precision of each estimate. When values derived from such rigorous methods are used to adjust counts to obtain a population estimate, the precision of the population estimate can also be determined. Measures of precision are extremely valuable in interpreting estimates of population size and

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growth rate. A common way to convey precision of a population parameter (population size or growth rate) is to report a 90-percent confidence interval (CI) for the parameter such that there would be 90-percent probability that the real value of the parameter lies within the interval (Williams et al., 2001). For example, one population estimation method (method 1) may provide a population-size estimate of 700 horses with an associated 90-percent CI of 680–720 horses. A second method (method 2) may yield the same population-size estimate of 700 horses, with an associated 90-percent CI of 500–900 horses. In that hypothetical example, the estimate of population size obtained with method 1 is said to be more precise than that obtained with method 2 because method 1 provides a relatively narrow CI. Whenever possible, a population estimation method that provides a more precise estimate is desirable in that one can have more confidence that the population estimate is a better approximation of the true number of animals occupying the survey area than a less precise estimate.

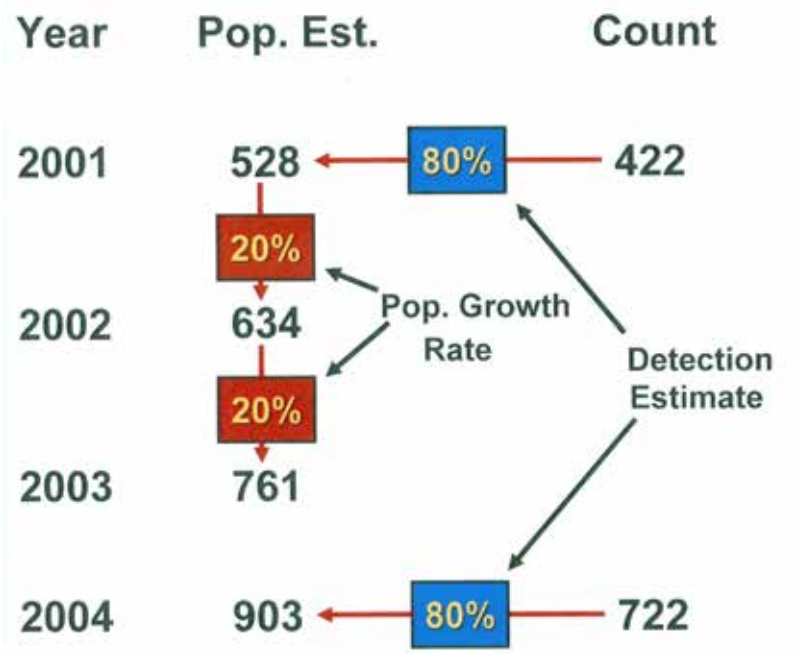


FIGURE 2-1 An example of how periodic counts of free-ranging horses on an individual Herd Management Area could be converted to estimates of population size by applying estimates of detection probabilities and the annual growth rate of the population.

NOTE: In this fictitious example, aerial counts conducted in 2001 and 2004 were used to obtain population estimates on the basis of estimates of (or assumptions about) the detection probability (proportion of horses detected on the surveys) and the growth rate of the horse population. The example assumes no horse removals during the 4-year period. If a removal had occurred, the number of horses removed would be subtracted for the appropriate year to obtain the next year's population estimate.

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The committee was informed by the national Wild Horse and Burro Program office that the HMA-specific data requested were not aggregated into a central database but were dispersed among the BLM field offices. It was suggested that a more manageable request for BLM personnel would be that the committee receive a sample of HMA data from a maximum of 40 HMAs. BLM provided a list of the 179 HMAs distributed among 10 western states, with associated data on AML and the current population estimate for each HMA, to aid the committee in selecting a sample of HMAs. The committee excluded HMAs for which the AML was zero, current population estimates were zero, or where reported numbers reflected a mix of burros and horses. To increase the uniformity of the data, HMAs that had burros (and no horses) were not included. The remaining 142 HMAs contained only horses and were ordered by the current population estimate, ranging from 5 to 1,355 (Figure 2-2; Appendix E, Table E-2). Of the 142 HMAs, the committee excluded the ones that had estimated populations of 50 or fewer, because the small populations represent less than 3 percent of the horses on western rangelands. From the remaining HMA list, every third one was then selected to obtain a sample distributed evenly over the range of population sizes that occur on BLM-administered lands. That process resulted in a sample of 36 HMAs. The committee subjectively added four other HMAs that had been included in earlier research on population dynamics of free-ranging horses in the western United States (Eberhardt et al., 1982; Garrott et al., 1991a), and that brought the sample to 40 HMAs (Table 2-1; Appendix E, Table E-3). The committee received the data that it requested on all 40 HMAs. The assessment of methods used by BLM to obtain field counts of horses and estimates of population size is based information on the 40 HMAs provided to the committee by BLM. The committee sought to provide a synthetic overview of the horse inventory methods used by BLM; nonetheless, it recognized that its assessment, summarized in the following, may not accurately reflect how horses are counted or population sizes estimated on every HMA.

TABLE 2-1 Distribution of 142 Herd Management Areas (HMAs) among Western States That Contained Only Horses and were Actively Managed by the Bureau of Land Management and Distribution of the Sample of 40 HMAs Used by the Committee to Evaluate Wild Horse and Burro Program Methods for Surveying Horse Abundance and Estimating Population Sizes

State	Number of HMAs Available	Number of HMAs in Sample
Arizona	1	0
California	15	2
Colorado	4	3
Idaho	6	1
Montana	1	1
New Mexico	2	0
Nevada	63	21
Oregon	17	6
Utah	17	2
Wyoming	16	4
Total	**142**	**40**

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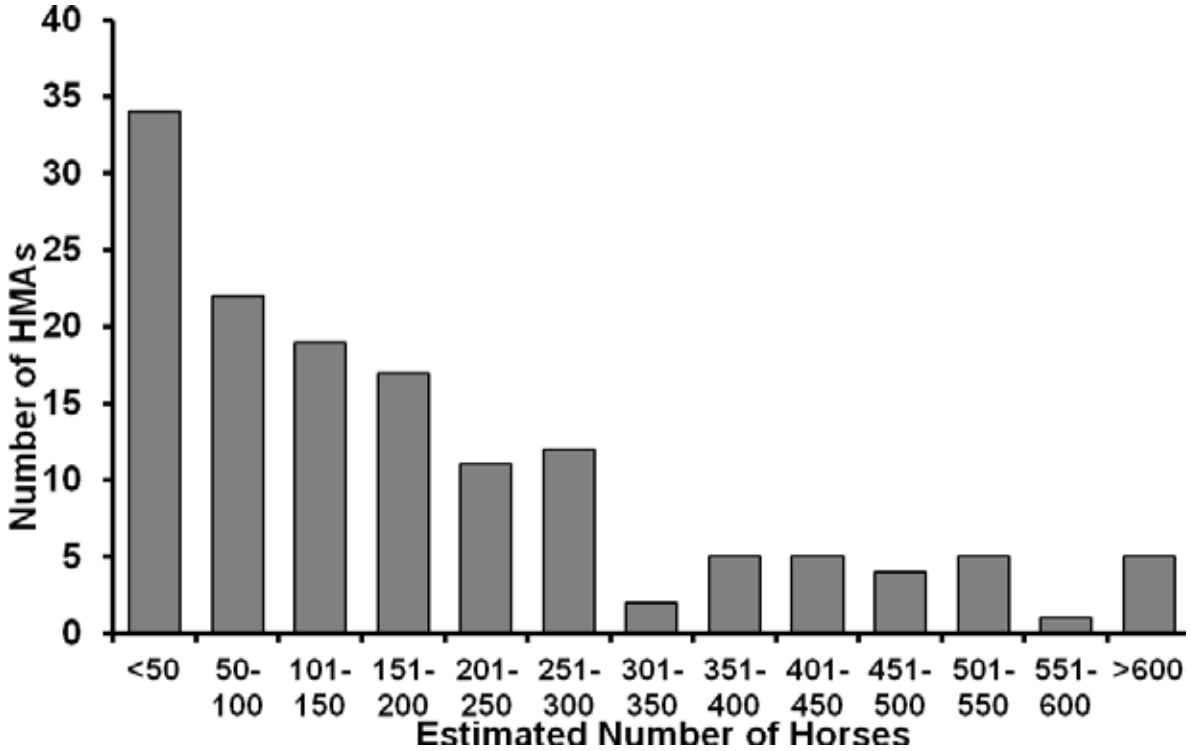


FIGURE 2-2 Distribution of 142 Herd Management Areas (HMAs) that contained free-ranging horse populations of various herd sizes.

NOTE: Population estimates were based on survey records available as of February 2011.
DATA SOURCE: Based on information provided to the committee by the Bureau of Land Management in December 2011.

Assessment of Horse-Count Data for the Sample of Herd Management Areas

The frequency with which surveys were conducted to count horses in each HMA in the sample was highly variable. Among the 40 HMAs surveyed, four reported counting horses no more than once a decade, nine counted horses an average of every 3-4 years, five counted horses an average of 2 of every 3 years, 17 about every other year, and five every year. In HMAs in which horses were not counted every year, there was no discernible pattern in the interval between counts. Information on the methods used for each reported count was frequently unreported (Tables 2-2 to 2-4).

Assuming that the reported data on the 40 sampled HMAs generally represent the procedures routinely used by BLM to enumerate horses on all HMAs, the committee made several generalizations about counts on all HMAs.[2] Most counts are obtained with aerial surveys in which an entire area is surveyed in an effort to obtain a complete count of the horses occupying an HMA with no attempt to apply sampling methods or to estimate the proportion of

[2]The data supplied by BLM for all 40 HMAs can be retrieved from the study's public access file. To obtain the information, contact the National Research Council's Public Access Records Office at paro@nas.edu.

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animals that were undetected. A helicopter was the preferred aircraft, although fixed-wing aircraft were also frequently used. Some surveys were conducted from the ground on foot, in vehicles, on horseback, or with a combination of the three. Ground-based surveys appeared to be performed primarily in states that had relatively few HMAs and in which the total number of horses on an HMA was low (under 150). It was also common for reported counts to be attributed to gather operations. Explanations were not provided for the individual gather-based counts, but the committee's best understanding of such counts was that a gather operation was conducted on an HMA for the purpose of removing horses from the rangeland. The gathers were assumed to have captured all horses on an HMA, and the reported count represented the number of captured horses that were released back onto the rangelands. Although survey methods used for some HMAs in the sample that the committee examined appeared to be consistent with respect to time of year and survey platform, the timing of surveys on many of the reviewed HMAs were inconsistent; they were often distributed over 6-9 months of the year, and this led the committee to conclude that such practices are common. It was also relatively common in the sample of HMAs that the committee examined for survey methods to differ from count to count on a given HMA—some counts were performed from helicopters, others from fixed-wing aircraft, and others from gathers.

It was difficult for the committee to understand the rationale for the timing and distribution of counts for the sample of HMAs, but it did detect what appeared to be a pattern related to timing of gathers and horse removals (provided to the committee in separate files by the national office). A common pattern observed in the HMA records was a report of a complete count followed by a variable period of years in which no counts were performed and then a report of another count immediately before a major gather and horse removal. On some occasions, a follow-up count was reported immediately after a removal. On the basis of recommendations of the National Research Council Committee on Wild and Free-Roaming Horses and Burros (NRC, 1982), BLM-published procedures for surveying and counting free-ranging horses (BLM, 2010), correspondence with Wild Horse and Burro Program administrators, and a review of a sample of HMA environmental assessment documents prepared for horse removals, the committee interpreted that pattern as reflecting a need to have a recent count of horses on an HMA before a removal. Thus, the committee speculates that after a period of no counts, when a population was assumed to have increased, expertise of the local manager indicated that the horse population needed to be reduced, and a count was conducted to determine whether the population was over the AML. If the count was sufficiently higher than the established upper bound of the AML, an environmental assessment was prepared, and a gather and removal occurred. Post-removal counts were often recorded as gather counts; this suggests that the gather was assumed to have captured all horses on the HMA and that the count reflected the number of horses that were released back onto the HMA. Alternatively the post-removal counts may have reflected a combination of the number of horses released and some estimate of the number on the HMA that remained uncaptured. It was unclear from the data that the committee received which of those assumptions was made by BLM managers for individual records.

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TABLE 2-2 Example of Horse Inventory Data on Little Book Cliffs Wild Horse Range in Colorado, Showing Routine and Methodologically Consistent Annual Surveys

Year	Annual Population Estimate	Population Count	Date of Count	Type of Craft	Percentage of Area Inventoried	Method	Adjustment of Count
2000	153	153	August	Vehicle/horse	All	Visual	None
2001	169	169	August	Vehicle/Horse	All	Visual	None
2002	195	195	August	Vehicle/Horse	All	Visual	None
2003	154	154	August	Vehicle/Horse	All	Visual	None
2004	178	178	August	Vehicle/Horse	All	Visual	None
2005	132	132	August	Vehicle/Horse	All	Visual	None
2006	144	144	August	Vehicle/Horse	All	Visual	None
2007	165	165	August	Vehicle/Horse	All	Visual	None
2008	122	122	August	Vehicle/Horse	All	Visual	None
2009	133	133	August	Vehicle/Horse	All	Visual	None
2010	138	138	August	Vehicle/Horse	All	Visual	None
2011	142	142	August	Vehicle/Horse	All	Visual	None

NOTE: The number of horses counted in complete surveys of the HMA is the same number reported for population estimates; thus, it is assumed that all animals were detected during the surveys.
SOURCE: Survey response from the Bureau of Land Management, February 2012.

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TABLE 2-3 Example of Horse Inventory Data on Reveille Herd Management Area in Nevada, Showing Irregular and Inconsistent Survey Methods

Year	Annual Population Estimate	Population Count	Date of Count	Type of Craft	Percentage of Area Inventoried	Method	Adjustment of Count
2000	164	190	November	Helicopter	100	Grid	None
2001	187						
2002	96						
2003	111	9	December 23	Fixed-wing airplane	70	Grid	None
2004	61	61	October 15	Helicopter	100	Grid	None
2005	71						
2006	135	119	January 6	Helicopter	100	Grid	None
2007	57	79	January 7	Helicopter	100	Grid	None
2008	66						
2009	77	213	September 9	Helicopter	100	Grid	None
2010	213	231	February 10	Helicopter	100	Grid	None
2011	91						

NOTE: These data provide an example of the difficulty of understanding how annual population estimates were derived from the survey count data.
SOURCE: Survey response from the Bureau of Land Management, March 2012.

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TABLE 2-4 Example of Horse Inventory Data on Desatoya Herd Management Area in Nevada, Showing Irregular and Inconsistent Survey Methods and Incomplete Records

Year	Annual Population Estimate	Population Count	Date of Count	Type of Craft	Percentage of Area Inventoried	Method	Adjustment of Count
2000		304	August	Jet Ranger	100%	Direct	
2001		294	December 1		80%	Direct	
2002							
2003							
2004			February 4				
2005							
2006							
2007		238	April 7	Jet Ranger	100%	Direct	
2008							
2009							
2010		434	April 10	Jet Ranger	100%	Direct	
2011		543	July 11	Jet Ranger	100%	Direct	

NOTE: These data provide an example of the difficulty of understanding how annual population estimates were derived from the survey count data.
SOURCE: Survey response from the Bureau of Land Management, March 2012.

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Relationship Between Direct Counts of Horses and Reported Herd Management Area Population Estimates

All annual population estimates for the 2000-2011 period requested were provided for 24 of the sample of 40 HMAs; no estimates provided for five HMAs, and estimates for the other 11 were incomplete (generally, less than 50 percent of the estimates were provided). No reported population estimates included associated measures of precision. The committee assumed that all population estimates were derived in some fashion from survey count data (as described and illustrated in Figure 2-1), and the description of the process used to develop annual population estimates provided by the national Wild Horse and Burro Program office supports this assumption.

> When the data [annual HMA population estimates] are updated for any given year the starting point is the previous year's population estimate. These data are updated based on the following: 1) removals (gathers) that have been conducted since February 28th of the previous year, 2) new population surveys (census) that have been conducted since February 28th of the previous year and 3) when no population surveys were conducted in the previous year, the previous year's data are increased to account for the year's foals based on historical experience regarding annual population increase typical of that HMA (normally about 20% if a gather/removal had not been conducted). When no population survey has been conducted consideration is also given to the estimated effects of any fertility control vaccines that have been previously administered. (BLM, email communication, May 2, 2012)

As mentioned, most population estimates reported in years when counts were conducted for the 40 sampled HMAs simply reported the number of animals counted without adjustment for the proportion of undetected animals or measures of precision. In the few instances in which a population estimate for a given year was higher than a count in the same year, there was little notation to indicate that the difference was due to application of a detection probability adjustment. In cases in which it seemed plausible that that occurred, the committee calculated the assumed detection probability by dividing the annual count by the population estimate; the resulting values of assumed detection probability generally ranged from 0.7 to 0.9. However, there were substantial records for the sampled HMAs of reported population estimates that were considerably smaller than the counts in those years when there were no records of horses being removed. There were also instances in which population estimates were much higher than reported counts but with no explanation for the differences.

The methods used to estimate population sizes in years in which no counts were conducted were seldom noted in the records provided to the committee. When records clearly stated that an assumed population growth rate was applied to the previous year's population estimate, an annual growth rate of 20 percent was generally used. As with detection probability, when it seemed plausible that a population growth rate was used to project population estimates for years in which no counts were conducted, the committee calculated the assumed growth rate by dividing the second year's annual population estimate by the previous year's annual population estimate to obtain an estimate of λ, that is, the population growth rate. The resulting values (reported as percent growth) were variable, generally ranging from 3 to 38 percent; values

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of 15 to 25 percent were most common. A substantial proportion of the population estimates reported for years in which no counts or gathers were conducted, however, diverged enough from the estimates reported both immediately before and after that without further explanations the committee could not understand how such values were obtained. One plausible explanation for at least some of those cases is that horses were freely moving on and off HMAs.

Relationship Between Direct Counts of Horses and National Population Estimates

National statistics that provide estimates of the total number of free-ranging horses and burros on public rangelands are published annually in BLM reports and on the Wild Horse and Burro Program website. Those are important statistics because they are interpreted by various public constituencies to gauge the success of the program's management, are used in formal government reviews of the program (NRC, 1980, 1982; GAO, 2008; OIG, 2010), and are foundational data for planning and budgetary documents, such as BLM's *Proposed Strategy: Details of the BLM's Proposed Strategy for Future Management of America's Wild Horses and Burros* (BLM, 2011). The procedure used to generate the annual state and national estimates was described to the committee as follows.

> Each year shortly after February 28th, field offices submit updated estimates for each HMA to the National Program Office. These field submissions are compiled into one national report that lists new estimates for each HMA and that is organized by state. (BLM, email communication, May 2, 2012)

Given the incompleteness of the counts and population estimates that the committee received for the sample of 40 HMAs, which came from the field offices, it was not clear how the national statistics could be calculated. Therefore, the committee requested the series of HMA estimates that were reported to the national office from the field offices and used in generating the state and national estimates for the most recent 5-10 years. In response to its request, the committee was pointed to the national HMA-specific estimates for fiscal years 2005-2011 that were posted on the program's website.[3] The committee also received files with earlier national HMA estimates from fiscal years 2000-2004. However, the corresponding information that the national office received from the field offices to generate the published estimates was not provided to the committee. The committee was informed that that information was discarded after the annual national statistics were published (BLM, personal communication, May 2012). Thus, the committee received no documentation linking the national statistics to information reported from the field offices. It was not clear whether the information from the field offices was modified by some procedure at the national office before publication on the program's website, but various correspondence with personnel at the national office suggested that some changes were made. That impression was reinforced when the committee compared the national HMA-specific population estimates with those reported by the field offices for the sample data on 40 HMAs provided to the committee. The committee found that a substantial proportion of the HMA estimates published by the national office did not correspond to the ones the committee received

[3]Available online at http://www.blm.gov/wo/st/en/prog/whbprogram/herd_management/Data.html/. Accessed November 20, 2012.

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from the field offices; discrepancies ranged from modest to many hundreds of animals. In addition, all HMAs in the reported national statistics had a population estimate for all years, whereas a substantial proportion of the HMA records that the committee received from the field offices had no population estimates reported for some of the years.

Evaluation of Current Methods for Enumerating Free-Ranging Horse Populations

The sample of HMA records made available to the committee and examined with the evaluation of the national population statistics indicates that robust inventory procedures were adhered to on few HMAs during the most recent decade of population monitoring. The committee identified five primary weaknesses in inventory procedures: inconsistent methods, likely movement of horses among HMAs, little or no effort to quantify detection probability and apply corrections accordingly, no attempt to quantify precision of abundance estimates, and inadequate record keeping and database management. It is reasonable to expect that different survey techniques may be optimal in inventorying animals depending on attributes of individual HMAs, such as the size of the equid population and of the area, accessibility, distinctiveness of individual horses, ruggedness of topography, and presence of tree cover. Once a survey method is determined for an HMA or HMA complex, however, it should be used consistently so that variation in the number of animals counted from one survey to the next can be reasonably attributed to population changes and is not confounded by the use of different techniques. The most prevalent problems that the committee identified in that regard were inconsistency in the timing of surveys and in the survey platform used (fixed-wing, helicopter, ground-based, or gathers). Movement of horses across HMA boundaries can seriously confound interpretation of changes in the numbers of animals counted from one survey to the next. Although there appear to be few data on this issue, field personnel recognize it as a common problem, and relatively large changes in the numbers of animals counted in consecutive surveys may be reasonably attributed to movement of animals on and off HMAs. It was not clear to the committee whether data on spatial distribution of animals are routinely collected during inventory surveys. Information on where animals are observed can provide important insights into habitat use and resource selection by free-ranging equids, which in turn would contribute to a better understanding of competition with livestock and wildlife and assist in decisions on forage allocation and other issues related to rangeland health (see Chapter 7).

It is also well documented that the types of survey methods used for counting free-ranging horses and burros are imperfect in that various proportions of animals will not be detected in any given survey and detection probability can vary over time and space. Evidence clearly indicates that, under some conditions that are common for rangelands occupied by free-ranging horses and burros, the proportion of animals missed can be substantial. Thus, the routine reporting of the uncorrected counts as population estimates results in inventory numbers that are systematically biased low. Finally, the apparent difficulty of meeting data requests from the committee, the incompleteness of many of the records provided to the committee, and the lack of data supporting the national population statistics indicate deficiencies in the routine documentation of survey efforts and results and in database management. Many of the same issues were also identified by the National Research Council Committee on Wild and Free-Roaming Horses and Burros, which reviewed similar records near the start of the Wild Horse and Burro Program over 30 years ago (NRC, 1980, 1982).

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Initiatives to Improve Methods for Enumerating Free-Ranging Horse Populations

At the time this report was written, BLM had initiated a number of actions aimed at improving the rigor, reliability, and utility of the procedures used to estimate the abundance of free-ranging horses and burros. First, in its *Wild Horses and Burros Management Handbook* (BLM, 2010), BLM provided guidelines for survey techniques used to enumerate free-ranging horses and burros, stating

- The target interval for conducting population surveys is every 2 years, as recommended by the National Research Council Committee on Wild and Free-Roaming Horses and Burros (NRC, 1982).
- Techniques that provide sightability and detection corrections are to be used.
- Survey methods and timing are to be consistent.
- All details of each survey are to be recorded and permanently on file.
- Survey data are to be entered into a centralized database (the Wild Horse and Burro Program System).

The committee readily endorses those guidelines. Adherence to them will greatly improve the utility of equid population estimates.

Second, in response to the widely held perception that free movement of animals among adjacent HMAs confounds inventory procedures and reduces the ability to interpret counts, managers have subjectively assessed their knowledge of equid movements among adjoining HMAs and aggregated 93 of 179 HMAs into HMA "complexes." Each complex is composed of two to six areas managed for equids; many HMAs are managed with adjacent U.S. Forest Service Wild Horse (or Burro) Territories. The goal is to coordinate surveys, gathers, removals, and other management actions among HMAs within a designated complex and thus to manage all horses in a complex as a single biological population (BLM, 2010). The committee thinks that that procedural change has the potential to improve interpretation of counts substantially, although the degree of improvement hinges critically on how often and how many animals move across HMA boundaries. Conducting aerial inventories over large areas, however, has its own set of challenges. The committee had no knowledge of implementation at the field level with respect to the coordination of population surveys and management actions (removals) among HMAs within designated complexes.

Third, for over a decade, scientists from the U.S. Geological Survey (USGS) Fort Collins Science Center have conducted research and provided scientific support to the Wild Horse and Burro Program. In 2004, an Aerial Survey Work Plan was developed and field research was implemented to develop and test improved techniques for inventorying free-ranging horses from both helicopter and fixed-wing survey platforms. Several methods were evaluated including various mark-resight techniques, distance sampling (transects), and sightability models. The research reaffirmed that substantial proportions of horses are not detected in aerial surveys and that detection is poorer in more rugged and tree-covered terrain than in flatter, more open landscapes (Lubow and Ransom, 2009). Several of the mark-resight techniques evaluated were successful in accounting for varied detection probability and for providing estimates close to the known number of horses in the experimental populations. Less successful techniques that were

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evaluated included distance sampling, forward-looking infrared technology, and remote sensing. In addition, GPS mapping technologies were incorporated into all aerial survey procedures and provided data on animal distributions and patterns of resource selection. At the time this report was written, the USGS team had trained eight BLM personnel in the new survey methods, and they had started to conduct rigorous surveys on 35 HMAs in seven states. In August 2012, BLM hired a national aerial-survey coordinator to continue to implement reforms in the inventorying procedures (BLM, 2012).

The committee encourages BLM to continue such collaboration and reform of its procedures. Those actions and adherence to the survey guidelines in the 2010 handbook will improve the accuracy and defensibility of its population estimates. More robust and transparent data may also improve its relationship with stakeholders (see Chapters 7 and 8).

EQUID POPULATION GROWTH RATES

The change in abundance of a population over some period is generally known as a growth rate. Understanding growth rates is important for efficient and effective management of free-ranging equid populations. Knowing population growth rates gives managers the ability to project how quickly populations will increase and when management actions (such as removals or fertility treatments) need to be applied. They are also key information for determining the magnitude of fertility treatments needed to reduce population growth rate to some desired level and, after treatment, to evaluate whether the intervention had the expected effect. Growth-rate estimates are used to estimate the size of populations in years in which counts will not be conducted (Figure 2-1), as estimates are needed for inventory, management, and planning purposes.

Like populations of most other terrestrial mammals in North America, free-ranging horse population dynamics have a seasonal cycle in which animals are added to the population by births during a relatively short interval in the spring and animals are removed from the population through deaths (and management removals) throughout the year. The natural interval for estimating population growth rates is the year. Each species has an inherent maximum population growth rate that is dictated by its life-history characteristics, including how often animals can reproduce, the number of young produced per reproductive event, the age at which animals become reproductively mature, and the death rates for the various age classes of animals.

There was essentially no knowledge of free-ranging horse population dynamics and growth rates when the populations received federal protection in 1971. During the decade that followed, federal land-management agencies, primarily BLM and the U.S. Forest Service, began to inventory horse and burro populations, and a number of studies of horse demography were undertaken. Scientific demographic investigations of free-ranging horses, however, were limited to three 1- to 2-year studies of western herds (Feist and McCullough, 1975; Nelson, 1979; Boyd, 1980), two studies of herds on barrier islands on the Atlantic coast (Welsh, 1975; Keiper, 1979), and a study of ponies in Britain (Tyler, 1972). A review of the studies by the National Research Council Committee on Wild and Free-Roaming Horses and Burros (NRC, 1980) and novel analyses conducted by that committee revealed ambiguities. The committee noted that the 16- to 22-percent annual growth-rate estimates derived from direct counts conducted by management agencies were notably higher (by up to 10 percent) than estimates obtained with population

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models (Conley, 1979; Wolfe, 1980; NRC, 1980, 1982) that used the best available survival and fecundity data on domestic horses and from the few studies of free-ranging horse populations. A good understanding of demographic processes can contribute substantially to the effectiveness of programs designed to manage wildlife populations; the 1980 National Research Council report recommended additional research on demography, and considerable progress has been made on horses. There have been a few studies of feral burro demography in Australia (Freeland and Choquenot, 1990; Choquenot, 1990, 1991), but little is known about the demography of free-ranging burros in the western United States. Because key aspects of burro life-history characteristics and their ecological niche differ from those of horses, this committee recommends separate studies on burro population growth rates.

Population Growth Rate Estimates Based on Counts

The most direct method for estimating growth rate of a population is to obtain counts or population estimates over multiple years. If the population is growing at a relatively constant rate over the period for which counts or estimates of abundance are available, the abundance values, when log-transformed, will be approximately linear. Linear-regression techniques can be used to fit a line to the data, and the estimated slope of the line provides an estimate of the instantaneous growth rate of the population, denoted by *r* (Caughley, 1977; Eberhardt, 1987). The procedure also provides an estimate of the precision of *r*. The slope estimate can be back-transformed (exponentiated) to obtain the finite population growth rate, denoted by λ. The λ value is also referred to as the population multiplier in that one can multiply a population estimate (or count) in a given year by λ to obtain an estimate of the number of animals in the population a year later (see Box 2-1 for an example). When λ is 1, the population is stable or unchanging; when λ is over 1.0, the population is increasing; and when λ is under 1.0 the population is decreasing. Thus, a λ of 1.03 indicates that a population is growing by 3 percent a year, and a λ of 1.20 indicates that a population is growing by 20 percent a year. For consistency in reporting growth rates, the committee used the convention used in BLM documents: reporting growth rates as annual percentages.

A number of studies have used log-linear regression of time series of counts of free-ranging horse populations in the western United States to estimate annual growth rates. The National Research Council Committee on Wild and Free-Roaming Horses and Burros (NRC, 1980) calculated a weighted mean of 16 percent for aerial count data on 25 HMAs in five states. Wolfe (1980) used count data on 12 HMAs in six states and calculated values ranging from 8 to 30 percent and an unweighted mean of 22 percent but in a later publication suggested a typical growth rate of 15 percent for western U.S. herds (Wolfe, 1986). Counts of two Oregon horse herds were used by Eberhardt et al. (1982) to estimate growth rates ranging from 20 to 22 percent. Similarly, Garrott et al. (1991a) estimated growth rates ranging from 15 to 27 percent with a mean of 21 percent for 12 HMAs in four states. Since those studies were published, a number of additional analytical methods have been developed to estimate population growth rates, and associated measures of precision, on the basis of a time series of counts or abundance estimates that can provide enhanced insight into population processes (Dennis et al., 1991, 2006; Humbert et al., 2009). The techniques would be useful in future studies of Wild Horse and Burro Program inventory data.

The Pryor Mountain herd in Montana is perhaps the most well-studied free-ranging horse population in the western United States. The herd's size (100-200) and the small and traversable

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geography of the HMA have been conducive to a number of estimates of this population's growth rate over the last 3 decades. Nearly all animals have been individually identified in the population because of unique color and marking patterns and have been closely monitored each year, so reproduction, mortality, and total number of horses on the range have been known with considerable certainty, and this allows each annual growth increment to be approximated relatively precisely. Under those special conditions, it is reasonable to estimate an annual λ by dividing the count obtained in a given year by the count obtained in the preceding year. Estimating annual growth rates from counts conducted in two consecutive years is not reliable for most free-ranging equid populations because variation in the proportion of animals detected from one count to the next and movement of animals between adjacent HMAs can dramatically bias λ estimates either upward or downward. Those problems are not prevalent in the small, isolated, and intensively studied Pryor Mountain herd, in which annual estimates from consecutive counts can be considered reliable.

Garrott and Taylor (1990) reported an average annual growth rate of about 18 percent in 1977-1986 in the Pryor Mountain herd, and a similar growth rate was reported by Singer et al. (2000) in 1992-1997. More recently, Roelle et al. (2010) reported a temporary decline in the herd's annual growth rate to about 11 percent. The lower growth rate was attributed at least partly to lower foal survival due to mountain lion predation and possibly the effects of contraceptive treatment of a modest number of mares, but growth had returned to higher rates near the end of their studies (2005-2007) coincident with hunters harvesting several mountain lions from the range. Similar individual-based studies of horse demography conducted in a number of populations occupying barrier islands along the Atlantic coast have documented annual growth rates of 4.3 percent in the Cumberland Island, Georgia, population (Goodloe et al., 2000), about 10 percent in the Assateague Island, Maryland, population (Keiper and Houpt, 1984), and 16 percent in the Shackleford Banks, North Carolina, population (Wood et al., 1987).

Population Growth Rate Estimates Based on Models

A more indirect method for investigating population growth rates of free-ranging horse populations is the construction of population models that use age-specific estimates of horse survival and fecundity rates obtained from field studies. Model-based approaches provide asymptotic or long-term population growth rate estimates that are based on input parameters as opposed to the abundance-based approaches discussed in the previous section that provide estimates of realized growth rates. Such exercises were initially conducted about 3 decades ago when little demographic information was available to provide a basis for assigning values to parameters in such models (Conley, 1979; Wolfe, 1980; NRC, 1980, 1982). During the decade after those studies, additional information on survival and reproductive rates was published (Seal and Plotka, 1983; Keiper and Houpt, 1984; Berger, 1986; Siniff et al., 1986; Wolfe et al., 1989; Garrott and Taylor, 1990; Garrott, 1991a; Garrott et al., 1991a). Garrott et al. (1991b) used insights from those studies to parameterize the Lotka/Cole equation with a variety of age-specific fecundity and survival schedules to model western free-ranging horse population growth rates. The modeling exercise yielded growth-rate estimates of 11-27 percent. Later published studies have provided additional estimates of the range of survival and fecundity rates in specific free-ranging and fenced-in horse populations on western U.S. rangelands (Greger and Romney, 1999; Turner and Morrison, 2001; Roelle et al., 2010) and Atlantic barrier islands (Goodloe et al.,

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2000) and herds in France (Monard et al., 1997; Cameron et al., 2000), New Zealand (Linklater et al., 2004), Argentina (Scorolli and Lopez Cazorla, 2010), and Australia (Dawson and Hone, 2012). Those studies generally reported survival and fecundity rates within the ranges of those used in earlier population modeling efforts.

When capture-recapture data collected on individually marked horses are available, Pradel's temporal symmetry models can also be used to estimate realized population growth rate (Pradel, 1996; Williams et al., 2001). That approach allows the estimation of other useful demographic parameters (such as apparent survival and recruitment rates) and the modeling of these parameters as functions of covariates. However, application of the approach requires that horses be individually marked and recaptured (physically or visually) in such a way that the capture history of each animal can be compiled. BLM does not regularly mark horses, and the effort required to describe and catalog unique identifiable natural markings of individual horses in most situations is not practical. Data on several intensively studied horse populations on Atlantic barrier islands and in the western United States are being collected and can be used in those types of models (Goodloe et al., 2000; Turner and Kirkpatrick, 2002; Lubow and Ransom, 2009; Roelle et al., 2010).

Population Growth Rate Estimates Based on Horse Age-Structure Data

Another source of data that was available to the committee to help in gaining insight into the average growth rates of free-ranging horse populations was the age structure of the horses captured and removed from western rangelands. Those data are routinely collected on all horses captured and removed during management gathers; irruption and wear of teeth are used to estimate the age of each horse removed from public rangelands as it was processed before transfer to adoption or holding facilities. The age structure of a population is the result of many interacting population processes, and this complicates interpretation of age-ratio data on individual populations (Caughley, 1974b). However, as discussed earlier in this chapter, analysis of inventory data on free-ranging horse populations and population modeling approaches provided relatively consistent results with respect to the average growth rate of horses on western rangelands. Thus, it is reasonable to use the aggregate age-structure data on horses captured and removed from the rangelands, which are collected independently of the inventory data, in an attempt to corroborate horse population growth rates derived from inventory data.

The committee had access to age data on 167,927 horses captured and removed during 1989-2011; the number of animals captured and removed each year varied from 2,468 to 11,416.[4] A reasonable index of the average growth rate of horses on western rangelands can be calculated by dividing the number of young-of-the-year horses (that is, horses less than 1 year old) by the total number of horses 1 year of age and older in a captured and removed sample and multiplying the result by 100 to obtain a percentage. The committee used a 5-year moving average with the 1989-2011 dataset of ages of captured and removed horses when calculating the index to have a large sample of captured and removed horses that would be characteristic of the diverse ecological settings of western rangelands and to reduce variation due to the particular subset of horse populations gathered in any given year. The growth rate index generally was 20-

[4]The data supplied by BLM for the removed animals can be retrieved from the study's public access file. To obtain the information, contact the National Research Council's Public Access Records Office at paro@nas.edu.

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25 percent with some indication of a modest increase during the 1990s; but during the most recent decade, the growth rate index was relatively stable or perhaps experienced a slight decline (Figure 2-3).

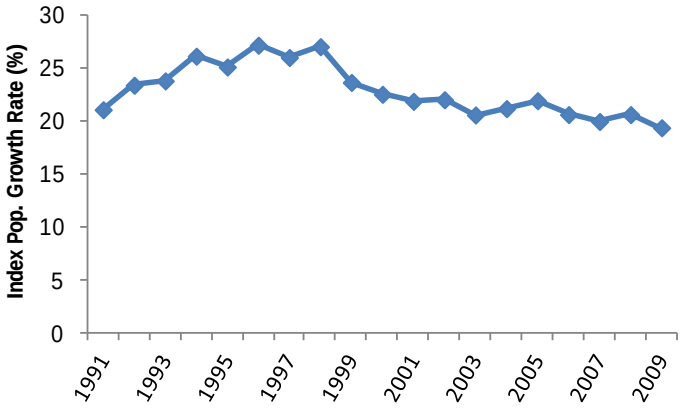


FIGURE 2-3 An index of population growth rate of free-ranging horses based on data on ages of 167,927 horses captured and removed from western rangelands in the United States to manage their abundance.

NOTE: Age-structure data were available for 1989-2011; the number of horses captured and removed each year ranged from 2,468 to 11,416. The index was calculated by dividing the number of young-of-the-year horses by the total number of horses 1 year of age and older in a sample of horses captured and removed from rangelands and then multiplying the result by 100 to obtain a percentage. A 5-year moving average was used to calculate a growth rate index; the annual values plotted in the graph were derived from the age data from a given year, the 2 preceding years, and the 2 following years.

The age-structure data would need to have come from horses captured and removed immediately before the birth pulse for the index to reflect realized growth rates of the free-ranging horse populations accurately and thus to account for all deaths of horses over the year after the birth pulse. Gathers, however, occurred throughout the year and were most concentrated in August-February. The index therefore probably overestimates growth rates to some extent. It is difficult to estimate the magnitude of the bias, but, on the basis of the available literature on timing and extent of mortality of horses, the committee believes that the bias is modest.

The index also assumes that the age distributions of horses captured and removed from rangelands were representative of the age structure of the free-ranging populations. A bias could have been introduced into the age-structure data of captured and removed horses if managers tended to remove the youngest horses, which were more easily adopted, and to return older, less adoptable horses to the rangelands. Such a practice, if widespread, would inflate the index and suggest that population growth rates were higher than what were actually realized. The

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committee had no way to evaluate such a potential bias directly. It did, however, review preliminary environmental assessments of a sample of recent HMA gather plans to gain some insight into the potential bias in the age-structure data. Age-selective removals were nearly always considered in the gather plans that the committee reviewed, but the preferred (proposed) actions often did not involve age-selective removals. The committee also noted that in a number of the environmental assessments that presented the history of gathers, usually no captured horses were returned to the rangelands. For gathers in which some captured horses were released, the number of horses returned to the rangeland generally constituted a small proportion of the total number of animals captured. In addition, diverse reasons for the selection of horses to be released were stated, including considerations of conformation, coat color and marking patterns, and the release of mares that were treated with a contraceptive vaccine. It was also stated that horses were selected for release to "maintain a diverse age structure." Thus, the committee found little evidence to suggest an overt and consistent bias in the age structure of horses that were removed from rangelands and concluded that the age-structure data can provide a reasonable assessment of the general growth rate of the free-ranging horse populations on public rangelands in the western United States.

The committee concludes that the population growth rate index derived from the age structure of captured and removed horses is generally consistent with the herd-specific population growth rates reported in the literature. That suggests that a mean annual population growth rate in the free-ranging western horse population approaching 20 percent is a reasonable approximation.

CONCLUSIONS

From its review of the information provided by BLM on population-survey methods, approaches to data collection and population estimation, and records on horse removals and the committee's review of the relevant literature on estimating ungulate populations and population growth rate, the committee draws the following conclusions.

Estimating the Size of Free-Ranging Equid Populations

Management of the nation's free-ranging horses and burros should be based on rigorous population monitoring procedures that are consistently applied by all BLM field offices. The methods reviewed by the committee for monitoring animal numbers on a small subset of HMAs may be adequate, but all reviews of the procedures routinely used by BLM to survey free-ranging horses and burros since the inception of the Wild Horse and Burro Program have identified substantial methodological flaws. On the basis of the information that was reviewed, the committee concluded that many of the shortcomings identified in previous reviews have persisted. At the time that the committee completed its review, inventory methods and statistical tools common to modern wildlife management were used to count horses on only a few HMAs. In addition, survey methods used to obtain sequential counts of horse populations on an HMA were often inconsistent and generally poorly documented.

Initiatives to improve population monitoring have, however, been implemented in recent years. Aggregating neighboring HMAs on which free movement of horses is known or likely into HMA complexes for the purposes of coordinating population surveys, removals, and other

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management actions is an important step that can improve data quality and interpretation and enhance population management. The committee commends the partnership between BLM and USGS to develop rigorous, practical, and cost-effective survey methods that account for imperfect detection of animals. The committee strongly encourages BLM to continue that collaborative research effort to identify and refine a suite of survey methods that are effective for the varied landscapes occupied by horses and burros. Transferring the resulting knowledge to those in the field offices responsible for routine monitoring of populations is essential if the reforms are to be institutionalized.

Once more rigorous survey methods are adopted, they need to be standardized and consistently used, as dictated in the *Wild Horses and Burros Management Handbook* (BLM, 2010). The committee reaffirms the recommendations of a previous National Research Council committee that annual population surveys are not required to adequately monitor and manage free-ranging horse and burro populations. BLM, however, should develop protocols for how frequently surveys are to be conducted and ensure that the resources are available to field personnel to maintain a standardized survey schedule. Consideration should also be given to identifying a subset of HMAs that typify the diverse ecological settings throughout western rangelands that can be used as sentinel populations in which detailed demographic studies are conducted annually to assess population dynamics and responses to changes in animal density, to management interventions, and to variation in seasonal weather and potential trends in climate. Record-keeping needs to be substantially improved; the committee recommends that the Wild Horse and Burro Program develop a uniform relational database—that is accessible to and used by all field offices—for recording all pertinent population survey data.

On the basis of the information provided to the committee, it cannot consider the national statistics scientifically rigorous. The data used in the national statistics are the HMA counts that the committee assumes are converted to population estimates for each year in which counts are conducted, and the counts are extrapolated to produce population estimates in later years in which counts are not conducted (Figure 2-1). The procedures used for developing annual HMA population estimates from counts are not standardized and often are not documented, but it seems clear that the national statistics are the product of many hundreds of subjective and probably independent judgments and assumptions by range managers and administrators about the proportions of horses counted in surveys, population growth rates, effects of management interventions, and potential animal movements between HMAs. Perhaps most important, the links between the national statistics and actual population-size surveys, which are the foundational data of all estimates (whether derived at the field-office or national level), are obscure. Thus, the procedures and processes used by the Wild Horse and Burro Program to generate the national statistics impart a large measure of uncertainty in the numbers and their interpretation. Development of a uniform and centralized relational database that captures all inventory and removal data generated at the level of the field offices and animal processing and holding facilities and that is used by the national office to generate annual program-wide statistics would provide a clear connection between the data collected and the reported statistics. The committee also suggests that the survey data at the level of the HMA and any procedures used to modify the survey data to generate population estimates be made readily available to the public to improve the transparency of and public trust in the management program (see Chapters 7 and 8).

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In addition to the methodological shortcomings of BLM's current animal inventory and data-management procedures, it is the committee's judgment that the reported annual population statistics are probably substantial underestimates of the actual number of horses occupying public lands inasmuch as most of the individual HMA population estimates are based on the assumption that all animals are detected and counted in population surveys—that is, perfect detection. A large body of scientific literature focused on inventory techniques for horses and many other large mammals clearly refutes that assumption and shows estimates of the proportion of animals missed on surveys ranging from 10 to 50 percent depending on terrain ruggedness and tree cover (Caughley, 1974a; Siniff et al., 1982; Pollock and Kendall, 1987; Garrott et al. 1991a; Walter and Hone, 2003; Lubow and Ransom, 2009). The committee has little knowledge of the distribution of HMAs with respect to terrain roughness and tree cover, but a reasonable approximation of the average proportion of horses undetected in surveys throughout western rangelands may be 0.20 to 0.30. If those proportions are applied to the 2012 population estimate of 31,453, the national statistic would need to be adjusted to 39,316–44,933. The conclusion by this committee that there are considerably more horses on public rangelands in the western United States than reported in the Wild Horse and Burro Program national statistics was also reached by an earlier National Research Council committee (NRC 1980, 1982) and by the Government Accountability Office (2008).

Population Growth Rates

The earlier National Research Council committee questioned claims of population growth rates in free-ranging horses on western rangelands exceeding 5-10 percent (NRC, 1980), but adequate studies conducted since then have clearly demonstrated that growth rates approaching 20 percent or even higher are realized in many horse populations. That conclusion is corroborated by studies of survival and fecundity rates and reinforced by population models that integrated these estimates to project growth rates. It is more difficult to estimate the typical or average population growth rate in western horse populations inasmuch as such an assessment would require estimating growth rates in an adequate representative sample drawn from all horse populations managed by BLM. Although the literature provides a relatively large number of growth-rate estimates, the studied populations constitute a sample of convenience in that they were selected simply because data for estimating growth rates were available or there was specific scientific or management interest in particular populations. Those studies collectively demonstrate that growth rates vary substantially from one population to another and may also vary from one period to another in the same population.

The age-structure data on animals removed from the range probably provide the most representative sample in that the data were collected over several decades, involved multiple management gathers from a large proportion of HMAs, and involved large numbers of animals. Those data also provided a relatively consistent estimate of the proportion of young-of-the-year animals in free-ranging populations that is consistent with the generally high growth rates documented for individual herds that were based on direct counts. It is also to be expected that most free-ranging horse population growth rates are close to the biological potential for the species, given the general management policy of periodically removing relatively large proportions of populations to meet AML goals, which, in turn, were established at least partially to ensure that horses were not routinely food-limited (see Chapters 3 and 7). On the basis of the

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published literature and the additional management data reviewed by the committee, the committee concludes that it is likely that most free-ranging horse populations on public rangelands in the western United States are growing at an annual rate of 15-20 percent.

Consequences for Management

The committee's conclusions that there are substantially more horses on public rangelands than reported and that horse populations generally are experiencing high population growth rates have important consequences for management. Population growth rates of 20 percent a year would result in populations doubling in about 4 years and tripling in about 6 years. Thus, if populations were not actively managed for even short periods, the abundance of horses on public rangelands would rapidly increase until animals became resource-limited (see Chapter 3). Resource-limited horse populations would affect forage and water resources for many other animals that share the rangelands with them and potentially conflict with the legislative mandate that BLM maintain a thriving natural ecological balance. They would also increase the possibility of conflict with the multiple-use policy of public rangelands (see Chapter 7). Thus, BLM should diligently monitor and manage free-ranging horse populations to meet the numerous congressional mandates in the Wild Free-Roaming Horse and Burro Act of 1971 and the Public Rangelands Improvement Act of 1978.

The larger the population of horses on public lands and the higher the growth rate of the populations, the larger the increment of new animals each year. BLM has been removing an average of about 8,000 horses from rangelands each year for the last decade in an effort to control horse populations and meet its legal obligations. Removing such a large number of horses each year has substantially exceeded the capacity of BLM to place horses into private ownership; a result is that many tens of thousands of unwanted horses are maintained in long-term holding facilities until they die. Despite the aggressive program to remove horses from public rangelands, BLM's population-management program has not been able to reduce the free-ranging horse population to the targeted AML. For 2012, the maximum AML for horses was 23,622 (the maximum AML for burros was 2,923).

Additional management interventions in the form of various fertility-control agents have been pursued to enhance the efficacy of population management. The emerging technologies have the potential to reduce population growth rates and hence the increment of animals added to the national population each year (see Chapter 4); this might substantially increase the opportunity for the removal program to attain management goals. The potential impact of fertility control, however, is limited by the number and proportion of animals that must be effectively treated with the contraceptive agents, and it is likely to affect the genetic makeup of populations unless carefully monitored (see Chapter 5). All modeling studies exploring the potential impacts of contraceptive treatments on horse population growth rates have demonstrated that the higher the intrinsic growth rate of the population, the higher the proportion of horses that must be treated to reduce population growth rates to a prescribed level (Garrott, 1991b; Garrott and Siniff, 1992; Garrott et al., 1992; Coughenour, 1999, 2000, 2002; Gross, 2000; Bartholow, 2007; Ballou et al., 2008). Thus, the potential implementation of broad-scale fertility-control management to aid in curbing population growth rates will be confronted by the challenge of treating the large number of horses that will probably be required to have

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appreciable affects on horse population demography. Studies specific to burro population demography will be necessary to tailor similar management actions to that species.

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3

Population Processes

The Bureau of Land Management (BLM) asked the committee to address the following questions as part of the discussion of potential rates of horse and burro population growth: Would free-ranging horse and burro populations self-limit if they were not controlled? If so, what indicators (such as rangeland condition, animal condition, and health) would be present at the point of self-limitation? To address those questions, it is necessary to review the factors that limit population growth in an unmanaged population[1] and that determine free-ranging horse and burro population growth and dynamics aside from management removals. Population growth and self-limitation are population processes in the sense that they involve a suite of underlying functions that lead to the result. The underlying functions include changes in natality and survival in response to environmental variables that affect forage availability, such as weather and population density.

The committee was also asked to assess whether there is compensatory reproduction as a result of population size control, such as fertility control or removal from Herd Management Areas (HMAs). Compensatory reproduction is defined as an increase in reproduction as a direct or indirect consequence of management reductions, including removals and contraception. Indirect responses could include increased fertility, foal survival, or adult survival due to reduced competition for forage.

For self-limitation to occur, it is necessary for population processes to respond to population density (Figure 3-1). That is, population processes—such as population growth rates, age-specific survival rates, natality, and age of bearing first offspring (primiparity)—must be density-dependent. As density increases, population growth rate decreases because of increased competition for resources. Population processes are also altered by density-independent factors, particularly climatic conditions and variations. Natality and mortality can be affected by climatic conditions through direct effects on animals. Climatic conditions also affect resource abundance, for example, through effects on forage production. Population size can be reduced by predation, and predator abundance is affected by prey abundance. Population growth can also be affected by dispersal, immigration and emigration, and management factors, such as removal of animals from the range and contraception. This chapter examines the changes in population processes of

[1]Unmanaged populations of horses and burros are not domestic animals, and they are not fed or given veterinary care. Their numbers are not controlled by removals or contraception.

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free-ranging equids due to density-dependent, density-independent, predation, and management factors.

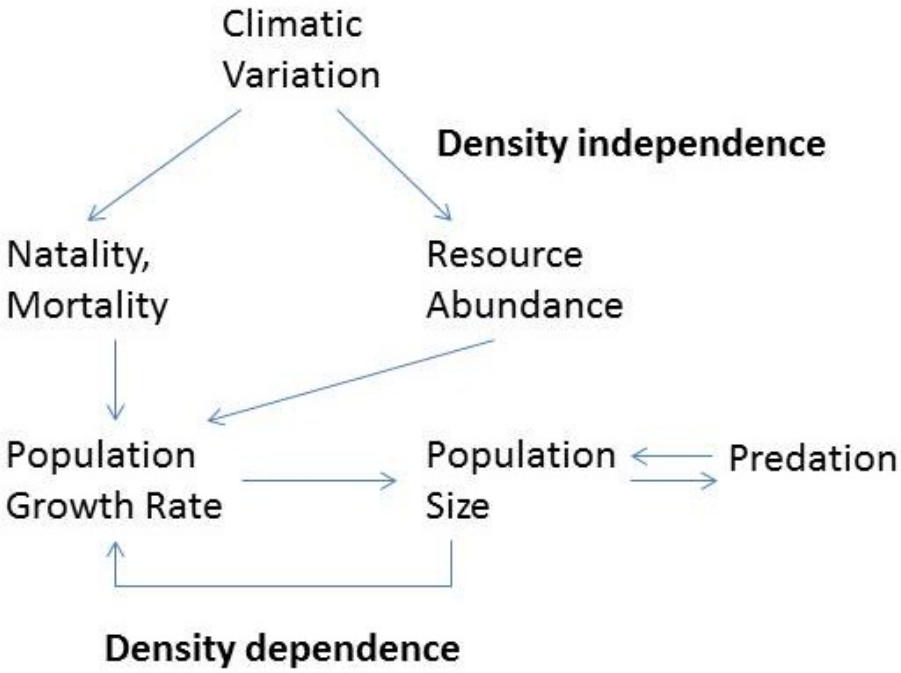


FIGURE 3-1 Population processes, including density-independent and density-dependent controls.

DENSITY-DEPENDENT FACTORS

It is a general principle of ecology that populations do not continue to grow indefinitely, but the mechanisms of reduction in growth as densities increase are not always well understood (Flux, 2001). Mechanisms may include competition for resources among members of the same species at high densities (Ginzburg, 1986; Berryman, 2003), complex social behaviors (Wynne-Edwards, 1965), and combinations of physiological responses to social cues (Wolff, 1997).

Density dependence can be seen most easily by examining the S-shaped curve of population size changing over time described by the logistic equation

$$dN/dt = rN([K - N]/K),$$

where dN/dt is the instantaneous rate of change in N, N is the size of the population (number of individuals), r is the intrinsic rate of natural increase, and K is the carrying capacity, that is, the maximum population size that the environment can support as affected by resource abundance. The discrete form of the equation defines the population increment over an interval of time, such as a year, and is expressed as

$$N_{t+1} = N_t + R(N_t[K - N_t]/K),$$

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where N_{t+1} is the population size in the next year or generation, N_t is the population size in the current year or generation, R is the maximum rate of increase per year or generation, and K is the carrying capacity. The annual or generational increment can be defined as

$$\Delta N = N_{t+1} - N_{t.}$$

Early in the growth process there is a period in which population grows without limitation because the difference between N_t and K is so large that the density-dependent term ($[K - N_t]/K$) produces little constraint on ΔN (Figure 3-2A). At the inflection point (point α in Figure 3-2A), ΔN (point β in Figure 3-2A) is maximized, but as N_t approaches K, growth slows; it even becomes negative if N_t is greater than K.

The population trajectory represented by the logistic equation, as portrayed in Figure 3-2A, assumes that R and K do not vary over time. If, however, environmental variation is great and harsh conditions periodically reduce R or K independently of density, the importance of density dependence diminishes. If such variations are great enough, the population will rarely experience density dependence. Population sizes that are strongly affected by such density-independent factors show sawtooth-like increases and decreases and do not come to a steady equilibrium with resources. Density independence is explained further below.

Carrying capacity is a concept that has multiple definitions that depend on the situation. For populations of unmanaged large herbivores, carrying capacity is determined by resource availability, primarily food, so it is sometimes called the food-limited or ecological carrying capacity. Food-limited carrying capacity (K in the logistic model) can be determined empirically by letting a population grow until it comes into quasiequilibrium with the resource base. That idea of carrying capacity is different from the idea of carrying capacity discussed in Chapter 7, in which forage supplies are estimated and combined with an appropriate forage utilization level to set an appropriate management level (AML) in an attempt to preserve a thriving natural ecological balance. That is not to say that a population at or near K cannot result in a thriving natural ecological balance. However, the value of K will most likely be higher than the carrying capacity set in the AML process. Similarly, food-limited carrying capacity will be higher than the stocking rate that maximizes animal or vegetation productivity, which Caughley (1979) referred to as economic carrying capacity. For example, the maximum rate of animal production would be attained at Point α in Figure 3-2B, which might be the objective if animals were being produced for sale or for hunting.

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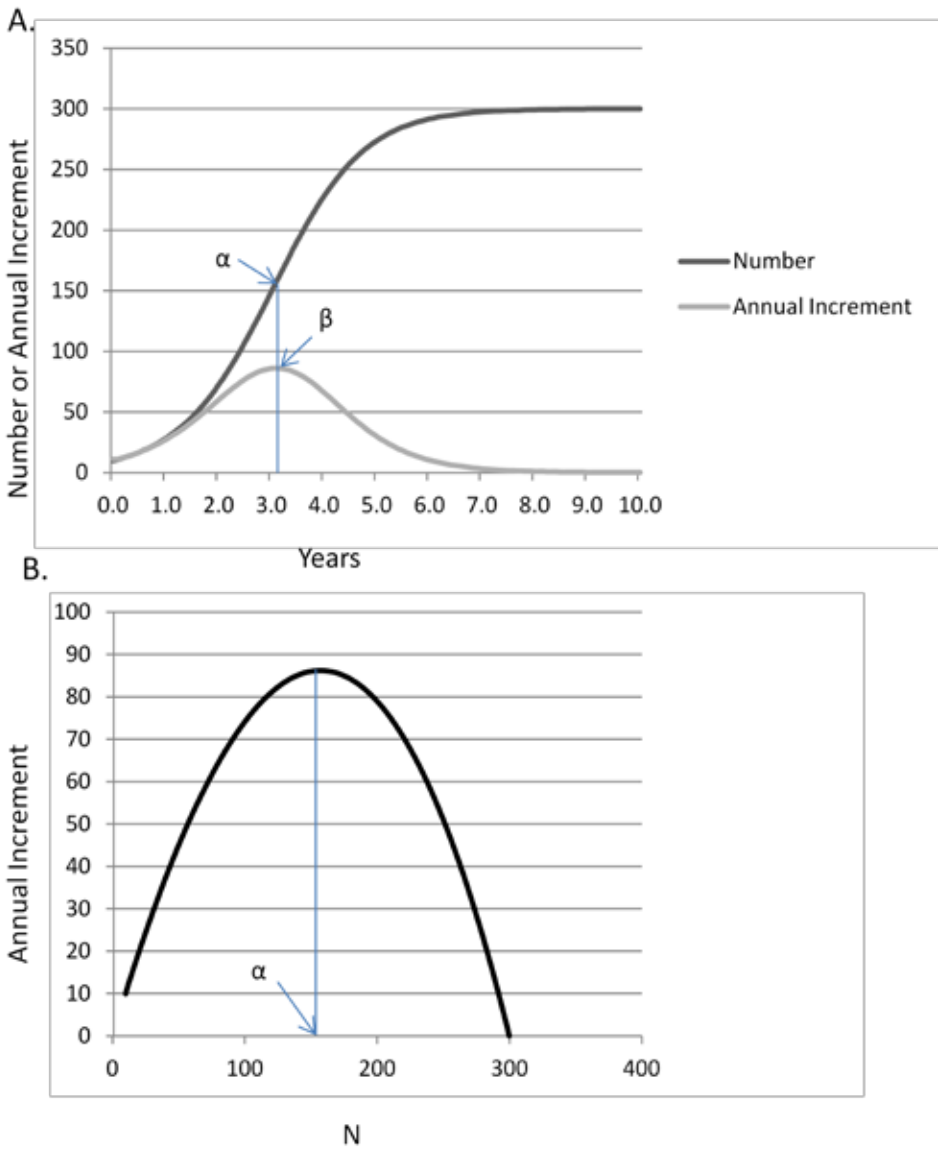


FIGURE 3-2 A, an example of logistic population growth, with R = 1.18 and K = 300. Population size N and the annual population increment ΔN are plotted against time. Point α is the inflection point, at which population growth begins to decrease as the population approaches K. The corresponding point β shows that annual population increment is maximal at the inflection point. B, the plot of annual population increment against population size, in which point α is the population size that maximizes the annual increment.

Numerous reviews and meta-analyses have shown that density dependence is common in large herbivore populations (Fowler, 1987; Sinclair, 1989; Gaillard et al., 2000). How density dependence affects individual animals and thus life-history traits varies with the ecological context, and effects are stronger in some age-sex classes than in others (Bonenfant et al., 2009). Effects of increased population density on reproduction are manifested through reductions in pregnancy, fecundity, twinning rate, number of offspring per female, percentage of females lactating, and young-to-female ratios and through an increase in age of primiparity, depending on

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the species, population, and environmental context. Survival rate responses to population density are common, but they vary among ungulate populations.

Effects of Density on Population Processes

Several studies of density dependence have included or focused exclusively on equids. In Kruger National Park, South Africa, adult and juvenile zebra survival rates were adversely affected by density and favorably affected by rainfall (Owen-Smith et al., 2005). Similarly, zebra population dynamics in Kenya were best explained by a model of rainfall-mediated density dependence (Georgiadis et al., 2003) that involved fecundity and survival. An unmanaged horse population in Argentina exhibited density-dependent responses. Reduced fecundity was the primary response to increased density. Adult female survival was also reduced at higher densities, but to a lesser degree (Scorolli and Lopez Cazorla, 2010). In a feral donkey population in Australia, fecundity was high and not related to density; however, ages of males at sexual maturity and juvenile mortality increased at higher densities (Freeland and Choquenot, 1990; Choquenot, 1991; also noted in Bonenfant et al., 2009). Pregnancy rates declined at higher densities in horses in the eastern United States (Kirkpatrick and Turner, 1991). In Nevada, it was not uncommon for 2-year-old mares to foal, in contrast to earlier evidence indicating foaling did not begin until the age of 3 (Berger, 1986; Garrott et al., 1991). Garrott et al. (1991) argued that age at first reproduction is more likely to be earlier when forage is more abundant and when competition for forage is reduced. Jenkins (2000) analyzed data from the Granite Range and Pryor Mountain horse herds and reported evidence that population growth rate decreased with increasing population. Roelle et al. (2010) confirmed those findings in the Pryor Mountain horse herd. Thus, density dependence appears to take a variety of forms in equids.

Responses to density are often age-specific. Gaillard et al. (1998) reviewed evidence related to the conceptual model proposed by Eberhardt (1977) in which density effects on population vital rates (e.g., birth and death rates) would occur first in juvenile survival, then in age at first reproduction, then in reproductive rates of prime-aged (most highly reproductive) adults, and finally in adult survival. They noted that Fowler's (1987) review supported Eberhardt's model. The Gaillard et al. review provided further support of the model and reported that survival of prime-aged adults is relatively invariant whereas juvenile survival varies considerably from year to year. They reported that the pattern of high, stable adult survival and variable juvenile survival is observed in a wide variety of environments regardless of whether mortality is density-dependent or density-independent. They noted that higher annual variation in juvenile survival as compared to adult survival can arise from multiple causes including increased vulnerability to predation, drought, harsh winters, and factors causing low birth weights and early growth rates. In an unmanaged horse population in Argentina that was approaching carrying capacity, fecundity was affected by density and rainfall, but adult, juvenile, and foal survival rates were not (Scorolli and Lopez Cazorla, 2010). Although juvenile survival varies more than adult survival, population growth rate is highly sensitive to variations in adult survival, less sensitive to changes in juvenile survival, and moderately sensitive to changes in fecundity (Gaillard et al., 2000).

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Possible Effects of Domestication

It is possible that domestication has selected for forms of density dependence that are different from those in undomesticated populations. Flux (2001) proposed that the tendency to self-regulate differs between feral and "wild-type" populations. It is believed that domestication of European rabbits by monks for over 600 years has led to feral populations that have been observed at densities of up to 200/ha in Australia and New Zealand (Thompson and King, 1994), whereas "wild" species seldom reach 4/ha. However, it is also likely that introduced rabbit populations in those locations are less affected by predation and disease. Other feral species also reach higher densities than their closest "wild" relatives, such as goats, pigs, cats, and domestic pigeons. Many of those species have been implicated in severely detrimental effects on habitats and native species (Flux, 2001).

Genetic history may contribute to the reproductive response of free-ranging equids to resource scarcity. A population of unmanaged horses in the Camargue (France) declined in body condition because of scarce resources, and this led to reduced foal and mare survival without a concurrent decline in fecundity (Grange et al., 2009). The authors pointed out that that pattern is different from the one in wild, nonferal ungulate populations, in which fecundity decreases well before adult survival as resources become more limiting. Other domesticated species, such as cattle, have shown the same pattern as the Camargue horses. The authors argued that domestication has selected for reproduction over survival even when resources are scarce. As a result, feral populations are more likely to oscillate strongly, and the tradeoff of decreased adult survival may make them more vulnerable to harsh environmental conditions.

Nutritional and Physiological Mechanisms

Fowler's (1987) review indicated that food shortage is the primary factor in density dependence. The mechanisms through which food limitation affects population vital rates are most likely effects of poor nutrition, energy balance, and body condition on reproductive processes and survival rates (e.g., Gaidet and Gaillard, 2008). Poor nutritional status may also impair animal feeding and predator avoidance and increase susceptibility to adverse weather. Feral donkey populations in Australia were regulated by food-limited juvenile mortality, which in turn was related to the nutritional status of lactating females (Choquenot, 1991). In an unmanaged population of horses in the Australian Alps, population growth rate declined as numbers increased because of decreased fecundity and decreased adult and juvenile survival (Dawson and Hone, 2012). Those response variables were related to body condition and available food, and mean body condition correlated positively with forage biomass. In the Pryor Mountains, foal survival rate was positively related to precipitation, and this suggests a link to forage production and availability mediated through the condition of the mares (Roelle et al., 2010). The authors cited several other studies, including Garrott and Taylor's (1990) study of the horse populations in the Pryor Mountains, whose results suggested that forage availability can affect mare condition and thus foaling rates.

In addition to the total quantity of food, the quantity of high-quality food items may be diminished when populations are near carrying capacity. When an Australian donkey population reached carrying capacity, females ingested a diet of low nutritional value, whereas those in a population below carrying capacity were able to ingest a nutrient-rich diet (Freeland and

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Choquenot, 1990). Low diet quality resulted in low levels of stored nutrients in the females, which impaired their ability to raise offspring.

When resources are scarce, females are induced into anestrus as a result of poor body condition (Ginsberg, 1989). Birth sex ratios may be affected because mares in poorer condition have more female foals (Cameron et al., 1999). The effect of body condition on sex ratio probably occurs at conception. The age at first reproduction and reproductive rates of 2- to 4-year-old horses are affected by competition for forage, which reduces the amount of forage per individual and thus increases the time needed for individuals to attain sexual maturity (Garrott and Taylor, 1990). Saltz et al. (2006) reported that rainfall during the year before conception and drought conditions during gestation were important determinants of reproductive success in Asiatic wild ass. They focused on rainfall before conception because females in poor condition would not go into estrus.

To summarize, the causal pathways underlying density dependence begin with population size (Figure 3-3). Climatic conditions and spatial accessibility determine the availability of forage for herbivores. Population size affects the amount of forage available per animal: as population size increases, forage per animal declines; this results in reduced forage intake and reduced body condition, which affect survival rates and natality.

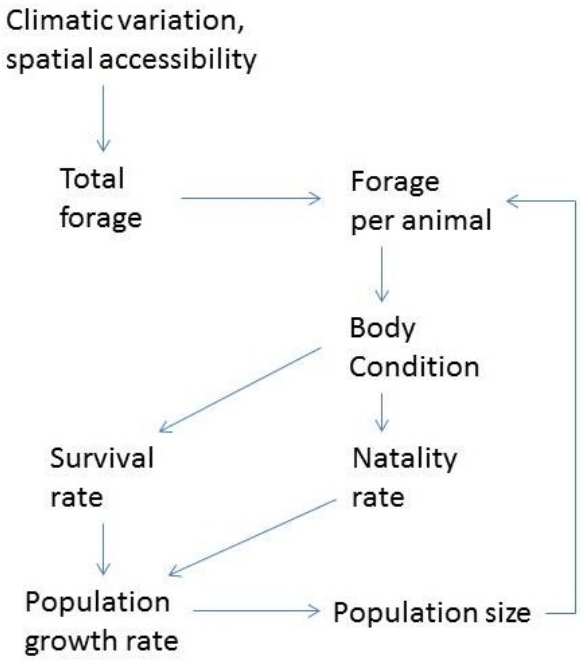


FIGURE 3-3 Nutrition-based mechanisms underlying density dependence and density independence.

Behavioral Mechanisms

There are two fundamental mechanisms of behavior-mediated density dependence: increased dispersal at high densities and changes in social interactions that affect reproduction.

The role of dispersal in density dependence remains uncertain because there have been few studies (Bonenfant et al., 2009). Duncan (1992) found no evidence of a social mechanism

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that regulates equid populations below levels determined by their food resources. However, others have found that increased social stress at high density may contribute to density dependence (Linklater et al., 2004). Tatin et al. (2009) found that reduced space can slow the growth of a population of a Przewalski's horse herd before forage becomes limiting. They suggested that reproduction decreased as a result of mare dispersals to avoid incest (Monard and Duncan, 1996).

Where populations are spatially unbounded, dispersal can forestall density-dependent control as long as there are places where populations are small and individuals in crowded locations can disperse (Owen-Smith, 1983; Pulliam, 1988). Such source-sink population complexes where emigration keeps densities low will be common where environmental forces—ranging from physical factors, such as climate, to biological factors involving predators—operate over large areas. But where there are boundaries to dispersal, as on natural islands or habitat islands created by human landscape change, densities can increase to a point at which feedback from crowding lowers fecundity and adult and juvenile survival.

Crowding changes behavior in many ways among horses and burros. In Nevada, high equid densities were associated with increased incidences of confusion, separation, and desertion of foals by mares at water points in the dry season (Boyd, 1979). Berger (1983a) reported that social instability, specifically high rates of turnover among harem males, adversely affect female reproductive success and patterns of age-specific fecundity. He also indicated that increased levels of sexual harassment can lower female body condition and disrupt normal endocrine function. By virtue of their hindgut fermentation system, equids can subsist on low-quality vegetation, and they typically compete by maximizing intake relative to other animals (Rubenstein, 1994). However, when densities increase, individual agonistic interactions increase, and this reduces time available foraging and thus competitive ability. Equid females rely on male protection to increase time spent in feeding, and this increases the likelihood that foals will survive to the age of independence (Rubenstein, 1986). Thus, any interference that impinges on a female's ability to forage can lower body condition and reduce fecundity and survival. Moreover, because band stability increases a female's long-term reproductive success (Rubenstein and Nuñez, 2009), disturbance that leads to more rapid turnover in the tenure of harem males or increased competition among females that leads to female movements among groups will alter important demographic vital rates.

Including Density Dependence in Models

Density dependence has been considered in a number of models of ungulate population dynamics. The trajectory of an unmanaged population of horses in Argentina was successfully modeled by fitting a simple logistic equation with a best-fit intrinsic rate of increase and carrying capacity (Scorolli and Lopez Cazorla, 2010). Georgiadis et al. (2003) developed a model of zebra populations that included density dependence in the form of a ratio of rainfall (as a surrogate of food availability) to density. The inclusion of that density-dependent term improved model accuracy despite the large fraction of variation that was explained by rainfall alone. Rubenstein (2010) modeled Grevy's and plains zebra populations. Density dependence was solely through age at first reproduction, inasmuch as population growth rate is very sensitive to the number of 3-year-olds reproducing. Overall fecundity was linked to annual rainfall. Density dependence was statistically significant in models of four horse populations (Eberhardt and Breiwick, 2012): *Equus ferus caballus* in Argentina (Scorolli and Lopez Cazorla, 2010), the

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Camargue (Grange et al. 2009), and Oregon (Eberhardt et al., 1982) and *Equus ferus przewalskii* in a fenced area in France (Tatin et al., 2009).

Density dependence in the population dynamics of Serengeti wildebeest was modeled by Mduma et al. (1999). Density dependence was most strongly exerted through adult mortality, and the primary cause of death was undernutrition. Thus, mortality was modeled as a function of food per capita, and food supply was modeled as a function of rainfall. The model predicted a period of population growth following a period when population size was reduced below food-limited carrying capacity by rinderpest.[2] Projected population dynamics varied within a wide range as a result of rainfall and food-supply variation, but the projected population nevertheless reached maximal levels because of density-dependent feedback.

Lubow et al. (2002) fitted a series of alternative population projection models to population data on elk in Rocky Mountain National Park. Logistic regression was used to estimate recruitment (the number of individuals added to a population through births) and survival rates of calves and survival rates of each sex and age segment as functions of population size and seasonal temperatures and precipitations. Because of the effects of population density in the models, populations stabilized at some upper limit, which the authors identified as the carrying capacity. The primary mechanism of density feedback was a nearly linear decline in calf recruitment followed by sharply declining calf survival.

An approach to the modeling of time-varying carrying capacity for Yellowstone elk populations was based on temporal variations in food availability (Wallace et al., 1995, 2004; Coughenour and Singer, 1996a). Food availability was affected by spatial heterogeneity, spatial overlap of elk, and spatially variable food availability. The latter was affected by the distributions of snow depth across the landscape throughout winter, which was affected by snowfall and temperature, which in turn were related to elevation. The effect of snow depth on forage-intake rate was explicitly represented. An energy-balance model was used to derive temporal changes in elk body condition (fat reserves) on the basis of the balance of energy intake and expenditure. Mean body condition was used to determine the fraction of animals in a normally distributed population that would die because of extremely low body condition—an approach originally developed by Hobbs (1989).

A similar idea was extended into actual population-dynamics modeling. A metaphysiological modeling approach was developed to represent the effects of energy storage on population dynamics (Getz and Owen-Smith, 1999; Owen-Smith, 2002a,b). Because animals and plants can store energy in body tissues, they have a reserve for use in times of food shortage. The approach links animal energy reserves to population dynamics; the reserves alter population dynamics, for example, through an increase in mortality when there are food shortages in the environment.

In an ecosystem modeling approach (Coughenour, 1992, 1999, 2000, 2002; Weisberg et al., 2006), the energy balance of the herbivore population is simulated as an outcome of forage intake and energy expenditure. The energy balance determines storage (fat) reserves, a measure of body condition. Condition in turn affects survival and fecundity. Forage intake depends on forage-biomass density, which establishes a link between population dynamics and forage. This type of model is explained in greater detail in Chapter 6.

Some equid population modelers have avoided considering density dependence and food-limited carrying capacity because populations are limited by other factors. Saltz and Rubenstein (1995) modeled Asiatic wild ass populations with a Leslie matrix, but because the populations

[2]An often fatal viral disease that affects even-toed ungulates.

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were so small relative to the expansive area available, it was unlikely that density dependence was important, so it was not included in the model. Although the WinEquus model that is used by BLM has the capability to consider K (carrying capacity), it is rarely invoked in most BLM applications of the model because populations are always held below food-limited capacity by management removals (see Chapter 6). Gross (2000) ignored food limitations and carrying capacity in his individual-based model of the Pryor Mountain herd. He presumed that horse populations will be managed below food-limited carrying capacity and therefore not allowed to self-regulate. Linklater et al. (2004) also did not attempt to consider density dependence in their model, although it was useful for estimating population growth rates below carrying capacity.

The assumption that most BLM-managed populations are below food-limited carrying capacity and thus unaffected by density dependence appears to be reasonable given that management has heretofore aimed to ensure the prevention of rangeland deterioration, largely interpreted as preventing overuse of the forage and habitat (see Chapter 7). However, an outcome of this situation is that few data or modeling studies have provided information on outcomes of density dependence in horse or burro populations on lands under the purview of BLM. Although density dependence has not been a concern in BLM-managed HMAs and models, it will be necessary to include it in any model that addresses the question posed to the committee regarding self-limitation.

DENSITY-INDEPENDENT POPULATION CONTROLS

Large herbivore population dynamics are generally influenced by a combination of stochastic environmental variation and population density (Saether, 1997). Unmanaged or minimally managed populations should be expected to fluctuate about some mean tendency in quasiequilibrium, and the degree of fluctuation will depend on the degree of climatic variability. The dynamics of more intensively managed populations can also be expected to vary in response to density-independent factors, inasmuch as density-independent effects are in play irrespective of whether populations are managed to levels below which density dependence takes effect.

Density independence is often incorporated into predictive models of equid population dynamics. Saltz et al. (2006) applied a Leslie matrix model with demographic and environmental stochasticity to an Asiatic wild ass population in Israel. Annual precipitation during the year before conception, drought conditions during gestation, and population size determined reproductive success. They reported that increased rainfall variability in global climate-change scenarios increased extinction probability by a factor of nearly 10. The widely used WinEquus population model (see Chapter 6) incorporates density independence as stochastic variation in recruitment and survival. At the other end of the model-complexity spectrum, the ecosystem modeling approach described in Chapter 6 represents density independence by simulating climatically driven variations in forage production and effects of snow cover on forage availability.

Effects of Climatic Variability

Variable precipitation and winter weather conditions can have marked effects on horse and burro population dynamics. Precipitation affects equids indirectly through its effect on total forage biomass production and the length of time that forage remains green and more highly

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nutritious (Figure 3-3). Winter weather can act directly on horses and burros through thermal stress, but more often it acts indirectly as snow cover affects forage availability.

A stage-structured model of an elk population in Yellowstone that included calf, cow, and bull elk classes modeled recruitment and mortality of each class by using the best equations determined from forward, stepwise multiple regression analyses and using precipitation amounts and elk number as the independent variables (Coughenour and Singer, 1996b). Winter precipitation was a surrogate for snow cover and later forage availability. The model revealed that expected population trajectories should exhibit wide variation in response to this density-independent regulation. Although a population equilibrium could be predicted and could be interpreted as one measure of food-limited carrying capacity, there was considerable variation above and below the equilibrium value. A series of mild winters, for example, could result in population sizes above mean K, and the converse would be true in a series of severe winters.

Precipitation appears to have a substantial influence on equid populations. Berger (1986) could find little evidence of density dependence in his data on the Granite Range HMA and suggested that responses to weather variations were overriding and confounding. Roelle et al. (2010) reported that foal survival rate in the Pryor Mountain Wild Horse Range was positively related to precipitation, probably because of the effects of variable forage production on mare condition. They noted that other investigators had suggested that forage availability can affect foaling rates in this manner (Green and Green, 1977; Nelson, 1978; Berger, 1986; Siniff et al., 1986, Garrott and Taylor, 1990). Horse populations in Australia possibly increased by a factor of 4 during good rainfall years in the 1970s (Berman, 1991), and dry conditions and more intense management reduced the population by 70 to 80 percent in the central part of the country. A 10- to 20-percent birth rate is probably realistic in poor years, and a 25- to 30-percent birth rate in good years (Berman, 1991). Joubert (1974) observed lower recruitment rates in a zebra population in dry years and a large dieoff during a drought. Owen-Smith et al. (2005) reported that juvenile survival was sensitive to rainfall variability in most of 10 African ungulate species, and there was no evidence of density dependence. Rainfall also affected adult survival in several declining species.

Density-independent mortality was documented by Berger (1983b) in the Granite Range of Nevada. Two horse groups perished as a result of severe winter snowstorms. High-altitude, snow-induced mortality may be common. He concluded that unpredictably heavy snow accumulation is a principal mortality agent in the Granite Range, as it may be elsewhere in the Great Basin. Berger (1983b) referred to the winter of 1977, when an estimated 300 horses (50 percent of the population) died in the Buffalo Hills near the Granite Range. Berger (1986) reported a pattern of low mortality in most years but markedly higher mortality in occasional years of bad weather. In Wyoming's Red Desert, abortions and still-births after a severe winter reduced natality by one-third (Boyd, 1979).

Reduction in Equilibrial Tendencies by Density Independence

In climatically variable environments, the importance of density-independent population dynamics increases. The implication of strong density independence is that in climatically variable environments herbivore populations should not be expected to reach a steady state in which population density is in stable equilibrium with forage production. Climatic variations include severe winters and droughts. When the coefficient of variation of annual rainfall, and presumably food availability, exceeds 30 percent, population size is less likely to be determined

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by mean food-limited carrying capacity (Caughley, 1987; see also the section "Understanding Ecosystem Dynamics" in Chapter 7). Saether (1997) also theorized that lags in the responses of populations to environmental variations, in the absence of predation, will make a stable equilibrium between ungulates and their food resources unlikely. As a result, horse populations may not necessarily decline rapidly during moderate droughts despite reductions in plant growth, and the grazing pressure, expressed as a percentage offtake, may periodically increase above average values.

Ellis and Swift (1988) proposed that plant-herbivore systems in climatically variable environments are unlikely to be equilibrial and that traditional concepts of food-limited carrying capacity have relatively little value in predicting herbivore population sizes and dynamics in such environments. They proposed that a herbivore population in an environment subject to periodic droughts is periodically reduced to a low level independently of density. The population then recovers slowly until the next drought causes another reduction. As a result, the population is kept below food-limited carrying capacity—it is unable to use available food resources fully because of low density. That idea was supported by a model of zebra population dynamics (Georgiadis et al., 2003) that provided realistic predictions for 2 decades (Georgiadis et al., 2007). The model captured the fundamental mechanism of rapid population decline during dry periods and slow increase during wet periods. The greater the variability in rainfall, the greater the proportion of time that the population spends below carrying capacity.

The Ellis and Swift (1988) study generated controversy: some interpreted it to suggest that plant-herbivore systems would be generally nonequilibrial and herbivore populations would naturally be held below food-limited carrying capacity and thus below sizes that would cause overgrazing and degradation. The conclusions of Ellis and Swift, however, were limited to environments that had a high degree of climatic variability, and the implication was that such systems have nonequilibrial tendencies, not that they are absolutely nonequilibrial. Illius and O'Connor (1999, 2000) showed that herbivore populations in drought-prone environments would be "disequilibrial," still in quasiequilibrium with critical food supplies during dry periods. Thus, plant resources should appear to be lightly used during wet periods, and on the average a small fraction of plant growth should be used. Illius and O'Connor recognized the importance of key resource areas on the landscape, such as natural dry-season grazing reserves that define the dry-season bottlenecks and thus limit herbivore populations to a particular density. Density dependence therefore exists, but it is temporally variable inasmuch as food-limited carrying capacity varies with precipitation and, in seasonally cold environments, with snow cover.

EFFECTS OF PREDATION

Predators prey on wild equids; predation on onagers and zebras has been reported in Asia (Solomatin, 1973) and Africa (Kruuk, 1972; Schaller, 1972), respectively. In Africa, predation may limit some zebra populations (Sinclair and Norton-Griffiths, 1982; Mills et al., 1995). Zebras and other ungulates were not limited by food in Namibia but most likely by predation or disease (Gasaway et al., 1996). Zebra maintained excellent body condition during dry seasons and after droughts. Recruitment rates continued to be high, corresponding to those of a growing population. Such recruitment rates could be balanced only by high rates of yearling and adult mortality, which would presumably be caused by predation or disease. Predation was suspected of being a major population control in a collection of ungulate populations in Kruger National

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Park (Owen-Smith et al., 2005). Adult zebra survival was strongly related to increasing density, but the steepness of the response indicated that it was strongly affected by prey-switching by lions in response to decreased availability of alternative prey species. Mills et al. (1995) reported that zebra populations in Kruger were influenced by predation but to a smaller extent than wildebeest or buffalo. However, rainfall was the primary determinant of zebra population dynamics. In Serengeti National Park, Tanzania, zebra populations have remained roughly constant for decades, despite large changes in wildebeest and other bovid numbers caused by a rinderpest epidemic (Sinclair and Norton-Griffiths, 1982; Grange et al., 2004). Very low first-year survival limits the zebra population in the Serengeti, according to Grange et al. (2004), who found evidence that rates of predation on zebras were high and hypothesized that predation potentially holds the population in a "predator pit." The principal predators, lion and spotted hyena, feed mainly on adult zebra, so it was not clear what the main sources of foal mortality were. Using data from 23 near-natural ecosystems in Africa, Grange and Duncan (2006) reported that zebra abundance relative to that of bovids is lower in ecosystems that have high lion densities and that zebra abundance is not as affected by forage abundance as bovid abundance; this suggests that zebras are more sensitive to predation than are bovids. Rubenstein (2010) reported that 73 percent of lion dung samples contained Grevy's zebra and 53 percent contained plains zebra hair. One wildlife conservancy had high rates of lion predation on zebra.

Wolves are quite capable of preying on equids. In southern Europe, equids constituted 6.2 percent of wolf diets (range, 0-24 percent) (Meriggi and Lovari, 1996). In Abruzzo National Park, Italy, horses constituted 70 percent of wolf diets; however, unguarded horses are commonly hobbled in that area to prevent long-range movements (Patalano and Lovari, 1993, cited in Meriggi and Lovari, 1996). In northwestern Spain, a population of free-ranging ponies is heavily preyed on by wolves (Lagos and Barcena, 2012). Foal survival rate was very low (0.41), and 76 percent of foal carcasses found were killed by wolves. Van Duyne et al. (2009) reported that wild Przewalski's horse foals were killed by wolves in Hustai National Park, Mongolia, and cautioned that predation could influence translocation efforts. However, those horses are sufficiently vigilant to survive and reproduce, so perhaps they have not lost essential skills (King and Gurnell, 2012). Wolves in a multiprey system have been reported to prey on feral horses in Alberta, Canada. Webb (2009) reported that one of 36 kills by wolves included a feral horse. Webb (2009) located 192 ungulates that had been killed by wolves in 11 packs from 2003 to 2006. Some 7 percent were feral horses, and they made up 12 percent of the total biomass consumed (0.01 ± 0.02 feral horse/pack/day). Despite evidence that wolves prey on equids elsewhere, the committee was unable to identify any examples of wolf predation on free-ranging equids in the United States.

Most predation on free-ranging equids in North America has been attributed to mountain lions. That has been reported by Robinette et al. (1959) and Ashman et al. (1983). Berger (1983c) cited an unpublished report of 21 cases of mountain lion predation on free-ranging horses in the Great Basin; those deaths spanned more than 20 years and had negligible effects on population growth. Feral (but not free-ranging) horses constituted 11 percent of mountain lion diets in Alberta (Knopff and Boyce, 2009). Horses constituted 10-13 percent of adult male lion diets, but female lion diets were almost devoid of horses (Knopff et al., 2010). Overall, mountain lion predation on free-ranging equids in North America is, with few exceptions, considered uncommon (Berger, 1986).

One of the exceptions is the free-ranging horse population on the central California-Nevada border. Turner et al. (1992) examined foal survival rates in the area (the Montgomery

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Pass Wild Horse Territory managed by the U.S. Forest Service) because there was a ban on mountain lion hunting in California and low hunting pressure in Nevada that led to a high density of mountain lions. The study was conducted from May 1986 to July 1991 by examining the horse and mountain lion populations and documenting deaths of horses. The average annual cohort of foals over the 5 years was 32. The annual survival rates were calculated for foals (0.27), yearlings (0.95), and adults (0.96). From 1987 to 1990, 48 foals were lost; 58 percent were located as carcasses and 82 percent of those were killed by mountain lions. The authors concluded that mountain lion predation had a substantial effect on the demography of that free-ranging horse population. The study was continued, and Turner and Morrison (2001) used 11 years of data (1987-1997) to examine again the influence of mountain lions on the horse population in Montgomery Pass Wild Horse Territory. Their results supported the earlier work of Turner et al. (1992): mountain lions were responsible for the deaths of 45 percent of the foals that were born. Mountain lion predation was also hypothesized as a major factor in limiting horse population growth in an area of southern Nevada where they use high-elevation forested habitats in summer (Greger and Romney, 1999). Those habitats are excellent for mountain lions because of their broken topography.

By and large, research that has addressed the question of predation on free-ranging equids in North America has been limited to anecdotal observations and a few published papers, but at the time of the committee's review, studies at the University of Nevada, Reno, that should provide more quantitative data were under way. The work in several mountain ranges of western Nevada was examining predation by mountain lions in multiprey systems in which free-ranging horses had various densities. Diet data were being obtained by using information from GPS-collared mountain lions to investigate predation events; more than 700 predation events had been investigated as of June 2012. Ten of 13 collared mountain lions that had access to free-ranging horses regularly consumed horses as prey. Horses were documented to have been consumed as prey by collared mountain lions in eight mountain ranges throughout the study area in western Nevada (Virginia, Pah Rah, Fox, Lake, Wassuk, and Excelsior ranges and Virginia and Smoke Creek Mountains). Preliminary data suggest that in that study area, where free-ranging horses are available as prey, more than 50 percent of the diet of collared mountain lions is made up of horses when diet data on individual mountain lions are pooled. Preliminary results suggest that mountain lions in that multiprey system are generalists at the population level but that some diet specialization occurs at the individual level: some lions select for deer where horses are more abundant, and some select for horses to the near exclusion of other prey items where mule deer, bighorn sheep, and domestic animals are present. There is also some evidence that the magnitude of predation on horses by mountain lions may be related to the density of free-ranging horses, greater predation on horses occurring where densities of horses are higher (Andreasen, 2012).

The potential for mountain lions to affect the sizes of populations of free-ranging horses in North America is limited by the fact that most HMAs are in areas that have few mountain lions. The ranges of mountain lions tend to be concentrated in forested areas and at higher elevations (Kertson et al., 2011) and in areas that have mountainous or otherwise broken topography with limited viewsheds. In contrast, many horse populations favor habitats that have more extensive viewsheds. Mountain lions are ambush predators and require habitats that provide opportunities for stalking or finding prey without being seen. Other predators, such as wolves are more cursorial—capable of pursuing prey across open habitats.

That a large predator, when abundant, can substantially influence the dynamics of free-ranging horses is not surprising inasmuch as black bears (Zager and Beecham, 2006), mountain

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lions (Wehausen, 1996), and other predators (Ballard et al., 2001; Boertje et al., 2010) have exerted strong influences on ungulate populations. However, the influence of predation on horses in the western United States is considerably limited by a lack of habitat overlap both with mountain lions and with wolves. Another constraint is that among free-ranging horse populations, foals are the usual prey, and predation on adults has rarely been documented until the recent studies in Nevada. Population size is not affected as much by foal survival as it is by adult survival (Eberhardt et al., 1982), and foal survival is strongly affected by other variables (such as weather).

CONSEQUENCES AND INDICATORS OF SELF-LIMITATION

If a population of herbivores were to self-limit, effects on the ecosystem would be expected. This section reviews the theory, expectations, and case-study examples of free-ranging horses in self-limiting circumstances.

Theory

Riney (1964) and Caughley (1970, 1976) proposed that, on introduction of a large herbivore into an ecosystem not previously occupied, there would be an initial irruption of the population that would lead to a decline in vegetation conditions, which would in turn lead to a decline in the herbivore population and allow partial vegetation recovery (Figure 3-4). The herbivore-vegetation system would then reach a new equilibrium between plant productivity and herbivore population density in which vegetation productivity and cover may be less than that in a system that does not have herbivores or in a system that is managed for maximal herbivore productivity. The resulting plant-herbivore system may be less productive, have less standing herbaceous biomass, and have a different plant species composition, but it may nevertheless be functional and sustainable. That conceptual model assumes that the vegetation-soil system has the capacity to persist in some form through and beyond the initial period after an introduction, in which it has been heavily used and reduced in function. It also assumes that surviving vegetation components would be adapted to withstand recurrent herbivory and would increase in relative abundance to form a plant community that is more adapted to withstand herbivory. As noted in Chapter 7, under some conditions, productivity of herbivory-adapted plant species may not be reduced by herbivory.

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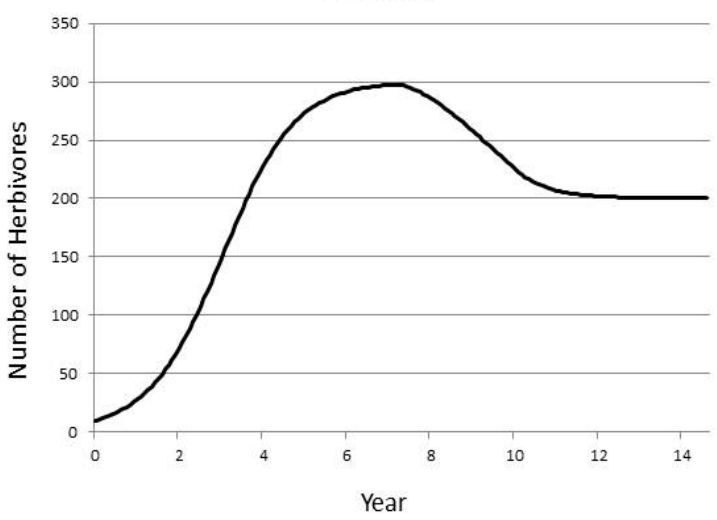


FIGURE 3-4 Large-herbivore population trajectory after an introduction. Herbivory causes a decline in plant production and thus in K. Here, K in the underlying logistic model declines linearly from 300 to 200 individuals from year 7 to year 10, and this results in a decline in herbivore population size.

General Expectations

There is no doubt that large herbivores have numerous effects on their environments that result from grazing, browsing, trampling, and behavioral and competitive interactions with other species (see Chapter 7). When the population is food-limited and population growth rate decreases to zero, the forage resource base will most likely be heavily grazed. Horses and burros have the ability to graze plants down to the ground. They can kill plants through uprooting and trampling, create areas of low vegetation cover, and change plant species composition to favor less desirable or exotic species. At some point, reduced vegetation cover can lead to accelerated soil erosion and decreased vegetation productivity and rangeland health (NRC, 1994; Pellant et al., 2005). If resulting feedbacks to equid population growth are ineffective or if they have been disrupted by human activities, rangeland ecosystems can be pushed across thresholds into degraded states from which recovery is difficult or impossible (see Chapter 7).

Grazing pressures can be expected to be spatially heterogeneous. In expansive habitats, it is simplistic to think of a mean grazing pressure uniformly distributed across the landscape; a variety of factors affect animal distributions beside forage. It is more realistic to expect that some areas will be heavily, perhaps "excessively," grazed while other areas are little used and may serve as refugia for plant species that are more sensitive to grazing by large herbivores. The heavily used, disturbed areas are, however, also refugia for disturbance-adapted plant species. One example is the existence of increased levels of disturbance near water sources. Such areas have sometimes been referred to as sacrifice areas because they are an inevitable outcome of the presence of large herbivores, their requirements for water, and the fact that water is distributed at point locations.

It can be expected—on the basis of logic, experience, and modeling studies cited above—that because horses or burros left to "self-limit" will be food-limited, they will also have poorer body condition on the average. If animals are in poorer condition, mortality will be greater,

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particularly in times of food shortage resulting from drought or severe winter weather. Indeed, when population growth rate is zero, mortality must balance natality. Whether that is acceptable to managers or the public is beyond the purview of the committee, but it is a biological reality.

It is difficult to generalize about whether these are natural and expected outcomes in unmanaged large-herbivore or, more specifically, free-ranging equid ecosystems. On the basis of evidence presented above, many large-herbivore populations are regulated through food limitation as a natural process. The evidence reviewed above also indicates that predation is a factor in some large-herbivore populations and some equid populations. Most horse and burro populations in North America appear to be little affected by predation because predators are absent or present at low densities, possibly because they have been extirpated or simply because habitats are not suitable for them. The degree of naturalness is also affected by other human activities, such as restrictions on dispersal and other movements, the presence of livestock, and water development.

Case Studies

The only way to know the consequences of self-limitation for the vegetation, horses and burros, and the ecosystem is to observe the consequences where self-limitation has been allowed to occur. As pointed out above, there are few cases in which free-ranging horse populations have not been managed and have been left to self-regulate and in which simultaneous scientific studies of the vegetation and of the equids have been carried out. But there are probably many cases in North America in which equid populations have gone unmanaged, or have been minimally managed, for a number of years. In some cases, the equids have been studied but their effects on habitats have not (e.g., Berger, 1986). In other cases, the equids and their effects on landscapes have not been studied. Some unmanaged populations on tribal lands have received little or no scientific study.[3]

The responses of equids to a situation of self-limitation have been discussed above with regard to density dependence. As noted, density dependence results from food limitation, a decline in animal nutritional condition, and consequent decreased recruitment and survival rates. Many examples of equid ecosystems around the world were given. Chapter 7 reviews the numerous effects that horses have on their habitats and on other species and examines the concepts of thriving natural ecological balance and AMLs. Horses will have some effects on their habitats at the point of food limitation, and these could be pronounced. On the basis of studies of systems that have high densities of horses, although not necessarily at the point of food limitation, reasonably well-informed hypotheses can be developed about the expected state of vegetation and other species when the equid population reaches the point of self-limitation. However, whether such a system can be self-sustaining (or perhaps even “thriving”) over the long term cannot be known without experimentation.

New Zealand

Free-ranging horses in New Zealand are derived from animals introduced from various sources in the 19th and 20th centuries (Rogers, 1991). They once ranged over much of the central North Island but have diminished since the 1950s. The only remaining population survives in the Kaimanawa Mountains because of restricted public access on military lands. The

[3]For example, Yakama Nation in Washington, available online: http://www.ynwildlife.org/.

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Kaimanawa unmanaged population was continuing to increase and had not reached food limitation as of 1990 (Rogers, 1991). However, in the southern portion of the area, horses were expanding their ranges in response to increased density. The most important habitats for horses included wide basins with areas of volcanic ash supporting tall red tussock and short hard tussock grasslands. Grazing by domestic sheep, cattle, and horses and burning since the 1890s converted tall red tussock to short tussock grasslands.

A 20-m x 20-m grazing exclosure in degraded short tussock grassland resulted in changed plant species composition. The dominant intertussock grass species increased while 12 low-stature species and total species diversity decreased as the hard tussock species increased in stature and shaded them. Adventive (introduced) species also expanded. It is notable that the tall red tussock grass decreased. The exclosure also showed that grazing was not reducing the recruitment of hard tussock. Thus, cessation of horse grazing did not restore the original red tussock species, so the vegetation might have been converted to an "alternate stable state" as explained in the section "Understanding Ecosystem Dynamics" in Chapter 7. Furthermore, cessation of grazing resulted in adverse changes in species composition toward the adventive species, and this indicates that a moderate level of grazing would maintain the more desirable hard tussock grassland physiognomy (appearance) and species composition.

Vegetation responses to horses varied from north to south. In the north, where horse numbers were low, in the most prevalent habitats, red tussock appeared to be slowly recovering from the degradation resulting from early European livestock. In some habitats in the north, particularly mesic sites, horse grazing continued to have substantial adverse effects on biodiversity. In contrast, in the south, the landscape was more resilient to horse grazing because of the changes in species composition that had resulted from prior European livestock grazing. Thus, it might be concluded that exposure to grazing in the south had changed the plant community to one that is more resilient, and thus adapted, to further grazing by free-ranging horses. Moreover, the persistence of the hard tussock physiognomy (appearance) depends on continued moderate grazing.

Balancing free-ranging horses with the conservation of biodiversity across the landscape depends on the recognition of spatial heterogeneity between the north and south. In the south, Rogers (1991) concluded that horse preserves could be recognized where their numbers could be manipulated for the benefit of the horses and indigenous landscapes. In the north, however, he concluded that horse grazing compromises nature conservation values, so their numbers may have to be controlled.

It should be noted that no mammalian herbivores were present in New Zealand before the introduction of domesticated livestock by European settlers. Consequently, the responses of vegetation in New Zealand to introduced mammalian herbivores could differ from responses of vegetation that has coevolved with mammalian herbivores.

Central Australia

Berman (1991) studied populations of feral horses in central Australia. Aerial surveys in 1981 and 1984 indicated that there were about 206,000 animals. Populations may have quadrupled during a period of good rains in the 1970s, but drier conditions, decreased rangeland availability, and management more recently have reduced the population by 70-80 percent. That suggests that horse populations increased and then decreased in response to forage availability; horses might have been above food-limited carrying capacity in dry conditions. Berman observed that variations in vegetation, wildlife, and soil erosion corresponded with changes in

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grazing intensity. High densities were associated with denudation, low densities of kangaroos, water holes with horse carcasses, and increased gully erosion. Horse and cattle dung density and gully erosion decreased with distance from water while plant cover and kangaroo dung increased with distance from water. Feral horses were able to affect almost all rangeland areas in central Australia because they are able to walk up to 50 km from water and traverse hills, which are barriers to cattle. Berman noted that many examples of soil erosion exist in parts of central Australia; although these have often been attributed to overgrazing by horses and cattle, it is difficult to prove that horses and cattle cause a substantial amount of erosion because erosion also takes place without them in these environments. Horse and cattle diets and habitats overlap, so it was not possible to differentiate vegetation and soil responses that were due to horses rather than cattle.

Argentina

In the Pampean grasslands of Ernesto Tornquist Provincial Park, Argentina, an unmanaged population of horses increased according to a logistic curve and was beginning to show signs of density dependence, as noted above (Scorolli and Lopez Cazorla, 2010). Although density had no effects on survival, it affected fecundity. The authors hypothesized that fecundity was reduced at higher densities because of reduced pregnancy in mares that had low body condition. De Villalobos and Zalba (2010) and de Villalobos et al. (2011) reported that the horses reduced herbaceous cover and facilitated establishment of an invasive pine species. They suggested that grazing had caused reduced plant diversity and species evenness and altered the composition of communities. Other native and exotic ungulate species had declined as a result of competition with the horses.

Shackleford Banks

Shackleford Banks, a barrier island off the coast of North Carolina, supports a population of free-ranging horses that has experienced increases and decreases in population numbers in response to changes in carrying capacity resulting from management practices. Before the National Park Service (NPS) acquired the island and incorporated it into the Cape Lookout National Seashore, free-ranging horses shared the island with domestic livestock, including cattle, sheep, and goats (Rubenstein, 1981). After NPS removed all domestic stock from the island in the late 1980s, free-ranging horse numbers more than doubled from a competitively determined, food-limited carrying capacity of 104 animals to a new level, without competition from livestock, slightly over 220. That provided an opportunity to witness changes in behavior and vital rates when density-dependent effects were removed and reappeared as the population expanded. At first, body-condition scores increased from 3.5 to over 4 (on a 1-5 scale, with a score of 1 representing a horse in poor condition) as food previously consumed by livestock was now being eaten by horses. Fecundity also increased slightly, the interbirth interval declined from about 3 years to slightly more than 2 years and mortality in adult and juvenile males and females dropped 15 percent (Rubenstein and Dobson, 1996). However, as the population reached the new carrying capacity, those patterns reversed, and vital rates returned to their previous equilibrium levels.

Observable declines in body condition and increases in mortality, especially after hurricanes and winter storms, prompted the development of a plan for population control (Rubenstein and Dobson, 1996). As the population climbed to its new peak of 225 animals, rates of aggression increased among males and normally peaceful females, the variety of social

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systems changed as territorial harems gave way to harems that had large overlapping ranges, and many harems became populated by more than one male. Although those changes helped to mediate some of the consequences of crowding while the population was in transition, in the end a new carrying capacity was reached and was accompanied by changes in behavior and vital rates. One of the biggest changes was a reduction in the stability of the harem. Pressure from increasing numbers of bachelor and harem males lowered female feeding rates, increased the percentage of females that changed groups each year from just under 11 percent to just over 25 percent, and increased the skew in reproductive success (a nonequitable distribution of reproduction among individuals) of males and females. Once NPS started managing the population to cycle around 125, average body condition and vital rates improved and the reproductive skew of both sexes was reduced, and this improved the genetic health of the population (Rubenstein and Nuñez, 2009).

Horses on Shackleford Banks decreased the abundance of *Spartina* grasses (Wood et al., 1987; Hay and Wells, 1991). Grazed habitats had less vegetation, a higher diversity of foraging birds, higher densities of crabs, and lower species richness of fishes (Levin et al., 2002). Horses altered habitats indirectly in many ways.

Oostervaardersplassen, the Netherlands

In the Oostvaardersplassen Reserve in the Netherlands, Heck cattle, red deer, and Konik horses have been left unmanaged since the 1980s and have reached high densities (Vulink, 2001). It is a relatively moist ecosystem, having been reclaimed from the sea and having high annual precipitation. The management objective is to allow natural processes to operate to the greatest extent possible although the reserve is fenced. The management is informed by an appreciation of the natural, expected, and even desirable effects of large herbivores on other components of the ecosystem and the possibility of natural regulation through density dependence. Herbivores were originally introduced to keep the vegetation in a more open state because there was considerable woody encroachment. The herbivore species are close analogues of the native herbivores that would have been present hundreds of years ago. Large predators are absent. The Konik horses have shown a higher intrinsic rate of population increase than Heck cattle (Vulink, 2001) and have outnumbered the cattle, which apparently are regulated by food shortage in winter. If current trends continue, the horses and red deer will probably outcompete the cattle and displace them (ICMO2, 2010).

Because the reserve is small and most of it is easily visible to the public, animals that die of starvation or old age can be seen, and this leads to dilemmas with respect to the ethical treatment of animals (ICMO, 2006; ICMO2, 2010). Large dieoffs during severe winters are periodic. On ethical grounds, animals that are suffering and dying are culled (shot) to prevent further suffering. That is also justified as a replacement for predators and as a moral responsibility of humans because of the creation of artificial barriers to movements out of the reserve (fences).

The following responses have been observed

- The number of animals culled in response to weather conditions is highly variable.
- The number of animals culled has increased over the last decade because populations have reached ecological (food-limited) carrying capacity.
- The average body condition of animals has declined over the last decade.

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- Mortality has increased with annual variability in mortality. Mortality is expected to balance recruitment in the near future.
- Plant productivity and the number of animals that the area can support will possibly decline somewhat because of depletion of soil nutrients.
- Grazing promotes short swards and prevents woody regeneration.
- Grazing increases plant diversity on the small scale but not the large scale. (ICMO2, 2010)

Pryor Mountain Wild Horse Range

A population of horses descended from Andalusian Spanish mustangs has inhabited the Pryor Mountains possibly since the 1700s (BLM, 1984). The earliest record of their presence is a photograph of a roundup of 101 horses in 1910. Although the horses have inhabited the Pryor Mountains since then, they were never counted until 1970. Horse traps were built by ranchers in the 1930s and 1940s, but the numbers removed were never recorded. When BLM announced plans to remove the horses in 1964, they appeared to be in good shape despite the condition of the range. Local ranchers commented that the range was not overgrazed, that horse birth rates were low, and that the horses were in no worse condition than they were 50 years before (Ryden, 1990). Notably, considerable numbers of domestic livestock were permitted to use the range from 1907 to 1930. Half as many livestock units were permitted after 1930. In 1970, when a census of the horses occurred, there were 270 horses (Feist and McCullough, 1975). Horse reductions began with roundups in 1971 and 1973 and reduced the herd to 120-130. The horses have since been managed through removals to about 85-120. Most recently, the U.S. Department of Agriculture's Natural Resources Conservation Service carried out an assessment (Ricketts et al., 2004), which recommended an AML of 45-142 and noted the following

- Over the last half-century, the conditions of the horse range were described as very poor to fair in a number of BLM assessments.
- The condition of the range is getting worse on the basis of low proportions of preferred plant species and evidence of soil erosion.
- In 2004, the health of the rangeland at six sites was rated at 2.0-3.75 (average, 2.75) on a scale of 0-5. A score of 4 or more is considered healthy relative to the historical potential climax vegetation. A score of 2.5 or less is considered unhealthy and to have a strong possibility of nonrecovery in the absence of external energy inputs (such as mechanical seeding). (Ricketts et al., 2004)

Apparently, although horses have been managed since 1973 at much lower numbers than were present initially and despite reductions in livestock numbers in the 1930s, unhealthy range conditions have persisted. However, Singer et al. (2000) noted that former managers who visited the range in 1997 remarked on an overall improvement in plant condition.

In an ecosystem modeling assessment (see Chapter 7) of the Pryor Mountain Wild Horse Range, it was possible to examine vegetation and animal responses to various horse densities, including the number present in 1970 (Coughenour, 1999, 2000, 2002). It was also possible to determine food-limited carrying capacity by letting the model run with no horse removals until it came into quasiequilibrium with vegetation productivity. With horse numbers held constant at 270, the model simulated markedly reduced herbaceous biomass compared with what happened with no horses. Forb biomass proportion increased while grass proportion decreased. Root

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biomass was also decreased. In the simulation in which horse populations were allowed to grow freely, plant responses were not much different from those with the number fixed at 270.

Grazing was predicted to be heterogeneously distributed. When 1971-1996 observed horse numbers (87-250 horses; mean, 157) were used, 40-70 percent of the landscape was predicted to be lightly grazed, 5-20 percent grazed less than 80 percent, and 5-15 percent grazed to 50- to 80-percent offtake. The model predicted that with historical horse densities, some parts of the landscape would experience substantial decreases in herbaceous biomass. With no culling, the fraction of the landscape that would be heavily grazed would increase markedly. The model simulated that horse numbers would initially increase to over 300, level off, plunge dramatically in response to a drought, and then gradually increase and level off at a mean of 270, the food-limited carrying capacity. In both the fixed number and the freely varying simulations, horse body condition declined to low levels, particularly in dry years or years with severe winters. In separate simulations comparing horse body conditions with no culling versus actual densities in 1970-1995, horse body condition was markedly lower with no culling. At food-limited carrying capacity, plant cover would be lower than what exists on the range, and the fraction of the landscape receiving extremely heavy use would increase (see Chapter 7). In the heavily used areas, herbaceous cover would be reduced to less than 20 percent of potential, and soil erosion rates in those areas would probably also be higher. Horses would be in poorer body condition, and horse mortality would be higher.

MANAGEMENT FACTORS

Management itself alters horse and burro population growth rates through a variety of mechanisms aside from the simple direct effects of removals or reduced fertility due to contraception. The indirect effects of management are considerable. One likely response is compensatory population growth as a result of reductions in numbers. Horse and burro populations are seldom limited by density because they are kept below food-limited carrying capacity through removals and to some extent through treatment with the contraceptive porcine zona pellucida (PZP; discussed in Chapter 4). Indeed, AMLs are usually set in such a way that considerable forage material is uneaten; this is the very purpose of the allowable use level (see Chapter 7). That leaves horses and burros in a position for compensatory population growth because they are below food-limited carrying capacity. If there were no intervention, herds would reach food-limited carrying capacity, body condition would decline, natality and survival rates would decline, and more animals would die of starvation. Removals are likely to keep the population at a size that maximizes population growth rate (see Figure 3-2B), which in turn maximizes the number of animals that must be removed and processed through holding facilities. Management may also alter population growth by affecting dispersal, particularly through fencing but also by permitting conflicting land uses that alter habitats for horses and burros. Impaired dispersal would decrease population growth because of increased competition for forage. Water provision, in contrast, could increase population growth rate by increasing the area of habitat that has water and thus total available forage. Horses in arid Australia were reported to range as far as 50 km from water (Berman, 1991), but maximum distances would probably be considerably less in rugged topography or where there are other impediments to movement.

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Compensatory Reproduction

Compensatory reproduction in response to gathers is likely in any population that exhibits density dependence. To the extent that a population is being regulated by food supply, decreased density will provide more forage per individual, increasing body condition, reproduction, and survival and thus population growth rate. Choquenot (1991), in a study of feral donkeys in Australia, reported that population growth was regulated by food-related juvenile mortality. Dawson and Hone (2012) advised that compensatory responses in survival, fecundity, and age at first reproduction in the population should be considered in any management program. In particular, they were referring to the fact that their data showed that survival and fecundity were increased and age at first reproduction decreased at lower densities, so it is likely that reductions in density due to culling will have the same effect.

The response of population growth rate to increased density must be known in order to predict the degree of compensatory growth that can be expected at a given population density. If the population size is above the theoretical inflection point of the logistic growth trajectory (point α in Figure 3-2A), reductions will increase the annual population growth increment. However, if the population size is below the theoretical inflection point, reductions will decrease the annual growth increment. Various models of density dependence, as discussed above, could be used to predict the degree of compensatory growth resulting from animal removals in relation to the population size and the rate of removal.

Gathering has also been shown to have varied indirect effects on reproductive success. In Idaho and Wyoming, foaling success rates were higher among gathered horses than among horses that were not gathered (Hansen and Mosley, 2000). Foaling success rates in Idaho were 29 percent, 31 percent, and 43 percent for mares not gathered, mares gathered and adopted, and mares gathered but released, respectively. In Wyoming, foaling success rates were 29 percent, 42 percent, and 48 percent in those groups. There were no statistically significant differences among groups, however, most likely because samples were small in relation to high variance. Effects of gathers on body condition, lactation status, and pregnancy were not reported. It is important to note that such results, if real, would most likely be attributable to forage limitation and lower body condition among ungathered than among gathered mares. In contrast, in another study, foaling was lower among gathered horses. Pregnant mares that were gathered and removed had substantially lower reproductive success than ungathered mares at one site, and gathered and released mares had less reproductive success than ungathered mares at a second site (Ashley and Holcombe, 2001). The authors speculated that that was a result of loss of fetuses due to the stress of being gathered and handled for a long period. Animals that were removed were transported 246 km to a holding facility, where they were held for 21 days before adoption. A number of miscarriages were observed at the holding facility.

Kirkpatrick and Turner (1991) compared a population managed with annual foal removals on Chincoteague Island, Virginia, with an unmanaged population on Assateague Island, Maryland. Management-level applications of PZP did not begin on Assateague Island until 1994, after the 1989 study (Turner and Kirkpatrick, 2002.) They hypothesized that there would be greater fetal losses in the unmanaged population because of the concurrent physiological stresses of lactation and pregnancy (weaning rarely occurs before 1 year and it commonly occurs at 2 years). They estimated pregnancy and foaling rates of 40 free-ranging mares on Assateague Island and 48 managed mares on Chincoteague Island and found a higher foaling rate in the Chincoteague population because a greater percentage of mares foaled annually (80 percent). The hypothesis of greater fetal loss was not supported: there was no

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difference between the two populations. However, pregnancy and foaling rates in the Chincoteague population were nearly double those in the Assateague population. The authors suggested that the greater pregnancy and foaling rates were due to cessation of lactational anestrus and that the cessation of lactation in mares that had their foals removed resulted in these animals going back into estrus. However, the authors provided no evidence that lactating mares were not cycling. Another possible cause of increased pregnancy and foaling in the managed population is reduced energetic demands due to cessation of lactation. In contrast, Wolfe et al. (1989) used plasma progesterone measurement to examine pregnancy rates in 553 free-ranging mares. They found no difference in pregnancy rate between lactating and nonlactating mares. Kirkpatrick and Turner (1991) suggested that the reason that no difference was found was that the method for detecting pregnancy—measurement of plasma progesterone—can be inaccurate. Although the method is widely used for detecting pregnancy in other species, it is not reliable for equids. It is also known that although lactational anestrus does occur, it is very uncommon, and most mares resume cycling 5-9 days after foaling. In summary, it is possible that population management via foal removals may result in increased fecundity, but evidence of a lactational anestrus mechanism is lacking. It is also possible that pregnancy and foaling rates are reduced in lactating mares because of the lower body condition that results from the energetic demands of lactation. Because horse populations on BLM lands are not managed through foal removals, this form of compensatory reproduction probably has little relevance.

The effects of PZP on population growth, longevity, and body condition were studied over a 10-year period on Assateague Island (Turner and Kirkpatrick, 2002). PZP clearly reduced foaling rates among contracepted animals. However, mortality in mares and foals decreased, and two older age classes appeared (21-25 years and over 25 years), which indicated an increase in longevity. Body-condition scores of nonlactating mares increased substantially but those of lactating mares did not change. The cause of the decrease in foal mortality was unclear, but it could have been due to increased body condition of the mares. Body condition of untreated mares, or of treated mares in which the treatment has lost effectiveness, could increase because of reduced competition for forage. In treated mares, contraception reduces the energetic costs of reproduction, and this also results in increased body condition and longer lifespan (Gray and Cameron, 2010). Nuñez et al. (2010) also found that treated mares had better body condition than untreated mares; this could result in an extended breeding season and increased chance of conception in animals that have low PZP antibody levels. Thus, the favorable effects of increases in body condition, longevity, foal survival, and length of breeding season on population growth rate could offset to some extent the adverse effects of contraception on reproduction and population growth rate. That might be termed compensatory population growth; however, it is unlikely that the degree of compensation would be sufficient to overcome the degree to which contraception reduces reproduction and population growth.

Effects Related to Ability of Animals to Disperse

Ecologically adaptive movement patterns are still exhibited by many extant horse populations. Free-ranging horses in Nevada move from low to high altitudes in spring or early summer after the wave of vegetation green-up, and they move to low elevations in fall (Berger, 1986). However, changes in land ownership and allocations of lands for livestock use may interfere with traditional movement patterns and may preclude the re-establishment of natural movements, ones that presumably exist in truly wild and free-ranging equid populations.

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The importance of movement for coping with drought is illustrated by observations in Namibia (Gasaway et al., 1996). Ungulates, including zebra, maintained near average mortality during severe drought because they could move over large areas and find food reserves in areas not regularly grazed. Low ungulate densities and clumped distributions were responsible for the existence of infrequently used areas that served as drought reserves. Such dry-season food reserves were also important in keeping mortality low in Kruger National Park during a drought in 1982-1983 (Walker et al., 1987). In contrast, populations in two other reserves, which were near their food-limited carrying capacity before the drought, lacked such lightly grazed food reserves and suffered high mortality (Walker et al., 1987, as noted by Gasaway et al., 1996).

An important question is the extent to which horse (and cattle) grazing can be managed to compensate for losses in natural movement patterns, which presumably were important determinants of the grazing regimes experienced by plant species that evolved during or before the Pleistocene in the presence of large herbivores. The mix of private, tribal, and public ownership often fragments landscapes that might have been more natural, expansive grazing areas. Differences between agency policies may exacerbate the fragmentation. Fencing can interfere with movement to other areas when forage is depleted and cause heavier intensities and frequencies of herbivory than would occur otherwise.

Confinement or restrictions on migration or dispersal movements will probably result in a plant-herbivore system that has different dynamics from one that does not have such constraints. In general, the smaller the area that a population is limited to, the greater the potential for a self-regulating system with undesirable qualities, such as population crashes and population oscillations. Spatial constraints can lead to reductions in vegetation cover to lower levels than would be seen otherwise, followed perhaps by vegetation recovery after horse populations decline in response to food shortages. However, there is also an increased likelihood of irreversible shifts in vegetation communities, in accordance with recent theory and observations of alternate stable states, to communities dominated by invasive plant species, by shrubs, or by bare ground with little or no seed bank to support recovery (see the section “Understanding Ecosystem Dynamics” in Chapter 7).

In contrast, such generalizations as “confinement will result in range degradation” are also unwarranted. The degree of confinement, the areas that are inaccessible, the availability and dispersion of water, climate, and vegetation productive potential can all modify the response. Confinement may have little or no consequences or great consequences, depending on those factors.

Additional challenges arise from migration and dispersal across HMA boundaries. A designated HMA may constitute the core range of a herd or population, but dispersal movements outside the HMA are possible. Dispersing animals may move onto areas that are subject to conflicting land uses or management objectives. Conversely, movements of animals into an HMA from surrounding areas that are under different management jurisdictions can work at cross purposes to the management objectives of an HMA. Where such cross-jurisdictional movements occur, it is necessary to establish co-operative relationships among adjacent land owners.

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CONCLUSIONS

Large herbivore populations are influenced by density dependence, density-independent factors, and predation. Most large herbivore populations show some degree of density-dependent limitation, particularly when predation is low. Likewise, many wild equid populations exhibit density dependence. Density dependence has operated in some free-ranging horse and burro populations in the western United States and elsewhere. The primary way that populations self-regulate or self-limit is through increased competition for forage at higher densities, which results in smaller quantities of forage per animal, poorer body condition, and decreased natality and survival rates. Behavioral mechanisms can also contribute to density dependence, particularly increased dispersal, and increased agonistic interactions and decreased band stability may interfere with foraging and reproductive success.

Clearly, it is possible to incorporate density dependence into models as a population process. Although it has been omitted from some models because populations were believed to be held below food-limited carrying capacity by management or other factors, it was found necessary to include in others when it was an important component of population dynamics, particularly in wild, unmanaged populations of equids. There are basically two approaches to modeling density dependence. One is through the inclusion of a direct effect of density, often in relation to an assumed or derived food-limited carrying capacity (K), which must be empirically determined for the system in question. Although total forage biomass may be estimated through vegetation sampling (see Chapter 7), there is still a need to demonstrate how population variables respond to diminished forage biomass; thus, there is a need for empirical studies. The other approach is through mechanistic modeling of competition for limited forage at higher densities and its effects on survival and reproduction. The first approach is more site-specific, but in either case, there is a need to assign values to parameters based on data from case studies of populations that are allowed to reach levels at which density dependence takes effect. However, there are few such case studies. The committee suggests that existing situations of self-limited populations be studied or that an experiment be conducted to enhance understanding of such systems.

Density-independent variation is also an important consideration. Most equids under BLM purview inhabit arid and semiarid environments characterized by high variability in annual precipitation and thus forage. In some environments, variable snow cover is also an issue. When climatic variation is high, plant-herbivore systems become increasingly disequilibrial. In such environments, density dependence may be relatively weak, and population dynamics may be driven largely by density independence, with resulting large variability in survival and recruitment. Populations may also be driven below any theoretical food-limited carrying capacity that is based on mean forage biomass.

Predation can be important in controlling the sizes of some populations of wild equids, but the degree of control is highly variable. In intact equid ecosystems in Africa, zebra populations are probably limited to some extent by predators, but climatically influenced variations are strong in comparison, so it is difficult to establish the effect of predation quantitatively. In some North American free-ranging horse populations, there clearly is predation by mountain lions. However, the degree of limitation has not been established. More problematic is the fact that mountain lion ranges are not widespread throughout the principal habitats of the horses under BLM purview. The limitation of the range is not necessarily due to human hunting or extirpation, inasmuch as these habitats may simply be poor habitats for mountain lions.

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Mountain lions are ambush predators, requiring habitats with broken topography and tree cover, whereas horses tend to use areas that have extensive viewsheds. Wolves are cursorial and capable of chasing prey across open, flat topography. They have a great impact on a few populations on other continents and certain areas in Canada, but their distribution in the western United States has been severely reduced by humans, and very few, if any, free-ranging horse habitats are occupied by wolves.

Several case studies have demonstrated the potential outcomes of a self-limited equid population. Equids invariably have some effect on vegetation abundance and composition (see Chapter 7). Vegetation cover is usually reduced, and often there are shifts in species composition. There is limited evidence that erosion rates are increased. However, none of the case studies included scientific experimentation that showed that the changed vegetation cannot persist over a long period of time or that complete loss of vegetation cover is inevitable. Case studies have also reported increased competition with other wildlife species and adverse effects on habitats of some species. In some cases, vegetation changes were probably due in part to historical livestock grazing. In other cases, horse population reductions were not shown to reverse vegetation changes.

The results of the case studies are consistent with theoretical predictions that when a herbivore population is introduced, vegetation cover will initially change and productivity will often be reduced by herbivory. In some environments, however, moderate levels of herbivory have little effect or even beneficial effects on plant production (see Chapter 7). Vegetation production may decline, but it may stabilize at a lower level as herbivore populations come into quasiequilibrium with the altered vegetation cover. The reduction in plant cover may be great enough to cause accelerated soil erosion, an important indicator of reduced rangeland health. If erosion reduces soil-water holding capacity and soil fertility, the productive capacity of the vegetation and of the forage base will decline and the resulting feedback effects on equid population growth might reduce grazing pressure and further erosion. Whether unmanaged, quasiequilibrial soil-plant-equid ecosystems can persist over a long term on rangelands administered by BLM is unknown, but there are pertinent examples of unmanaged equids in Africa that have persisted for millennia, in some cases despite weak or no evidence of predator limitation. Feedbacks from the plant-soil system to equid population growth must have enough functionality for long-term ecosystem persistence. Such feedbacks may be disrupted by various human activities. Thus, there is a need to be able to predict equid population responses to decreased forage productivity concurrently with vegetation productivity declines in response to erosion in landscape ecosystems that are affected by human activities, such as habitat fragmentation.

The literature clearly demonstrates that density dependence due to food limitation will reduce population growth rates in equids and other large herbivores through reduced fecundity and survival. The total annual population increment will decline at higher densities (Figure 3-2A). Some of the reduction in annual population increment at high densities will probably be due to reduced fertility, and much of the reduction can also be expected to be due to increased mortality. The literature and the case studies show that although density dependence can regulate population sizes, responses will probably include increased numbers of animals in poor body condition and high numbers of animals dying from starvation. Those may be unacceptable outcomes for some stakeholders, particularly those who perceive that they result from human interference with natural processes of dispersal, access to key forage resources, or predation. If so, it could be argued that humans are potentially responsible for the starvation and mortality.

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The committee was charged with addressing the question of compensatory reproduction in response to population controls. As discussed above, it is quite likely that there would be compensatory increases in recruitment and decreases in mortality in response to lower animal numbers, whether because of removals or contraception, because of decreased competition for forage, and or because of improved body condition. Mares in better body condition can be expected to have higher fertility rates, and foal survival can also be higher. An increased foaling rate has been observed in one population that was managed through foal removals, but the likelihood of observing that response generally is questionable, and, because horse populations on BLM lands are not managed by foal removals, this possibility is irrelevant in any event. Finally, there is no evidence that contraception stimulates reproduction through physiological mechanisms. On the contrary, the purpose of contraception is to decrease fertility.

A managerially important finding was that free-ranging horse populations are often limited by removals to levels below food-limited carrying capacity, so population growth rate could be increased by the removals through compensatory population growth related to decreased competition for forage. Thus, the number of animals that must be processed through holding facilities is probably increased by management.

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Methods and Effects of Fertility Management

This chapter reviews and assesses current options for controlling fertility of free-ranging horses and burros. Investigation of potential fertility-control options was one of the mandates of the previous National Research Council studies. In the late 1970s and early 1980s, the Committee on Wild and Free-Roaming Horses and Burros reviewed the status of contraception, including sterilization, for population control in free-ranging herds. That committee reported on the feasibility of several techniques, including hormone injections for stallions and hormone treatments, intrauterine devices (IUDs), and surgery for mares. It concluded that endocrine contraception in stallions or mares was the most promising approach because IUDs often dislodged and surgery was impractical in field conditions (NRC, 1980). The 1980 report noted that studies of endocrine contraception in stallions were going on at the time and recommended a study of contraception in mares. In 1991, the Committee on Wild Horse and Burro Research reviewed the proposal for and later the results of a study that examined steroid implants in mares captured from the range and held in pens, steroid implants in free-ranging mares, and vasectomies of free-ranging dominant stallions. That committee found some steroid treatments to be effective in mares. Vasectomies were effective in sterilizing individual animals, but the committee questioned the technique's effectiveness at a population level, given that only dominant stallions were treated (NRC, 1991).

Research on effective methods of fertility control remains important to the Bureau of Land Management (BLM) because fertility control is the major alternative to gathering and removing horses that is generally accepted by the public. In the 20 years since the last National Research Council report was completed, considerable progress has been made in developing and testing fertility control for wild animal populations, both free-ranging and captive. Research with captive animals has been especially valuable in allowing more extensive and careful monitoring and analysis of efficacy and safety of a wide array of products. In particular, pathological conditions associated with some types of contraceptive treatment have been detected and are under systematic investigation, which is difficult to accomplish in free-ranging populations.

Although the committee's report includes information on burros as well as horses, the need for fertility control in horses is considered more pressing because their populations are much larger (BLM, 2003, revised 2005). In addition, many more studies have focused on horses,

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so considerably more data are available on them than on burros. Nevertheless, given similarities in reproductive physiology, the efficacy and safety of methods could be expected to be generally similar in the two species. Their social structures differ, however, as described in the following sections, and this could influence the effects of fertility-control methods on behavior and social organization.

Reversible contraception and permanent sterilization are achieved by interrupting reproductive processes, and the committee's evaluation of these methods is based in part on understanding their effects on an animal's reproductive physiology and behavior. Accordingly, this chapter starts with two reviews: one on equine social and mating behavior, social relationships, and social structure and a second on reproductive physiology in domestic horses and donkeys, with information on free-ranging horses and burros when available. The brief reviews are intended to serve as background for understanding the potential effects of fertility-control methods on behavior and reproductive processes. The chapter then evaluates available fertility-control treatments for both females and males and summarizes the advantages and disadvantages of the most promising methods.

EQUINE SOCIAL BEHAVIOR AND SOCIAL STRUCTURE

Horses, zebras, and asses (the primogenitors of donkeys and burros) are highly social animals, but their social structures vary. Klingel (1975) was the first to document that equids exhibit two types of social organization. In one, typified by horses and plains and mountain zebras, females and their young live in closed membership groups with one, and occasionally a second, male. In those so-called harem groups, females benefit by receiving material rewards from their males (Rubenstein, 1986). Enhanced male vigilance against potential intruder males not only reduces a male's chances of being cuckolded but reduces harassment experienced by females. Consequently, females can devote more time to feeding and increase the likelihood that their offspring will survive to independence (Rubenstein, 1986). That type of society emerges under more mesic environmental conditions in which food is relatively abundant and distributed near predictable watering points.

In more arid areas, where abundant food is far from water, the second type of society appears, as typified by Grevy's zebras and the wild asses, including the African wild ass that is the ancestor of the donkey. Arid and semiarid conditions make it difficult for females, whether with or without young foals, to remain together in closed-membership groups, meet their different physiological needs, and benefit from the extra foraging time that heightened male vigilance provides. Nonlactating females and mares that have older foals need drink only every 3-5 days (Ginsberg, 1989; Becker and Ginsberg, 1990), whereas ones that have foals 3 months old and younger must drink daily. The latter females stay near water whereas the others wander more widely in search of better pasture. Because both types of females are fertile and males cannot be with both simultaneously, males establish territories. The most dominant hold areas near water, where they have exclusive access to females that have young foals and intercept those coming to water every few days. Aridity thus alters the nature of relationships among both females and males and leads to a more fluid, fission-fusion type of social system (Rubenstein, 1994).

Although the two social systems emerge from differences in individual social relationships and environmental conditions, they share some important characteristics. First, the

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mother-infant bond is strong in all equids. Second, sons and daughters leave their mothers when they reach sexual maturity; males join bachelor groups, and females are immediately integrated into adult society. Third, the female reproductive state influences female nutritional needs; meeting these needs sometimes permits long-term stable bonds to form but sometimes does not. Much depends on long-term evolutionary responses to ecological circumstances that lead to the emergence of different social systems. In free-ranging horses, the norm is a stable society in which females can meet their needs while benefiting from limited interruptions. In free-ranging burros, fluidity of social relationships is the norm in that close bonds among females and between males and females are precluded by the disjunctive nature of high-quality feeding and drinking locations.

REPRODUCTION IN DOMESTIC HORSES AND DONKEYS

This section provides an overview of the various points in the reproductive processes of male and female horses and burros that can be targeted for fertility control (see Asa, 2010, and Asa and Porton, 2010, for further details).

Sexual maturity in free-ranging male and female horses occurs at the age of about 18 months, but onset of reproduction is dependent on social parameters within the population. First reproduction for males is typically delayed for up to several years while they reach social maturity. Sexual maturity in domestic donkeys and free-ranging burros is reported to occur at the age of 1-2 years in females (Fielding, 1988; Pugh, 2002) and 1.5 years in males (Nipkin and Wrobel, 1997). The earliest possible age of puberty in males and females of both species is 1 year, so preventing reproduction in those animals would require that treatment begin before that age.

Both species have seasonal breeding patterns, but seasonality is less pronounced in domestic donkeys and free-ranging burros (Ginther et al., 1987). Seasonal reproduction is controlled primarily by photoperiod, but temperature and body condition can also influence reproductive timing (Sharp and Ginther, 1975; Guillaume et al., 2002). Thus, local conditions can affect the length of the breeding season, especially for female horses. Male domestic horses can produce sperm year round, but the quality declines during winter, the mares' nonbreeding season (Pickett et al., 1975).

Most female free-ranging horses give birth in the spring, and this is followed within 5-12 days by postpartum estrus (foal heat), when conception is again possible. Female domestic donkeys also show postpartum estrus (Pugh, 2002). Nonpregnant female domestic donkeys also begin to have reproductive cycles in the spring, and domestic horses and donkeys both continue cycling until conception or the end of the breeding season.

For horses and donkeys, as for many other mammals, the ovarian or estrous cycle is divided into phases. During the follicular or estrous phase (when females will stand for mating), follicle growth is stimulated by gonadotropin-releasing hormone (GnRH) from the hypothalamus and follicle-stimulating hormone (FSH) and luteinizing hormone (LH) from the pituitary. The follicles produce estradiol, which stimulates estrous behavior. The estrous phase in donkeys and horses reportedly lasts about 6-9 days (Ginther, 1979; Vandeplassche et al., 1981).

During estrus, the female is attractive to males and receptive to mating. Courtship behaviors are generally similar in horses and donkeys with some important exceptions. Estrous horses often raise their tails, exposing the genital area, as they approach and follow males (Asa,

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1986). Tail raise is not as obvious in female donkeys, but they spend more time in proximity to males and respond to male vocalization by approaching (Henry et al., 1991). Courtship interactions tend to be more vigorous in donkeys and include more elements of aggression, such as kicking and chasing. Female horses urinate more frequently during estrus, and males assess urine via the flehmen response, which introduces pheromones into the vomeronasal organ for neural processing of the female's reproductive status (Stahlbaum and Houpt, 1989). Vocalization appears to be more important in donkeys, males of which commonly initiate sexual interactions by vocalizing (Henry et al., 1991).

Ovulation occurs toward the end of the estrous phase, but courtship and mating may continue for an additional couple of days in both horses and donkeys. An LH surge triggers ovulation, which is followed by conversion of the follicles to corpora lutea (CL), which produce progesterone. Progesterone domination during the luteal phase, also called diestrus, inhibits further estrous behavior. The total cycle in horses lasts about 3 weeks but in donkeys may last as long as 28 days (Ginther, 1979; Vandeplassche et al., 1981; Fielding, 1988). Estradiol and progesterone prepare the uterus for implantation and nourishing the embryo.

Fertility rates in domestic horses are reported to range from about 80 to 100 percent per breeding season, depending on factors such as breed, age, and reproductive history (reviewed in Ginther, 1979). Fertility rates are lower in older and very young mares (Carnevale and Ginther, 1992; Vanderwall et al., 1993). Rates are also lower in domestic mares that have not previously foaled than in currently lactating mares (reviewed in Ginther, 1979). In one study of pasture breeding of domestic donkeys, all 14 females that were examined were pregnant (Henry et al., 1991).

Gestation length is 11 months in horses and 12-12.5 months in domestic donkeys (Ginther, 1979; Fielding, 1988). However, possible ovulation or spontaneous luteinization, resulting in the formation of secondary CL, around day 40 can confound calculation of gestation length in field studies. Estradiol secreted by the follicles that precede CL formation can stimulate estrous behavior in a small percentage of pregnant females (Tomasgard and Benjaminsen, 1975) and give the appearance of a natural estrous cycle.

With a gestation length of about a year, horses and donkeys can give birth every year. However, that may not occur, especially in nutritionally stressed females. In particular, nursing females, experiencing the energetic drain of lactation in addition to maintenance, may not succeed in sustaining a pregnancy. But lactation itself does not prevent estrous cycles, so conception may occur, although the embryo may be lost if the female is nutritionally stressed. Early embryo loss (defined as up to day 40 of pregnancy) is reported to be 5-15 percent even in well-fed domestic mares but can be 30 percent or higher in mares that are 18 years old or older (Vanderwall, 2008). Pregnancy loss may also be high in yearling mares (Mitchell and Allen, 1975). In a small study of domestic donkeys, three of 14 pregnant females experienced early embryo loss (Henry et al., 1991).

POTENTIAL METHODS OF FERTILITY CONTROL IN FREE-RANGING HORSES AND BURROS

First, it is important to note that, when the committee prepared its report, no fertility-control methods that were highly effective, easily delivered, and affordable were available for use across all BLM Herd Management Areas (HMAs). In addition, there were no fertility-control

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methods that did not alter the behavior or physiology of free-ranging horses and burros in some way. Any method that prevents reproduction can do so only by affecting some aspect of the reproductive system. Even if the only effect were to prevent births, that would change the age structure of a herd by reducing the number of young and could enhance the health of females by reducing the caloric demands of reproduction. Thus, in evaluating fertility-control methods, it is important to compare them not only for obvious factors—such as efficacy, mode of delivery, and cost—but for the constellation of their effects on physiology, behavior, and social structure. It is also critical to extend the comparisons to the social-structure changes and behavioral and health effects that are caused by gathers.

The porcine zona pellucida (PZP) vaccine, an immunocontraceptive, is the most extensively tested method in free-ranging horses and may be the most promising option at present. Several other methods that are potentially useful in horse and burro populations will be considered in this chapter, but more research may be required before their application can be recommended. Fertility-control methods range from other types of vaccines to hormone agonists;[1] some methods are more appropriate for treatment of females, and others could be used to control male fertility. Some of the methods are reversible—and allow the possibility of future restoration of fertility—but others are permanent sterilants that have the economic and logistical advantage of making repeated treatment unnecessary. In particular, nonsurgical approaches to sterilization will be evaluated.

Methods that are not considered permanent may not be 100-percent reversible in all animals. Even if a contraceptive, such as an implant, is removed or its effect wears off (in the case of an injectable contraceptive), other factors may slow or even prevent complete restoration of fertility. Many factors affect fertility and time to conception or birth even in females that have never been treated with contraceptives (reviewed in Asa, 2005). Female age is the most obvious factor, but parity (the number of times that a female has given birth), age at production of first offspring, time elapsed since last pregnancy, nutritional status, health, genetics, and other more subtle factors can also influence a female's ability to conceive and maintain a pregnancy to term. Fertility of previously contracepted females can be affected by those factors and by lingering effects of the contraceptive itself. Individual differences are common.

The process of selecting the best method for the species and situation includes an evaluation of many equally important factors, such as delivery route, efficacy, duration of effect or reversibility, physiological side effects, and possible effects on behavior and social structure. It is also important to know whether a method is safe for prepubertal animals and whether females can be treated during pregnancy or lactation. Although methods can be male- or female-directed, more research in control of fertility in free-ranging equids has targeted females, specifically different formulations of the PZP vaccine, than males. The following review includes methods for both males and females and methods that have been tested with other species that could be considered for use in free-ranging equids.

ADJUSTMENT OF SEX RATIO TO LIMIT REPRODUCTIVE RATES

Adjustment of the sex ratio to favor males has been proposed for managing population growth rates of horse and burro populations. Sex ratio typically is somewhat adjusted after a gather in such a way that 60 percent of the horses returned to the range are male. At that ratio,

[1]A hormone agonist binds to a receptor of a cell and has the same action as the native hormone.

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however, population growth would be only slightly reduced: modeling by Bartholow (2004) suggests that birth rates could decline from about 20 percent to 15 percent a year if the proportion of males increased from 0.50 to 0.57. If more aggressive sex-ratio adjustments are initiated by drastically altering the number of females relative to males beyond a 40:60 ratio, care should be taken to assess possible additional consequences. In the Pryor Mountain Wild Horse Range, Singer and Schoeneker (2000) found that increases in the number of males on this HMA lowered the breeding male age but did not alter the birth rate. Because the existing females were distributed among many more small harems, estimates of genetic effective population size increased.[2] In addition, bachelor males will likely continue to seek matings, thus increasing the overall level of male-male aggression (Rubenstein, 1986). Male condition may decline because of the increase in time spent in competing, and the disruption caused by male-male competition may affect female foraging success. Both those outcomes might reduce overall population growth more than would a reduction in the number of breeding females. Because horses and burros have polygynous mating systems (multiple females mate with one male), additional males would not be expected to affect the likelihood of reproduction in individual females. Reduction in reproductive rate would depend on the number of females remaining. Having a larger number of males competing could favor females by enhancing the opportunities for mate choice, could mean that males of higher genetic quality would achieve harem stallion status, or both. Given that the addition of males or the subtraction of females can lead to a similar sex ratio but have different effects on population growth rates, forecasting models tuned with population-specific survival and fecundity levels can be used to determine how to adjust sex ratios to limit population growth in individual populations effectively.

FEMALE-DIRECTED METHODS OF FERTILITY CONTROL

Potential methods of fertility control directed at female equids include surgical ovariectomy (removal of the ovaries); immunocontraceptives, which trigger the animal's immune system to prevent pregnancy; GnRH agonists; steroid hormones; and intrauterine devices. The mode of action and effects of each method are reviewed below.

Surgical Ovariectomy

Surgical ovariectomy and ovariohysterectomy are commonly used in domestic species, such as cats and dogs (including feral cats and dogs), but seldom applied to other free-ranging species. Accessing the female reproductive tract, which lies within the body cavity, in contrast with the reproductive tract of males of most species, which have external testes, carries the risk of dehiscence of sutures or infection. However, an alternative vaginal approach, colpotomy, avoids an external incision and reduces the chances of surgical complications or infection (Rodgerson and Loesch, 2011). The mare is sedated and tranquilized while standing but restrained; a local anesthetic is sometimes used as well to reduce movement during surgery. An

[2]Effective population size is the size of an idealized population that would experience the same magnitude of random genetic drift as the population of interest. Populations that have experienced fluctuating sizes between generations, unequal sex ratios, or high variance in reproductive success are likely to have effective population sizes that are lower than the number of animals present. The concept of effective population size is discussed in Chapter 5.

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incision is made through the wall of the vagina and then through the peritoneum to access the ovaries. Although the risks are lower than with transabdominal surgery, episioplasty (suturing to close the vulva) and stall restriction for 2-7 days are recommended to reduce the chance of evisceration. Monitoring for 24-48 hours for signs of hypovolemic shock due to internal bleeding is also recommended. The procedure is not without risk.

Duration and Efficacy

Removal of the ovaries is of course permanent and 100-percent effective. Ovariectomy during the first 2-3 months of pregnancy results in abortion because of the loss of progesterone from the corpus luteum (Holtan et al., 1979). Ovariectomy during the period of lactation would not be expected to affect milk production, inasmuch as gonadal hormones (estrogen and progesterone) are important during late pregnancy when mammary glands are developing but not after milk production is established.

Side Effects

Typical side effects associated with ovariectomy in many species include decreased activity and weight gain. The absence of gonadal hormones could affect sociosexual behavior but perhaps not as profoundly as in most other species. Although the cyclic production of estrogen by the ovaries is required for stimulation of estrus and mating behavior in virtually all species, the horse is an exception. The full repertoire of courtship and mating behavior has been displayed by ovariectomized mares and by anestrous mares during the nonbreeding season (Asa et al., 1980a; Hooper et al., 1993). The behavior was found to be hormonally supported by adrenal sex steroids (Asa et al., 1980b), for example, estrone and dehydroepiandrosterone, a weak estrogen and an androgen, respectively. In contrast with ovarian hormones, adrenal sex steroids are not secreted cyclically, so estrous behavior is displayed sporadically. No comparable study of the sexual behavior of free-ranging, nonpregnant mares has been conducted during the nonbreeding season. However, if free-ranging ovariectomized mares also show estrous behavior and occasionally allow copulation, interest of the stallion would be maintained, and this would foster band cohesion.

Immunocontraceptives

No other class of contraceptives has been as extensively researched in domestic and free-ranging equids as immunocontraceptives. Immunocontraception relies on the target species' immune system to produce an immune reaction (usually in the form of antibodies) to some target tissue or biochemical that is required for successful reproduction. The immune response is most often triggered by inoculation of the target species with biochemicals or tissues from other species that are similar in structure to the biochemicals or tissues of the host. The target animal's immune system responds to the foreign compounds injected into the body by producing antibodies that bind to both the injected, foreign compounds and the structurally similar tissues or biochemicals in the target species. The biological effects of the immunocontraceptive, aside from prevention of conception, depend on which biochemicals or tissues are the intended targets, the ability of the immunocontraceptive to induce an immune response (its immunogenicity), the specificity of the immune response to the target biochemicals or tissues, and the duration of the immune response.

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In equids, the two most studied immunocontraceptives are vaccines directed against GnRH, a peptide hormone produced by the hypothalamus, and the zona pellucida, the outer membrane layer surrounding the mammalian oocyte (egg). Both are discussed below in further detail with regard to delivery routes, efficacy, duration of effect or reversibility, and side effects. This review focuses on published studies of captive and free-ranging horses, where available; otherwise, results from studies of other ungulates are used to provide an approximation of what might occur after application of the treatment to horses.

Porcine Zona Pellucida Vaccine

Sperm must bind to the zona pellucida of the oocyte to initiate the sperm acrosome reaction that is required for fertilization. Anti-zona pellucida vaccines prevent conception late in the chain of events required for successful fertilization by preventing sperm from fertilizing eggs (Figure 4-1). There are three formulations of the PZP vaccine: a liquid formulation accompanied by a primer that is effective for 1 year (liquid PZP), a time-release pellet formulation that can be effective for up to 22 months (PZP-22), and a formulation in which PZP is encapsulated in liposomes[3] to extend contraception efficacy (SpayVac®).

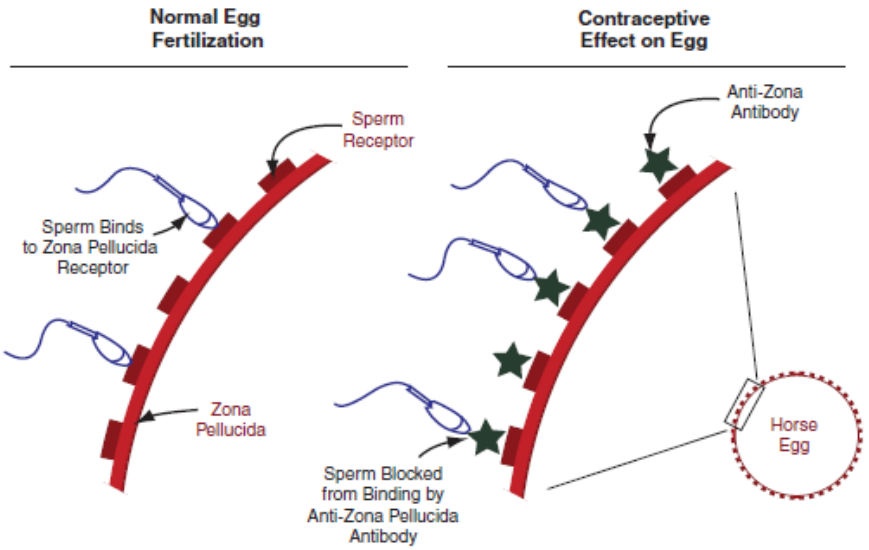


FIGURE 4-1 Mode of action of porcine zona pellucida vaccine.

SOURCE: Illustration provided by I.K.M. Liu.

It is important to note that PZP vaccines are not a homogeneous set of compounds. The term *liquid PZP* used below refers to a PZP vaccine prepared according to the methods originally outlined for the horse by Liu et al. (1989) in which pig ovaries are finely sliced to release oocytes from surrounding tissues. The PZP in SpayVac is different in two ways. First, it is prepared

[3]A liposome is an artificially prepared vesicle composed of a lipid bilayer that can incorporate drugs for controlled delivery.

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differently: whole ovaries are ground and homogenized to separate oocytes from tissues (Yurewicz et al., 1983). Second, the PZP is encapsulated in liposomes to extend the period of release (Brown et al., 1997). In both procedures, the product passes through a series of filters of decreasing pore size to remove other ovarian debris, but it is likely that the SpayVac preparation contains more non-zona pellucida ovarian proteins than liquid PZP produced with the Liu et al. method. Ovarian proteins cannot reliably be separated from zona pellucida proteins by filtration, and the initial grinding and homogenization of whole ovaries in the Yurewicz et al. method results in more non-zona pellucida debris in the initial suspension. Less pure products (containing with more ovarian debris) may be more immunogenic than zona pellucida proteins alone and enhance the immune response. Miller et al. (2009) suggested that the difference in antigen preparation might explain the longer duration of efficacy in their SpayVac-treated deer than in deer treated with liquid PZP, but more work is needed to determine whether antigen preparation methods result in differences in PZP efficacy. Ovaries were not examined for pathological effects in horses, deer, or other species treated with SpayVac, nor were any long-term studies done on its reversibility. It is possible that SpayVac prevents fertilization by means in addition to or other than sperm blockage. Reversibility also requires further investigation. All published studies that have used SpayVac liposome preparations in free-ranging horses included the adjuvant AdjuVac™ prepared by Miller at the U.S. Department of Agriculture's National Wildlife Research Center (NWRC). However, Miller has shown that liposomes are dissolved by the lipid-based adjuvant AdjuVac, which would be expected to shorten its period of efficacy in that the liposomes were designed to prolong contraceptive effect (L. Miller, NWRC, personal communication).

It is also important to note that over the years liquid PZP has been administered to horses with several treatment protocols for the first inoculation, and the effects of the different protocols and of protocols for administering boosters are still not fully understood. For example, in the first study of liquid PZP in domestic mares, Liu et al. (1989) administered the vaccine in four initial injections at 2-week intervals, whereas much of the later work with PZP by Kirkpatrick, Turner, and colleagues (e.g., Kirkpatrick et al., 1991; Turner et al., 1997) involved two initial injections 4 weeks apart. Much of the more recent work (e.g., Liu et al., 2005; Turner et al., 2007) used single-injection protocols that appear to be more feasible in field settings. It is also unclear whether annual booster vaccinations with liquid PZP (e.g., Kirkpatrick et al., 1991) and timed-release PZP pellets (e.g., Turner et al., 2007) generate the same immunologic dynamics needed to prolong the effect of PZP. For example, the total amount of PZP released from a timed-release pellet during the boost period may differ from the amount of PZP in a liquid booster vaccination, and the duration of exposure may not be equivalent. Furthermore, the immune system may respond to these alternative antigen presentations in different ways. The immunologic dynamics induced in the target species with different treatment and boosting protocols are not yet definitively understood.

Delivery Route. Both the liquid and pellet formulations of PZP can be administered by hand to free-ranging equids that have been captured. Liquid PZP can be delivered by dart to animals in the field (Kirkpatrick et al., 1990). Pelleted PZP must be given by hand because darts cannot provide adequate pressure to release pellets into the animal effectively; this was verified in a study of pelleted PZP that was effective for 1 year: the efficacy of the hand-injected PZP was twice that of the dart-injected PZP (Turner et al., 2008). SpayVac (Brown et al., 1997) can be given by hand or dart.

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Although the ability to deliver liquid PZP via dart is a useful option, it is not clear how successful attempts would be to dart populations of horses at the desired level of treatment intensity, given the large number of animals needing treatment, variability in the temperament of the horses, and the terrain of HMAs. Two studies of free-ranging horses and one of white-tailed deer have found that over time, with repeated boosters, the difficulty of approaching animals on foot for darting increased (Kirkpatrick and Turner, 2008; Rutberg and Naugle, 2008; Ransom et al., 2011). At the time the report was prepared, the most effective and most reliable method of delivery was hand injection after a gather. However, alternative methods, such as trapping near water holes or blinds, have been used in other areas and could be useful in some HMAs.

Efficacy. Liquid PZP, the first formulation produced, has been assessed for efficacy more often than other PZP formulations. The overall mean of published efficacy values in horses is 88.4 percent (median, 89 percent). Kirkpatrick and Turner's (2008) value of 95 percent is based on cumulative experience on Assateague Island[4] and represents the most up-to-date information available to the committee on that site. Turner et al. (1997) evaluated several adjuvant formulations.[5] If the less effective adjuvants in their study and another study that acknowledged poorly timed boosters in one population (Ransom et al., 2011) are eliminated, the mean efficacy increases to 91.5 percent (median, 90 percent), representing hundreds of animals across several sites. In most of the studies, efficacy was assessed by determining how many treated females had foals in the following foaling season or had pregnancy diagnosed with hormone assays.

Only one study of any PZP formulation has been conducted in burros. Turner et al. (1996) found that liquid PZP significantly reduced fertility for a year after vaccination. A two-shot protocol was more effective (none of 13 females became pregnant) than a one-shot protocol (one of three became pregnant).

Turner et al. (2007) assessed a pelleted form designed to release PZP into the animal's circulatory system at 1, 3, and 12 months in 96 free-ranging mares in Nevada. Fertility rates over 4 years after vaccination were 5.2 percent, 14.9 percent, 31.6 percent, and 46.2 percent, respectively, in treated mares. The formulation has come to be called PZP-22 because it remains about 85-percent effective after 22 months. Turner et al. (2008) concluded that the optimal time to administer PZP-22 for maximum duration of effect is fall or winter. BLM began using PZP-22 in free-ranging horses in the late 2000s. However, the efficacy has varied as treatment has been extended to additional field sites. Foaling has been reduced by 30-79 percent in the 2 years after a single injection of PZP-22 at various field sites (J.W. Turner, University of Toledo, personal communication, November 2012). The variability is believed to be due to the time of year of injection, whether delivery was by dart or by hand, the location of the injection (the hip is considered ideal, but that is not always possible when delivery is by dart), and possible differences in preparation in the field. In addition, there has been a change in vaccine production during the last few years: heat extrusion versus cold evaporation (J.W. Turner, University of Toledo, personal communication, November 2012).

[4]Assateague Island National Seashore is on a barrier island off the coast of Maryland and operated by the U.S. Department of the Interior's National Park Service (NPS). A free-ranging herd lives on the island. NPS is not subject to the Wild Free-Roaming Horses and Burros Act of 1971. Nevertheless, because it is a free-ranging population, results of studies of the use of liquid PZP on this herd can inform management of horses under BLM's jurisdiction.

[5]An adjuvant enhances the immune response by encouraging the production of antibodies.

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Only one published study (Killian et al., 2008a) has evaluated SpayVac efficacy in horses. In a study of captive horses in Nevada, 12 mares received a single hand injection in the neck of 400 µg of SpayVac emulsified with AdjuVac adjuvant for a total volume of 1 mL in March 2003. In fall of each year, treated mares were examined for pregnancy via ultrasonography or rectal palpation, and the observations were later verified by whether a foal was born. In a few cases in which a mare's behavior prevented that kind of examination, the birth of a foal (or the absence of a birth) in spring of the following year was used to assess fertility and treatment efficacy. In the 4 years of the study, contraception efficacy in the SpayVac-treated mares was 100 percent in year 1 and 83 percent in years 2-4. Bartell (2011) determined that SpayVac in combination with nonaqueous Freund's modified adjuvant (FMA) induced the strongest immune response in domestic horses as measured by antibody titers and exhibited the strongest suppression of progesterone compared with an aqueous preparation of FMA and mycobacterium-based adjuvant, but she did not assess pregnancy or foaling.

SpayVac has also been evaluated in deer. Miller et al. (2009) evaluated SpayVac and liquid PZP in combination with different adjuvants in 30 captive white-tailed deer grouped into six treatment groups of five does each. SpayVac was administered in three preparations: with liposomes in AdjuVac emulsion, lyophilized with liposomes in AdjuVac suspension, and with liposomes in an alum adjuvant suspension. PZP was produced with two protocols (labeled IVT and NWRC for the providers of the antigen). The SpayVac/AdjuVac emulsion and the IVT-PZP/AdjuVac emulsion had the longest duration of effect: 80 percent of treated deer were contracepted for at least 5 years. Monitoring of the SpayVac/AdjuVac group ceased at 5 years; the IVT-PZP/AdjuVac continued to be effective for 7 years. The estimated decline in fecundity (fawns produced per female) was greater than 90 percent. All other formulations were inferior in performance. The authors concluded that AdjuVac is critical and should be used in emulsion form rather than suspension. They also suggested that, because of production differences, the IVT-PZP probably contained more porcine ovarian tissue and was thus more effective. Fraker et al. (2002) evaluated the efficacy of SpayVac emulsified with Freund's complete adjuvant (FCA) administered to 41 free-ranging fallow deer. Contraception of treated does was 100 percent over 3 years; however, the samples obtained in the 3 years were from different animals because some animals were culled for analysis. The authors suggested that, on the basis of the antibody titers present after 3 years, the SpayVac vaccination would probably continue to be effective for a longer period. Locke et al. (2007) evaluated SpayVac emulsified with AdjuVac over a 2-year period in wild white-tailed deer (34 treated, 11 controls) and found 100-percent efficacy in both fawning seasons. Killian et al. (2005) cited data from their studies of captive white-tailed deer in Pennsylvania that showed 80-percent efficacy in does for 4 years.

Gray et al. (2010) evaluated a PZP vaccine that was mistakenly referred to as SpayVac (Fraker and Brown, 2011; Gray et al., 2011) in 20 treated and 18 untreated free-ranging mares in Nevada over a 3-year period. The liquid PZP vaccine was prepared as SpayVac but without liposomes. Efficacy was lower (50-63 percent) than reported by Killian et al. (2008a) for SpayVac. Gray et al. (2010) suggested that the lower efficacy might have been due to their more conservative methods of assessing efficacy in the field; however, in a follow-up published erratum, they acknowledged that the vaccine formulation that they used lacked the liposome compounds included in the SpayVac vaccine (Gray et al., 2011) and suggested that this could explain the differing results. Thus, the studies by Gray et al. (2010) should not be compared to other results for SpayVac specifically, and it is not clear whether these results should be

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compared to those for liquid PZP. In both the Killian et al. (2008a) and Gray et al. (2010) studies, the AdjuVac adjuvant was combined with the vaccine.

Reversibility. Immunocontraception depends on the immune response to the vaccine reaching and staying above threshold concentration (Adams and Adams, 1990; Zeng et al., 2002). Reversibility of the contraceptive effect depends on the reduction of circulating antibody titers. Substantial variability in reversal time is likely and can be due to the vaccine formulation, the adjuvant used, the treatment protocol, genetic factors, and the nutritional status of the individual animal because these factors may affect the initial and continuing immune response to the vaccine (Homsy et al., 1986; Chandra and Amorin, 1992; Turner et al., 1997, 2001, 2007; Liu et al., 2005; Lyda et al., 2005; Bartell, 2011).

In the first study of liquid PZP in equids, Liu et al. (1989) found that, of 10 feral and six domestic mares, most mares had reversed within 8 months of treatment. Kirkpatrick et al. (1990) first demonstrated that three of seven free-ranging mares became fertile in the first year after 1 year of liquid-PZP treatment, although foaling rates of treated mares overall were lower after treatment than in control mares. Turner et al. (1997) found similar results in horses in Nevada, where 103 mares were treated with various combinations of PZP and adjuvants and 92 mares served as controls. Data from Assateague Island on reversibility continued to accumulate over the years, and Kirkpatrick and Turner (2002) stated that liquid PZP was 100-percent reversible in three mares treated for 4 consecutive years and two mares treated for 5 consecutive years. The time between final treatment and pregnancy ranged from 1 to 8 years. At the time the committee's report was prepared, none of the five mares treated for 7 consecutive years had reversed after 7 years of monitoring. In a study of 16 burros, 46.1 percent of treated females were determined to be pregnant via fecal hormone monitoring during the second year after liquid-PZP treatment (Turner et al., 1996)

Studies of longer-acting PZP formulations, such as PZP-22 (pellets) and SpayVac, have assessed reversibility more in the context of measuring the duration of effect of the vaccine; declining infertility in years after vaccination reflects reversibility. In a study by Turner et al. (2007) of 96 treated mares, 15 percent of mares had not reversed after 22 months, 31.6 percent after 3 years, and 46.2 percent after 4 years. In that study, however, not every mare was assessed for reversibility every year. Turner et al. (2008) suggested that more rigorous study of reversibility in PZP-22 treated mares is warranted.

Ransom (2012) studied liquid PZP and PZP-22 in three horse populations in the western United States. Twenty-two mares on the Little Books Cliffs HMA and 38 mares on the Pryor Mountain Wild Horse Range were treated with liquid PZP up to 5 consecutive years. At the McCullough Peaks HMA, 28 mares were treated with PZP-22. Among all the sites, in mares that had foaled previously, the probability of not foaling was 74.4 percent after PZP treatment and 35.9 percent in control mares; this indicates that fertility may be suppressed after the planned period of infertility. At Little Book Cliffs and Pryor Mountains, the time from the last liquid-PZP injection to first parturition ranged from 1.5 to 8.1 years and was strongly affected by the total number of years in which the mares were treated. On average, time to parturition increased by 411 days per consecutive year of treatment. At McCullough Peaks, 64 percent of PZP-22 treated mares did not produce a foal during the posttreatment period (5 years). Return to parturition took 1.4-5.5 years. The results reinforce the notion that return to fertility after immunocontraception can be longer than expected.

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SpayVac has not been thoroughly assessed for reversibility in captive or free-ranging horses, although the study by Killian et al. (2008a) demonstrated that two of 12 treated mares became pregnant 2-4 years after vaccination. The studies of SpayVac in deer described above did not systematically address reversibility, nor have they been of sufficient duration to detect decreases in vaccine efficacy (animals were contracepted at the same level of efficacy in all years of the study).

Side Effects: Physical and Physiological. Because the antigen target of PZP contraception (liquid, pellet, or SpayVac formula) is highly specific—the egg's zona pellucida—there appear to be relatively few physical side effects. Barber and Fayrer-Hosken (2000) found that PZP antibodies did not bind to other somatic tissues in horses. Liu et al. (1989) found no evidence of pathological conditions in ovaries of mares treated for 1 year; however, this remains the only study of ovarian pathology in relation to liquid-PZP treatment in horses. Bartell (2011) found that the ovaries of SpayVac-treated domestic mares were lighter, had smaller oocytes, and had thinner zona pellucidae than control mares. Killian et al. (2008a) found that SpayVac-treated mares had unexplained higher rates of uterine edema, but they cited literature (Samper, 1997) suggesting that in healthy mares this is a sign of estrus when mares are under the influence of estrogen produced by ovarian follicles. Fraker (2012) also observed uterine edema in connection with SpayVac. It is not known whether the extent of edema observed in the SpayVac-treated mares was equivalent to that in normal estrous mares or more severe; the latter might be a possible indication of pathology. Because of the pathological potential, further research on uterine changes during and after treatment with SpayVac is warranted. There are no documented reports of persistent uterine edema after the use of liquid PZP or PZP-22, but comparable data on the effects identified with the use of SpayVac do not exist.

Mares that have been treated with liquid PZP for 3-7 consecutive years have been reported to have decreased ovulation rates in successive years of treatment (Kirkpatrick et al., 1992, 1995); this suggests that PZP may act at sites other than just the zona pellucida. Powell and Monfort (2001) did not find a statistically significant relationship between the likelihood of ovulatory failure and current contraception status (currently versus previously treated with PZP). It is possible that the likelihood of physiological side effects depends on the delivery of PZP as repeated vaccinations (for example, annually in the case of liquid PZP) as opposed to one long-term vaccination (in the case of PZP-22 and SpayVac).

There are many other possible causes of subfertility in horses (McCue and Ferris, 2011), but in none of the analyses described above were the same mares assessed for cyclicity before and after PZP treatment, so other possible factors contributing to subfertility were not assessed. It is estimated that about 20 percent of domestic horse mares are subfertile (I.K.M. Liu, University of California, Davis, personal communication, August 2012). Ovarian senescence has also been documented in some domestic mares over 20 years old, as evidenced by a longer follicular phase, a prolonged interovulatory interval, and later first ovulation of a breeding season (McCue and McKinnon, 2011) —all of which are reported in mares currently or previously treated with PZP (Powell and Monfort, 2001). Thus, assessing reproductive competence after many years of PZP treatment is confounded by the concomitant effects of aging.

There has been much discussion over the years of the effects of different adjuvants used in combination with PZP in relation to reactions at the injection site, which have included stiffness, swelling, nodules, and abscesses. The traditional application of liquid PZP involved an initial primer dose administered with FCA and a follow-up booster 2-4 weeks later with Freund's

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incomplete adjuvant (FIA). Kirkpatrick et al. (1990) were the first to mention potential concerns with using FCA in wildlife, but in their study only three of 26 treated mares had injection-site abscesses, and all healed within 14 days. One concern with FCA is its ability to produce false positive results in tuberculosis tests; this in part led to the development of FMA, which did not produce such results (Lyda et al., 2005). Chapel and August (1976) also suggested that FCA could be hazardous to people exposed to it when administering injections.

In their study of FCA and FMA use in the primer liquid-PZP dose, Lyda et al. (2005) found only one case of injection-site abscess. The mare was treated with FMA in the primer dose and FIA in the booster. The abscess appeared after the FIA booster dose, and it drained and healed without incident. Antibody titers produced with FMA and FCA did not differ significantly. Neither adjuvant had an effect on the delivery of healthy foals. The authors cited unpublished data suggesting that the incidence of injection-site abscesses was less than 1 percent when injections were given in the hip, but it was higher when injections were given in the neck.

In a large study of free-ranging horses, Roelle and Ransom (2009) found no statistically significant differences in occurrence of dart-site reactions due to adjuvant (FCA or FMA) and suggested that reactions are probably more likely to be due to dart trauma or in some cases a combination of dart trauma and adjuvant. Hand injection led to fewer injection-site reactions than darting. Overall, abscesses in response to darting were rare, in accordance with other studies (Kirkpatrick et al., 1990; Turner and Kirkpatrick, 2002; Lyda et al., 2005). Nodules at the injection site were the most common reaction (25 percent of cases), and these persisted for up to a year or more but did not appear to affect the animals. Swelling was the second-most common reaction (11 percent and 33 percent at two study sites), and this disappeared within 30 days. Stiffness was the third-most common (1.4 percent and 11 percent at two study sites) and disappeared within 24 hours.

In their studies of both PZP and GonaCon™ (a GnRH vaccine), Gray et al. (2010, 2011) found no cases of abscesses after hand injection of either compound with AdjuVac as an adjuvant. Similar results have been found in deer when AdjuVac has been used (Fraker et al., 2002; Locke et al., 2007; Miller et al., 2009).

Contracepted females should generally be in better body condition than uncontracepted females because they do not face the energetic demands of pregnancy and lactation. Turner and Kirkpatrick (2002) found that body-condition scores of mares on Assateague Island were significantly higher in 1999 than in 1988 before PZP contraception was widely applied. Body-condition scores of lactating females at those two times were not significantly different, and this suggests that prevention of pregnancy can enhance body condition. Ransom et al. (2010) found no difference in body-condition scores between treated and untreated mares in three western populations of horses on the basis of a similar body-condition scoring index, but mares that had foals had lower body condition than mares that did not. The most likely reason for the absence of significant body-condition differences between treated and untreated mares is that most treated mares were already pregnant when the study began and therefore did have foals at their sides during the study. In addition, some treated mares that did not respond to contraception and produced foals were exposed to the same energetic demands of gestation and lactation as untreated mares (J. Ransom, National Park Service, personal communication, May 3, 2012). In contrast, Fraker et al. (2002) found that fallow deer does treated with SpayVac had lower stores of kidney fat than untreated does; treated does might have expended more energy during the rut because they were engaged in reproductive behavior more often than untreated does.

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Side Effects: Pregnancy, Birth Seasonality, and Survival. Liquid PZP has been demonstrated to be safe to administer to pregnant mares in a number of studies (e.g., Kirkpatrick et al., 1990, 1991). Turner and Kirkpatrick (2002) found that foal survival to 1 year is equivalent between untreated mares and mares treated with liquid PZP during pregnancy; female foals born to PZP-treated females also successfully bred and reared offspring. Kirkpatrick and Turner (2003) analyzed birth records on Assateague Island and found that most foals born to treated and untreated mares are born in season (April-June): 75.8 percent of births to control mares, 64.9 percent of births to treated mares, and 68.9 percent of births attributed to contraceptive failure. None of those differences was significantly different. The authors did note that out-of-season births had been increasing on Assateague Island since 1984 (the contraception management program began there in 1994) for unknown reasons. Turner and Kirkpatrick (2002) found no difference in survival between in-season and out-of-season foals but stated that it probably depends on the environment (Kirkpatrick and Turner, 2003). On Shackleford Banks,[6] PZP-treated mares foaled over a broader range of months than untreated mares (Nuñez et al., 2010). Mares given PZP in the year before they conceived gave birth 3-4 months later than untreated mares. Mares that had been on PZP at some point before the year in which they conceived gave birth almost a month later than untreated mares. However, in an investigation of PZP contraception in free-ranging mares in Nevada, Gray et al. (2010) found no differences in foal survival, birth seasonality, or foal sex ratio between treated and untreated mares. Ransom (2012) also studied the effect of liquid and pelleted PZP (PZP-22) on birth seasonality at three sites in the western United States. Overall, mares that gave birth to foals after treatment (liquid and PZP-22 considered together) did so an average of 31.5 days later (range, 17-46) than untreated mares. Ransom stated that that effect varied among sites and PZP formulations, but these factors were confounded because PZP-22 was used exclusively at one site and not at all at the others. In addition, a monsoon rain at one site allowed a second peak in spring vegetation quality. There was no effect of treatment on foal survival; however, foal survival did decrease the later a foal was born after the peak in spring vegetation quality. Ransom indicated that the average delay in birth of a posttreatment foal results in about a 4.2 percent reduction in survival probability and that this is probably why the treatment effect was not statistically significant (J. Ransom, National Park Service, email communication, July 6, 2012). Ransom also noted that posttreatment mares that gave birth "late" in a given year would often not foal in the following year but then would foal in the third year during the normal birthing season for that site; such factors as photoperiod and temperature might be able to "reset" a mare's reproductive system so that conception and birth occur during the normal birth season in later years.

Studies of liquid PZP contraception in the Assateague Island horse population have also revealed effects on survival of mares. In the 4 years before 1994, when management-level contraception began, annual adult mortality was greater than 10 percent; in the first 4 years after contraception, adult mortality decreased to less than 4 percent (Turner and Kirkpatrick, 2002). It should be noted, however, that in 1990 and 1992 many deaths were attributable to an equine encephalitis outbreak and severe storms, respectively. Even so, mare mortality in 1991 and 1993 was about 3-4 percent; from 1994 to 1998, mare mortality was less than 2 percent (Turner and Kirkpatrick, 2002). There was also a shift upward in age classes in the entire herd, which

[6]Shackleford Banks, part of the Cape Lookout National Seashore, is home to a herd of free-ranging horses managed by the U.S. Department of the Interior's National Park Service. Although they were not treated with PZP for as many years as the Assateague Island horses, the results of behavioral studies of the Shackleford Banks horses can inform management of horses under BLM's jurisdiction.

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indicated increased survival and the attainment of new, older age classes (Turner and Kirkpatrick, 2002). In a later study (Kirkpatrick and Turner, 2007), untreated mares were compared with mares on PZP for less than 3 years and mares on PZP for more than 3 years. Mean age at death was significantly lower in untreated mares (6.47 years) than in treated mares, and mares on PZP for more than 3 years had a higher mean age at death (19.94 years) than mares on PZP for less than 3 years (10.27 years). At the time the committee's report was prepared, pelleted PZP and SpayVac had not been examined for effects on adult survival or demographic changes.

Side Effects: Genetic. Concerns have been raised about possible unintended genetic effects of immunocontraception. In a review of ecological and immunogenetic issues surrounding immunocontraception, Cooper and Larsen (2006) suggested that because immunocontraceptives are rarely 100-percent effective and resistance to vaccines (contraceptive failures) might have a genetic basis, managers may be unintentionally selecting for animals that do not respond to immunocontraceptive techniques. Using Falconer's (1965) equations, they suggested that if the proportion of nonresponding females is 10 percent, which could be considered a valid estimate for liquid PZP in horses, after one generation of selection via immunocontraception, the percentage of female offspring produced that would themselves be resistant would range from 15 to 23 percent, depending on the degree of heritability of resistance to immunocontraception. The authors also suggested that such selection for nonresponders could occur in the major histocompatibility complex or in genes that regulate the immune system, either of which could alter resistance to other pathogens.

However, when the committee's report was prepared, there were no data on resistance to immunocontraception, the heritability of such resistance, or the identity of specific genes that might affect responses to immunocontraceptives. National Park Service staff reported on Assateague Island that there were no indications that resistance was developing or that responses to immunocontraception were changing over time, after 19 years of herd management with PZP. Contraceptive effectiveness continues to be high (A. Turner, Assateague Island National Seashore, email communication, February 24, 2013). The immune response to immunocontraceptives depends on many nongenetic factors, such as nutritional status (Homsy et al., 1986; Chandra and Amorin, 1992; Chandra, 1996; Demas et al., 2003; Houston et al., 2007), and it was not possible for the committee to determine whether resistance to immunocontraception could develop. Similarly, it was not clear whether immunocontraception could inadvertently select for less immune-robust animals because they would not mount a strong response to PZP and would thus remain fertile. Presumably, any genetic background that would predispose animals to being immunocompromised would be under strong selection to be eliminated; even in a small population in which a deleterious mutation that compromised the immune system could become fixed, selection could act against individual animals that have the mutation, although the pressure of selection is smaller in small populations. In addition, Falconer's (1965) equations apply to threshold or "all-or-none" characters whereas lifetime reproductive success—which contraception affects—is a continuous variable that is not subject to some threshold, so it is not clear whether the Falconer model applies, although other models might. Cooper and Larsen (2006) suggested that immunocontraception could be appropriate for management of species that have long generation times, like horses, because genetic changes (if any) due to immunocontraception would take decades to develop. That would also assume that large numbers of individual animals are contracepted indefinitely and never allowed to breed;

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this does not seem likely if populations are managed for genetic diversity. However, those concerns highlight the importance of monitoring genetic diversity in immunocontracepted populations (see Chapter 5).

At the population level, removing females even temporarily from the breeding pool is likely to reduce the effective population size (N_e) and genetic diversity of the population. As will be discussed in Chapter 5, reducing the number of breeders or increasing the variance in family size, which will occur as more females bear no young, will reduce N_e and increase the loss of genetic variability. (Tables 5-2 and 5-3 show that some populations display low levels of heterozygosity.)

Side Effects: Behavioral. There are two important considerations in evaluating the literature on contraceptive effects on particular aspects of behavior, particularly bonds between animals and stability of social groups. First, in no published study of immunocontraception have treatment and control groups been matched or balanced with respect to other variables that might affect behavior (such as age, dominance rank, tenure in the group, group size, social or reproductive history, and characteristics of other group members). Rather, investigators have had no control over those variables and thus only compared treated with untreated (or not currently treated) females. Studies in which those factors could be controlled or specifically have their effects measured would require large samples of animals of known history and would be virtually impossible to conduct in the field or even in captivity. Second, no study has been able to differentiate the behavioral effects of a contraceptive compound administered to an animal and the resulting absence of offspring. Thus, in no case can the committee conclude from the published research that the behavioral differences observed are due to a particular compound rather than to the fact that treated animals had no offspring during the study. That must be borne in mind particularly in interpreting long-term impacts of contraception (e.g., repeated years of reproductive "failure" due to contraception).

Gray (2009) and Gray et al. (2010, 2011) studied the effects of a liquid-PZP vaccine on behavior of free-ranging horses in Nevada during breeding and nonbreeding seasons. There were no treatment effects on activity budget, rates of sexual behavior, proximity between stallions and mares, attempts to initiate proximity, aggression given or received, or band changing by mares. Powell (1999) found no differences in spatial relationships, dominance rank, or aggression between mares currently on PZP and those not currently on PZP on Assateague Island; however, at the time of Powell's studies, all mares had been treated with PZP at some point in the past, so true controls were not available. On Shackleford Banks, an island where some mares were never treated with PZP, changes in time budgets were observed. Many factors—such as the presence of a foal, the size of a harem, and features of the male associated with the harem—affected time spent in various activities, but a female's contraceptive status also affected time budgets. In "best fit" general linear models attempting to identify individual and group characteristics that account for variation in the proportion of time spent in grazing and standing, a female's contraceptive status and an interaction involving contraceptive status and a harem male's identity had significant effects, as did total harem size and the interaction of male identity and total harem size. In general, PZP-treated females and females in large harems graze less and stand more than non–PZP-treated females and females in smaller groups, but these effects are related to the particular males with which they interact (Madosky et. al., in review).

In a study of liquid and pelleted PZP in three populations of horses in the western United States, Ransom et al. (2010) found no effect of treatment on activity budgets, but they did find

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that treated females engaged in significantly more reproductive behavior (0.05 behavior per hour in control mares versus 0.11 behavior per hour in treated mares), which could be expected with a contraceptive that causes females to cycle repeatedly during the breeding season. Powell (1999) also found no difference in activity budgets between mares currently on PZP and those not currently on PZP. Nuñez et al. (2009) saw significantly more sexual or courtship behavior in treated mares than in controls outside the breeding season but also cited data on other temperate equids that showed that out-of-season cycling is known to occur. Powell (1999) found a nonsignificant trend for currently treated mares to engage in more social behavior overall; however, when only sexual behavior was considered, there was no effect of current contraception status on behavior (Powell, 2000). Turner et al. (1996) did not discern any differences in reproductive behavior between liquid-PZP–treated burros and untreated burros, but they did not provide quantified behavioral data. No other studies of PZP contraception in burros have been published.

The effects of liquid PZP on harem stability in horses have been studied in Nevada during breeding and nonbreeding seasons by Gray (2009) and on Shackleford Banks during the nonbreeding season by Nuñez et al. (2009) and during the breeding season by Madosky et al. (2010). Stability was also assessed on Assateague Island by National Park Service staff (A. Turner, Assateague Island National Seashore, email communication, December 13, 2011). The studies on Shackleford Banks suggest that PZP is associated with increased harem changing by mares, whereas the Nevada and Assateague studies found no differences between treated and untreated mares in harem-changing. The studies all differ in methodological approaches, definitions of treated and untreated animals, and ecological and social contexts. No studies have been able to control all the factors that could affect harem stability in the field, which could include age, pregnancy status, characteristics of other mares and stallions in the harem, distribution of resources, stallion turnover rates, population size and demographics, and more. Finally, harem-changing by mares occurs to varied degrees in horse populations in varied ecological contexts in uncontracepted populations (see Feist and McCullough, 1975; Berger, 1977, 1986; Nelson, 1978; Rubenstein, 1981; Stevens, 1990; Goodloe, 1991; Jensen, 2000 for examples).

Figure 4-2 below shows a frequency distribution of the percentage of mares observed changing bands in population studies before or without contraception (Feist and McCullough, 1975; Nelson, 1978; Rubenstein, 1981; Berger, 1986; Rutberg, 1990; Stevens, 1990). Values range from 8-61 percent (mean, 27 percent; median, 25 percent). The study by Madosky et al. (2010) found that 70 percent of PZP-treated mares changed bands; that is, significantly higher than the percentage of mares that change bands in uncontracepted populations (Wilcoxon signed-ranks test, $T = -18$, $p = 0.008$, $df = 7$). The percentage of control mares changing bands (33.3 percent) did not differ from that of mares in uncontracepted herds (Wilcoxon signed ranks test, $T = -6$, $p = 0.44$, $df = 7$) (analysis provided by D. Rubenstein).

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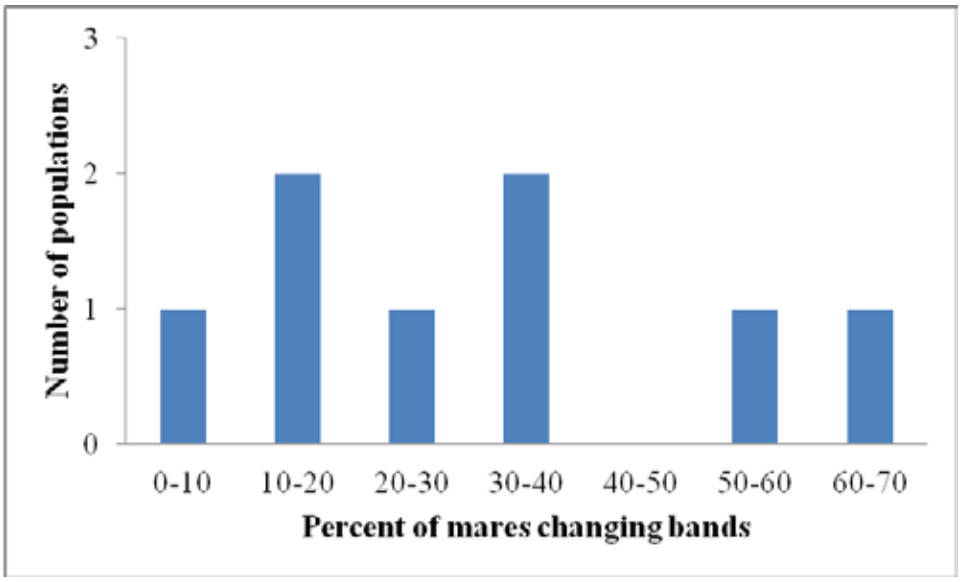


FIGURE 4-2 Percentage of band changes by mares as shown in a review of published literature.

SOURCE: Feist and McCullough (1975), Nelson (1978), Rubenstein (1981), Berger (1986), Rutberg (1990), Stevens (1990).

Whether Shackleford Banks is a unique case or not, additional study is needed to understand whether the absence of foaling as a result of contraception has an effect on band stability. Gray (2009) argued that sexual behavior and the ability to form consortships were adequate to maintain band stability in her study in Nevada. The studies on Shackleford Banks (Nuñez et al., 2009; Madosky et al., 2010) suggest that there is an interaction between pregnancy and social cohesion. The importance of harem stability to mare well-being is not clear, but considering the relatively large number of free-ranging mares that have been treated with liquid PZP in a variety of ecological settings, the likelihood of serious adverse effects seems low.

Side Effects: Demography and Population Processes. The easiest way to envision the effect of contraception on population processes is to examine its effect on demographic vital rates (e.g., birth and death rates) contained in the equation that approximates the intrinsic rate of population increase (r). The demographic vital rates are related to r via the Lotka-Euler equation; a reasonable approximation is

$$r \approx \frac{\ln R_0}{G},$$

where $R_0 = \sum l_x m_x$ is the net reproductive rate, and $G = \sum x l_x m_x$ is the generation time, which is proportional to age at first reproduction (α) (May and Rubenstein, 1985); l_x and m_x are age-specific survival and fecundity rates, respectively (Stearns, 1992; Gotelli, 2001). Intuitively, female fertility control effectively reduces r by reducing m_x. The degree to which r is reduced depends on the effectiveness of the fertility-control method used, the proportion of females of a given age class that are treated, and the age classes that are targeted for treatment.

Female fertility control would also have indirect and unintended consequences, which may include changes in ages at first (α) and last reproduction (ω), longevity, and the population's

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age structure. If young females are targeted, fertility control can potentially increase the average α. Because treated females no longer have to sustain pregnancies or lactate, their energy needs will be reduced, their body condition will improve (e.g., Kirkpatrick and Turner, 2007), and they can potentially survive better, live longer, and possibly have a longer reproductive lifespan. Because *r* correlates negatively with α and positively with ω (Oli and Dobson, 2003; Stahl and Oli, 2006), these can have contrasting effects. However, elasticity (or proportional sensitivity) patterns in age-structured populations suggest that the elasticity of population growth rate to changes in age-specific vital rates declines with age and that growth rate generally is more strongly affected by changes in α than in ω (Caswell, 2001; Oli and Dobson, 2003; Stahl and Oli, 2006). Thus, targeting younger females for contraception would be the most effective strategy if the goal is to reduce *r*.

Evidence suggests that repeated application of PZP can lead to prolonged infertility (beyond the treatment period), so the effects on population growth may be more dramatic in later years and longer-lasting than might have been planned at the start of fertility control. Fertility control via PZP may also increase longevity in females (Kirkpatrick and Turner, 2007), and this would have both direct and indirect ecological effects. Females that survive longer will increase the number of animals using the range, and this is likely to affect the setting of appropriate management levels (see Chapter 7). However, females that live longer may or may not contribute to *r* via reproduction. In addition, targeting younger age classes for repeated and prolonged fertility control would affect a population's age structure and the likelihood of a given animal's contribution to the gene pool (see Chapters 3 and 5). The impact of those consequences will depend on a population's initial size and structure and should be accounted for when strategies for fertility control are developed.

Many of the behavioral changes associated with fertility control that are discussed in the preceding section are also likely to affect population dynamics. A longer breeding season could affect band stability and would probably extend male sexual activity into months when they normally recover strength and rebuild body condition. Such sexual activity in horses and other equids can involve males herding, pushing, and nudging females (and sometimes even forcing copulations [Berger, 1986]), which lower foraging success and freedom of movement (Rubenstein, 1986, 1994; Linklater et al., 1999; Cameron et al., 2009). Sexual harassment has been seen in many but not all equid populations. Where it occurs, if levels of harassment remain high year round, both males and females could enter the breeding season in lower condition, and fertility could be compromised. Fecundity (m_x) and survival (l_x) of nontreated females could be further reduced, again limiting the population growth rate (r). Whether that cascade of events will occur in particular horse or burro populations will depend on the magnitude and interaction of three factors: environmental harshness in the nonbreeding season, social instability, and improvement of body condition in treated females due to absence of energetic demands of pregnancy and lactation. It is known from studies on Assateague Island that PZP-treated mares tend to have higher body-condition scores than females that reproduce regularly (Kirkpatrick and Turner, 2007). More recent results from Shackleford Banks show increased longevity in PZP-treated mares, probably because of their increased body condition and general health (Stuska, 2012). However, it is known that social disruption and harsh conditions during stressful periods can lower body condition (Pollock, 1980). What is not known is how those factors may interact when PZP use is extended to populations in harsher habitats or during periods of harsher climatic conditions, such as drought. It is something that will need to be monitored.

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Gonadotropin-Releasing Hormone Vaccine

GnRH stimulates the pituitary gland to produce follicle-stimulating hormone (FSH) and luteinizing hormone (LH), which then stimulate growth of follicles (which produce estrogen) and ovulation. GnRH vaccines prevent the action of GnRH, so that in the absence of FSH and LH the failure of follicle growth and ovulation prevents reproduction (Figure 4-3). Two formulations of the most common GnRH vaccine, GonaCon™, have been reported in the literature. Specifically, the GnRH peptide has been conjugated to a keyhole limpet hemocyanin protein (KLH) or to blue mollusk protein (B). Both formulations appear to work well, but the B formulation may be more effective (Killian et al., 2008a; Miller et al., 2008) and is less expensive to produce than the KLH formulation (K. Fagerstone, NWRC, personal communication, April 18, 2012). GnRH vaccines not identified as GonaCon in the literature will be labeled as experimental vaccines because they are formulated in a variety of ways.

Studies of GonaCon as a contraceptive in horses are rare in the published literature; studies of GonaCon in deer are more numerous. Two additional GnRH vaccines are available in other parts of the world: Equity™ and Improvac® are produced by Pfizer Animal Health, Australia. Results of studies of efficacy, reversibility, and side effects of these vaccines are discussed in this section.

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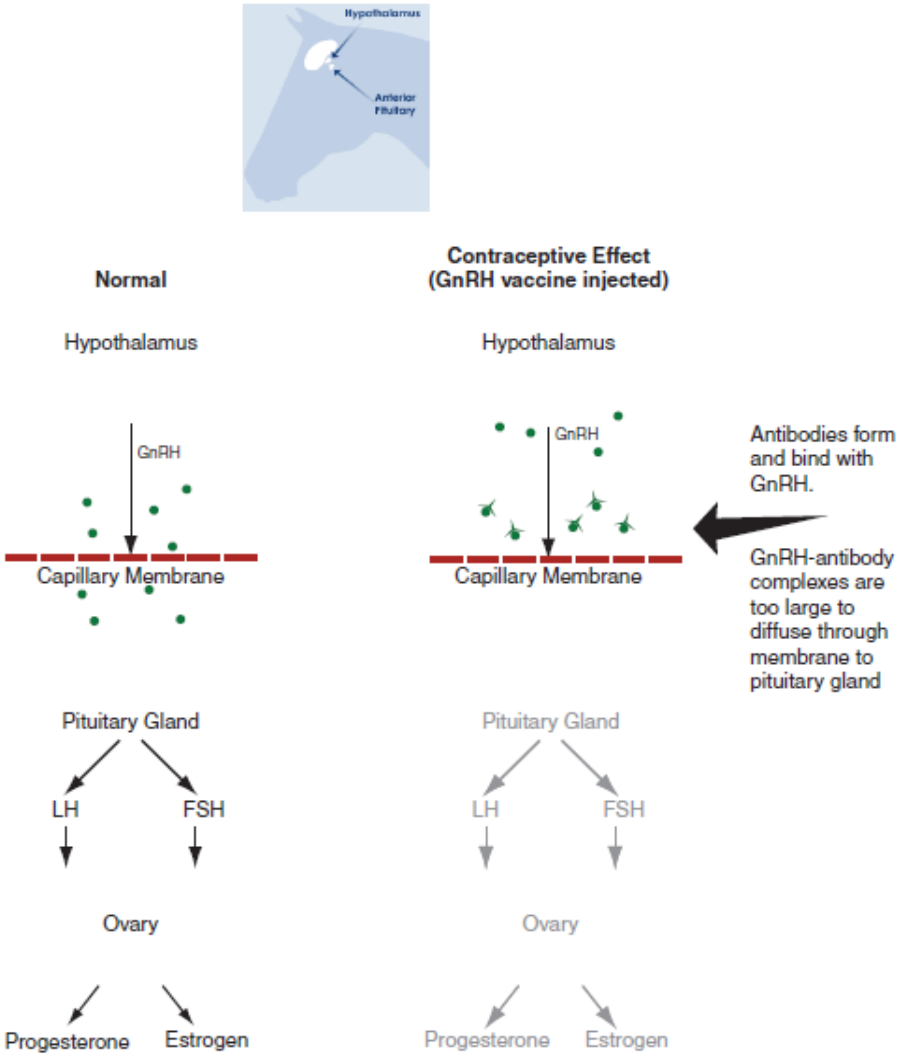


FIGURE 4-3 Mode of action of gonadotropin-releasing hormone (GnRH) vaccines.

NOTE: Without GnRH to stimulate follicle-stimulating hormone (FSH) and luteinizing hormone (LH), there is no production of ovarian estrogen or progesterone and no ovulation.
SOURCE: Adapted from Asa et al. (1996).

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Delivery Route. GonaCon™ Equine, developed by NWRC and licensed by the U.S. Environmental Protection Agency (EPA) for use in horses, can be delivered by hand injection or by dart. An experimental version of GonaCon-KLH™ was delivered by dart to white-tailed deer in New York (Curtis et al., 2002).

Efficacy. Killian et al. (2008a) studied the efficacy of GonaCon-KLH in 16 penned horses (eight controls) in Nevada and found that efficacy over the 4 years of the study was 94 percent, 60 percent, 60 percent, and 40 percent, respectively. Gray et al. (2010) evaluated the efficacy of GonaCon-B™ in 24 free-ranging horses in Nevada and found efficacy of 61 percent, 58 percent, and 69 percent during each year of the 3-year study, respectively. As mentioned above, Gray et al. (2010) used a conservative method to estimate efficacy compared with most authors who have assessed contraceptive efficacy and suggested this as one possible explanation for the discrepancy between their results and others' results. A second explanation put forward by the authors was potential differences in body condition between the captive and free-ranging mares used in the two studies. Research suggests that animals that have more energy reserves or are in better body condition have stronger immune systems and thus are able to mount stronger responses to foreign antigens (Chandra, 1996; Demas et al., 2003; Houston et al., 2007). In both studies GonaCon was emulsified with the AdjuVac adjuvant.

Botha et al. (2008) studied Improvac in a large sample (n=55 treated) of mares kept in very large pastures in South Africa. Mares were vaccinated twice (day 0 and day 35) in the middle of the breeding season. By day 35, only 14.5 percent of treated mares showed evidence of ovarian activity as assessed with ultrasonography; at day 70, no treated mare demonstrated ovarian activity. The authors indicated that the 14.5 percent of treated mares that had evidence of ovarian activity at day 35 received their first vaccination during the luteal phase and suggested that the timing of vaccination in the ovulatory cycle is important. Imboden et al. (2006) also evaluated Improvac in nine mares by vaccinating them twice, 4 weeks apart. Ovarian suppression occurred at 4 weeks and lasted a minimum of 23 weeks, but the authors found significant variability in duration and strength of suppression that did not correlate with antibody titers.

In a study of Equity in Australia, Elhay et al. (2007) vaccinated 24 domestic mares at day 0 and boosted them on day 28. All treated mares showed reduced ovarian activity; by 4 weeks after the booster, ovaries of treated mares resembled those of seasonally anovulatory mares.

The efficacy of GnRH vaccines has also been studied in other species. In an early study with an experimental version of GonaCon-KLH, Miller et al. (2000) reported an 88-percent reduction in fawning in eight white-tail does. In a series of studies of white-tailed deer in Maryland (n=28, Gionfriddo et al., 2009) and New Jersey (n=32, Gionfriddo et al., 2011a), GonaCon-KLH emulsified with AdjuVac resulted in 67- to 88-percent contraceptive efficacy in year 1 and 43- to 47-percent efficacy in year 2. Those values were lower than the ones reported for captive deer. Miller et al. (2008) found 100-percent efficacy in years 1 and 2 and 80-percent efficacy in years 3-5 for five does treated with GonaCon-B compared with 100 percent in year 1, 60 percent in year 2, 50 percent in years 3 and 4, and 25 percent in year 5 for GonaCon-KLH given as a single injection to five does. A two-injection protocol of GonaCon-KLH was identical in efficacy to GonaCon-B in years 1-2. Gionfriddo et al. (2011a) suggested that their efficacies were lower because their wild deer were in poorer nutritional condition and living in overgrazed habitats. However, Perry et al. (2006) found only 60-percent efficacy over 3 years in 28 captive black-tailed deer, so species differences also seem possible. Curtis et al. (2002) reported an 87-

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percent efficacy in 32 white-tailed deer over 2 years using an experimental version of GonaCon-KLH administered as a two-shot series in year 1 and a booster at year 2. In years 3 and 4 of their study, efficacy declined to 71 percent and 43 percent, respectively, in the absence of a booster. Fawning rates were significantly lower than those of controls in years 1 and 2.

Killian et al. (2009) evaluated two doses (1,000 or 2,000µg) of GonaCon-KLH in 22 captive female elk over a 3-year period. Low-dose efficacy was 92 percent, 90 percent, and 100 percent over the 3 years compared with high-dose efficacy of 90 percent, 100 percent, and 100 percent; these differences were not significantly different. Ten captive female Rocky Mountain elk treated with GonaCon-B had significantly reduced pregnancy rates for 3 years (90-percent reduction in year 1, 75-percent in year 2, and 50-percent in year 3) compared with controls (Powers et al., 2011).

Efficacy of GonaCon-KLH was 100 percent in six female bison for 1 year (Miller et al., 2004). In a short-term study (12-14 weeks) of six female wild boar, 100 percent of GonaCon-treated sows became infertile (Massei et al., 2008). In another short-term study (36 weeks) of feral swine treated with two different doses of GonaCon-KLH, Killian et al. (2006) found that none of the nine sows receiving the higher dose was pregnant at the end of the study and only 10 percent gave birth during the study. Of the 11 sows receiving the lower dose, 56 percent gave birth during the study and 11 percent were pregnant by the end of the study. The authors reported 80- to 90-percent efficacy in domestic pigs in previously published studies from their laboratory.

Reversibility. Elhay et al. (2007) found that in mares treated with Equity the duration of ovarian quiescence ranged from 4 to 23 weeks in 10 of 16 treated mares. The remaining six mares did not return to cyclicity during the study (the duration was about 34 weeks for a sample of mares monitored over a longer term). Three mares with short-duration effects (4-8 weeks) were characterized by low antibody titers. The most frequent duration of contraceptive effects was 23 weeks.

Massei et al. (2008) cited their own unpublished data on GonaCon treatment in wild boar sows that suggest that the vaccine works for several years. Miller et al. (2000) stated that their experimental version of GonaCon-KLH appeared to be reversible in white-tail does and that infertility appeared to last for 2 years without boosting.

Side Effects: Physical and Physiological. GonaCon-B-treated free-ranging mares showed no evidence of injection-site reactions to vaccination (Gray et al., 2010). Mares treated with Improvac demonstrated significantly reduced progesterone concentrations that were still at baseline at day 175; in addition, treated mares had reduced ovarian volume (Botha et al., 2008). Injection-site reactions were transient and disappeared by day 6. In the Imboden et al. (2006) study of Improvac, vaccination significantly affected the number, size, and types of ovarian follicles, corpora lutea, and progesterone concentrations but not estradiol. Most mares showed reactions to the injections, including swelling, pain, stiffness, pyrexia, and apathy, but these signs disappeared within 5 days. The difference between these Improvac studies in occurrence and severity of injection-site reactions could be related to injections being given in the neck (Imboden et al., 2006) instead of the hip (Botha et al., 2008). Mares treated with Equity have demonstrated reduced progesterone concentrations, reduction in ovary and follicle size, and absence of corpora lutea (Elhay et al., 2007).

Kirkpatrick et al. (2011) expressed concerns about GnRH vaccines, pointing out that GnRH receptors are found in various body tissues and that GnRH can act as a neurotransmitter.

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GnRH can affect olfaction in rodents, can depress activity of the cerebral cortex, and is associated with two genetic disorders of the cerebellum. However, many of the results mentioned are from studies that used GnRH agonists that result in supranormal concentrations of GnRH. GnRH vaccines block rather than enhance any effects of GnRH, so the effects of the two methods would be expected to be opposite in some or all tissues that have GnRH receptors (see section below "Gonadotropin-Releasing Hormone Agonists").

Side Effects: Pregnancy, Birth Seasonality, and Survival. In probably the earliest study of a GnRH vaccine, Goodloe (1991) found no differences in birth seasonality between treated and untreated mares on Cumberland Island, a barrier island off the coast of Georgia. She did observe significantly higher mortality in foals born to treated mares in 1 year and a nonsignificant trend in the same direction in the second year, but other possible effects (such as age, body condition, dominance rank, and habitat quality) were not considered. Gray et al. (2010) found no effects of GonaCon-B on birth seasonality, foal survival, or foal sex ratio in free-ranging horses. In a review of contraceptive vaccines in wildlife, Kirkpatrick et al. (2011) stated that GnRH vaccines should be safe for pregnant horses because pregnancy is maintained by the placenta in this species, but they presented no data. However, pituitary LH, which depends on GnRH, is needed for pregnancy maintenance during about the first 6 weeks of pregnancy, after which equine chorionic gonadotropin (eCG) takes over this role.

In other species, Powers et al. (2011) found that GonaCon-B administered mid-gestation to captive female Rocky Mountain elk did not affect calving or calf survival. Miller et al. (2000) found that fawns born to white-tail does treated with an experimental version of GonaCon-KLH were normal and healthy. They did find indications that some treated does were able to produce enough LH to conceive, but the progesterone produced by the corpus luteum was not adequate to carry pregnancy to term. In a study of an experimental GonaCon-KLH, Curtis et al. (2002) found that fawning dates of treated white-tail does were later than those of control does in the first 2 years of the study when efficacy was high but not significantly different when efficacy was lower (less than 71 percent). Female bison treated with GonaCon-KLH in the final months of pregnancy delivered healthy calves at calving dates comparable with those of controls (Miller et al., 2004); this suggests that it can be used safely in the last trimester of pregnancy in this species.

Side Effects: Genetic. Because a GnRH vaccine is an immunocontraceptive, its potential genetic side effects (that is, its selection against a stronger immune response) would be similar to those of PZP mentioned above.

Side Effects: Behavioral. Reviews of the effects of GnRH vaccines and independent studies have suggested that GnRH vaccines have a stronger suppressive effect on LH than on FSH, so sexual behavior may not be suppressed completely in females (Thompson, 2000; Stout and Colenbrander, 2004; Imboden et al., 2006; Powers et al., 2011). That is, continued production of FSH, and later of estradiol, may support estrous behavior but without ovulation, which requires LH. An additional or alternative explanation might be continued production of adrenal sex steroids in the absence of ovarian steroids; this has been shown to support estrous behavior in domestic horses during the nonbreeding season or after ovariectomy (Asa et al., 1980a). In Gray's (2009) study of the effects of GonaCon on behavior of free-ranging horses in Nevada during both breeding and nonbreeding seasons, there were no treatment effects on activity

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budget, rates of sexual behavior, proximity between stallions and mares, attempts to initiate proximity, aggression given or received, or band-changing by mares. In white-tailed does previously treated with GonaCon, the recovery of estrous behavior in years 3, 4, and 5 after vaccination was suppressed when does received an additional vaccination with an anti–follicle-stimulating, hormone-releasing hormone (Killian et al., 2008b), a peptide similar in structure to GnRH.

Effects of GonaCon in Other Ungulate Species. Because GonaCon has not been tested extensively in equids, its effects in other ungulate species are reviewed in this section. Killian et al. (2008b) found that 10 white-tailed does treated with either formulation of GonaCon exhibited estrous behavior less frequently in the first 2 years after treatment, but in later years estrous behavior was displayed more often, even though does were still infertile; this suggests that estrous behavior may return before fertility is fully restored. Miller et al. (2000) found that eight does treated with an experimental version of GonaCon-KLH demonstrated the same number of estrous events, defined by bucks sniffing and chasing does, as control does during 30-44 days of observation during the rut. In their study of an experimental GonaCon-KLH, Curtis et al. (2002) found that treated does cycled later in the year during the second year of treatment than in the first year. Perry et al. (2006) found significantly reduced progesterone in female black-tailed deer treated with GonaCon-KLH. Gionfriddo et al. (2006) found no histopathological effects in a variety of tissues in 28 female white-tailed deer treated with GonaCon-KLH; 29 percent of treated does had injection-site reactions, but they were not discernible externally and were not considered serious. Gionfriddo et al. (2011a,b) found that ovaries and uteri of 32 GonaCon-KLH-treated white-tailed does were smaller than those of controls. Major organs, organ systems, and blood-chemistry parameters were normal in most treated deer (Gionfriddo et al., 2011b). When abnormalities were seen, they could not be clearly related to treatment, and treated does had higher body-condition scores than controls.

Captive female Rocky Mountain elk treated with GonaCon-B did not differ from controls in biochemistry or hematology parameters, and there was no effect on female precopulatory behavior (Powers et al., 2011). There was a nonsignificant trend for males to direct more precopulatory behavior toward treated does than at controls. Treated females did have more follicles than controls, but the follicles were smaller and fewer corpora lutea were present. The authors also commented that GonaCon-B used in conjunction with AdjuVac can cause a positive result on Johne's disease antibody testing. Injection-site abscesses occurred in 35 percent of treated does, and some lasted for years, but most treated or sham-treated animals showed some level of reaction.

Adams and Adams (1990) vaccinated 30 heifers with GonaCon-KLH mixed with Freund's complete adjuvant. All treated animals had significantly reduced progesterone, reduced uterine and ovarian tissue mass, and reduced GnRH receptor numbers. GonaCon-KLH-vaccinated female bison demonstrated suppressed progesterone (Miller et al., 2004).

Massei et al. (2008) found no effects of GonaCon on activity budgets, social rank, injection-site reactions, or hematology and biochemistry parameters in a 14-week study of wild boar sows. Treated sows gained more weight, but the gain was considered modest. In a short-term study (36 weeks) of feral swine treated with two different doses of GonaCon-KLH, Killian et al. (2006) found that treated sows had significantly reduced progesterone and numbers of corpora lutea, although females in both treatment groups showed some evidence of follicular activity. There was also evidence of regression of the uterine epithelium.

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In studies of GonaCon, injection-site reactions were likely in most species, even if they were not externally visible, but these reactions appeared to be minor and relatively short-lived in most cases. Miller et al. (2008) explained that the water-in-oil emulsion that is often mixed with GonaCon is necessary to induce a long-term immune response, and it is generally accepted that some local reactions (cysts, granulomas, or sterile abscesses) at the injection site are common.

Gonadotropin-Releasing Hormone Agonists

As described above, GnRH, which is produced in the hypothalamus, initiates the cascade of reproductive hormones by causing pituitary release of FSH, which enhances follicle growth, and LH, which triggers ovulation. GnRH agonists (synthetic versions of GnRH that have activity similar to the natural hormone) are commonly used in many domestic species to stimulate follicle growth, estrus, and ovulation. Ovuplant® (deslorelin in a short-acting implant; Peptech Animal Health, Australia, now part of Virbac, France) was developed specifically to induce ovulation in domestic mares. Another GnRH agonist product, Suprelorin® (deslorelin in a slow-release implant matrix; Peptech Animal Health), was developed for use in domestic dogs and is now widely used for contraception in a broad array of captive wildlife species, including female ungulates. GnRH agonists can act as reversible contraceptives when treatment is extended for more than a few days. After the initial stimulation phase, continued administration results in down-regulation of the pituitary cells that synthesize FSH and LH. Without FSH and LH support, the ovaries become quiescent; this condition is sometimes referred to as reversible chemical ovariectomy.

Delivery Route and Efficacy

Suprelorin implants, similar in size to animal ID microchips, are inserted with a trocar, which requires brief restraint but not anesthesia. Two formulations that are active for a minimum of 6 or 12 months are available, but experience has shown that the duration of contraception is longer in most animals—an average of 12 and 18 months, respectively.[7] At an adequate dose, GnRH agonists are effective in females of virtually all mammal species, but they have not been tested specifically as contraceptives in horses, burros, or wild equids. Short-term treatment to control ovulation and to investigate their action on pituitary function indicates that GnRH agonists could be effective in suppressing reproduction in mares (Montovan et al., 1990; Fitzgerald et al., 1993). For example, even the short-acting product Ovuplant, designed merely to stimulate but not down-regulate reproduction in mares, has delayed return to cycling in some animals (Johnson et al., 2002). That observation suggests that continued treatment with a long-acting, slow-release implant, such as Suprelorin, would be effective for fertility control, even though the mare appears to be more resistant to pituitary desensitization than other species (Porter and Sharp, 2002).

Reversibility

GnRH agonists are considered generally reversible, primarily on the basis of studies of domestic dogs (Junaidi et al., 2003; Ludwig et al., 2009), cats (Toydemir et al., 2012), and humans (Plosker and Brogden, 1994). However, the duration of effect is greater in some

[7]Database managed by the Association of Zoos and Aquariums Wildlife Contraception Center (St. Louis, MO). Accessed July 20, 2012.

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individual animals, and this confounded documentation of reversal before data collection stopped in a study of domestic cats (Munson et al., 2001). In addition, long-term treatment is associated with a longer time to recovery (Nejat et al., 2000). Other studies have reported what may be permanent effects, for example, during treatment of prostate cancer in men (Murthy et al., 2007).

Side Effects

GnRH agonists have not been used often during pregnancy, so potential effects have not been systematically investigated. Possible effects can be predicted by examining another role of LH: maintenance of corpora lutea (CL) that produce the progesterone required for pregnancy to become established. However, around day 40, increasing concentrations of eCG produced by specialized cells in the uterine endometrium assume the role of stimulating CL progesterone production. Later, the feto-placental unit takes over progesterone synthesis from the CL for the remainder of gestation. Because LH is needed for support of progesterone secretion only during very early pregnancy, treatment with a GnRH agonist after that time would be unlikely to cause abortion.

Data from captive wild canids (African wild dogs and Mexican wolves) treated with Suprelorin during pregnancy revealed an unexpected consequence of GnRH agonist treatment. Females given Suprelorin implants in early pregnancy gave birth but did not produce sufficient milk to feed their pups; this indicates that some aspect of mammary development and milk production was affected.[8] However, initiation of treatment during lactation after milk production has been established appears to have no effect.

Effects of GnRH agonists on behavior, after the initial stimulation phase when estrous behavior might result, should be similar to those associated with ovariectomy. That is, estrous cycles would be absent, but sporadic expression of estrus supported by adrenal sex steroids might occur.

Repeated administration of various formulations of GnRH agonists (e.g., deslorelin acetate) for the induction and enhancement of ovulation and for the initiation of cyclicity in the transitional and anestrous phases of the estrous cycle in domestic mares is a standard and routine procedure used on broodmare farms worldwide (Squires, 2011). No adverse effects of repeated administration of these GnRH agonists have been reported in the literature over the last 2 decades since its acceptance, and they continue to be used in the manipulation of the estrous cycle in domestic mares (I.K.M. Liu, University of California, Davis, personal communication, August 2012). Because of the possibility of species differences in response, the relevance to free-ranging wildlife is unclear and deserves further study.

Steroid Hormone Treatments

Progesterone and estrogen are the hormones that change with estrous cycles and support pregnancy in mammals. However, administration of natural or synthetic forms can prevent pregnancy, usually by negative feedback on the reproductive hormone axis.

Natural and Synthetic Progestagens

In the luteal or diestrous phase of the ovarian cycle and during pregnancy, high levels of progesterone suppress the final stages of follicle growth and ovulation. Thus, synthetic

[8]Association of Zoos and Aquariums Wildlife Contraception Center database. Accessed July 20, 2012.

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progestagens are attractive candidates for contraception and in fact are widely used for that purpose in women (e.g., Implanon® implants; etonorgestrel; Depo-Provera®, medroxyprogesterone acetate in a depot vehicle for injection) and in captive wild animals (MGA implants; melengestrol acetate, Wildlife Pharmaceuticals).

Delivery Route, Efficacy, and Reversibility. Progesterone or its synthetic equivalents can be administered as implants or as injections that might be delivered remotely by dart. With a sufficient dose, the efficacy rate approaches 100 percent. Silastic implants containing a progestagen can be effective for 2 years or more[9] and generally have a high reversal rate. The likelihood that a female will reproduce after such treatment is subject to other factors that affect fertility, such as age, health, and parity before treatment. Reversal can be hastened by removing the implant.

The vast number of studies on the treatment of mares with progesterone or synthetic progestagens have been for short-term control and timing of ovulation, not for contraception (e.g., Pinto, 2011). However, results of this body of work have shown that only one synthetic progestagen, altrenogest, is consistently effective in suppressing reproductive function in mares. Two others have been effective at very high concentrations in only some studies (Storer et al., 2009; Pinto, 2011). Those results are attributed to the specificity of the progesterone receptor in mares (Nobelius, 1992). At the time this report was prepared, the only progestagen product approved for use in domestic mares was altrenogest (Regu-Mate®). The only studies of progestagen contraception in mares used native progesterone in silastic implants to treat feral mares in holding pens in Nevada. Those placed subcutaneously in the neck area were lost, became infected, or both and so were not effective for limiting reproduction (Plotka et al., 1988). In a later study of the same population of captive feral mares, insertion into the peritoneal cavity prevented loss, and no evidence of infection was reported (Plotka et al., 1992). However, the doses of progesterone used (implants contained either 8 or 24 g of progesterone) suppressed signs of estrous behavior but did not prevent ovulation and conception. That work was suspended also because of the invasive nature of the surgery and the unacceptable stress placed on mares (BLM, 2003, revised 2005). It is possible that treatment with altrenogest would be more successful than progesterone because synthetic steroid hormones typically have substantially higher bioactivity and affinity for the receptor and a lower metabolic clearance rate. The consequence is that smaller doses are needed for increased binding and efficacy. However, at the time of the committee's study, there was no altrenogest product that was active for more than 30 days.

Side Effects. Progesterone and synthetic progestagens support pregnancy but interfere with parturition by suppressing contractility of uterine smooth muscle. At doses high enough to be contraceptive, progestagens can block parturition, as documented, for example, in white-tailed deer (Plotka and Seal, 1989). Altrenogest is often used to maintain pregnancy and delay parturition in horses, but a study by Neuhauser et al. (2008) found that it did not prevent parturition, raising the question of its efficacy for maintaining pregnancy. However, there were some differences in health and survival of foals born to altrenogest-treated mares in that study. Although progesterone (as the "progestational" hormone) supports gestation, synthetic progestagens often have affinity for other steroid hormone receptors as well. For example,

[9]Wildlife Pharmaceuticals, Association of Zoos and Aquariums Wildlife Contraception Center database. Accessed July 20, 2012.

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binding to androgen receptors might masculinize female fetuses, depending on the dose and stage of fetal development. However, fillies born to mares treated with the synthetic progestagen altrenogest during pregnancy (but not around the time of expected parturition) showed normal reproductive development, hormone production, and fertility (Naden et al., 1990). Progestagen treatment during lactation would not be expected to have a deleterious effect on milk production and in fact might enhance it. There are no data specifically on horses, but progestagens are a preferred method of contraception in women (Tankeyoon et al., 1984) and are not contraindicated in other species.

Side effects of progestagens vary taxonomically. Progestagen treatment of carnivores is associated with life-threatening mammary and uterine pathological conditions, whereas several uterine pathological conditions in primates (including women) are reversed by treatment with progestagens. Information on long-term administration of progestagens in equids is lacking, but extrapolation of results in other ungulates suggests that hydrometra (fluid accumulation in the uterus) might be expected.

Natural and Synthetic Estrogens

Estrogen is instrumental in the sexual characteristics of mammals and in the regulation of the menstrual cycle. Estrogen treatment can reduce concentrations of FSH and LH in the blood stream and thus decrease the development of viable eggs.

Delivery Route, Efficacy, and Reversibility. Both natural estradiol (a specific estrogen) and synthetic ethinyl estradiol, incorporated into silastic implants, have been tested as contraceptives in captive and free-ranging feral horses (Plotka et al., 1988, 1992; Eagle et al., 1992). In the trial with 8-g estradiol implants placed in the neck of 30 feral mares in holding pens (Plotka et al., 1988), loss of many implants compromised results, but most of the mares that retained the implants mated and conceived, probably because the dose was insufficient. In a subsequent trial at the same facility, 1.5-g, 3-g, and 8-g ethinyl estradiol implants were placed intraperitoneally to prevent loss in three groups of 8-10 mares each. Contraceptive efficacy of those implants was 75 percent, 75 percent, and 100 percent, respectively (Plotka et al., 1992). Extrapolation from assays of ethinyl estradiol from blood samples up through 21 or 30 months suggested contraceptive efficacy from 16 months (1.5-g implants) to 60 months (8-g implants). Efficacy was judged by the number of mares ovulating or pregnant according to cyclic or sustained increases in progesterone, respectively. On the basis of data on duration of efficacy, it appears that all treated mares returned to cycling, and this suggests reversibility. However, follow-up did not extend to production of young. Behavioral data were not collected, and no deleterious effects were reported.

Side Effects. Estrogens are more effective in suppressing follicle growth than progestagens, but at contraceptive doses they have been associated with serious side effects. A general action of estrogen is to stimulate cell proliferation, but it also can be mutagenic (Liehr, 2001). At the high doses required to achieve contraception, the result can be abnormal growth (hyperplasia) and even cancer (neoplasia) of organs that have estrogen receptors, such as the uterine endometrium, mammary glands, pituitary, and liver (Gass et al., 1964; Santen, 1998). In mares, estrogen is associated with uterine edema (Pelahach et al., 2002). Therefore, unopposed estrogen treatment is not prescribed; instead, estrogen is typically combined with a progestagen, which tempers its

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effect on most target tissues. Almost all formulations of human birth-control pills contain synthetic estrogen plus progestagen; one contains only progestagen.

Treatment of mares with estrogen stimulates estrous behavior (Asa et al., 1984), but male-like behavior has been observed with continued treatment (Nishikawa, 1959), suggesting a shift in steroid metabolism to favor conversion to an androgen. Such male-type behavior was observed (C. Asa, unpublished) in free-ranging mares in Nevada treated with ethinyl estradiol (study by Eagle et al., 1992). However, no systematic observations were conducted on expression of social or sexual behavior in the studies by Plotka, Eagle, and colleagues (Plotka et al., 1988, 1992; Eagle et al. 1992).

Combination Estrogen Plus Progestagen

As mentioned above, all formulations of human birth-control pills except one contain synthetic estrogen plus progestagen. The major contraceptive action of estrogen is to inhibit follicle growth, whereas progestagen prevents ovulation, so the combination is more effective than progestagen-only contraceptive formulations (because of the associated pathological changes, there are no commercially available estrogen-only contraceptives). The addition of a progestagen allows the use of a lower estrogen dose and reduces the probability of side effects. In addition, progestagen counters some estrogen effects, such as inhibition of estrous behavior. In general, the hormonal effect of the combination is most analogous to pregnancy.

A combination of natural progesterone and ethinyl estradiol in silastic implants was tested in captive and free-ranging mares (Plotka et al., 1992; Eagle et al., 1992) and found to be effective in preventing pregnancy or foaling, respectively. Efficacy was 100 percent in captive mares and 84-90 percent in free-ranging mares; the discrepancy was attributed to the less exact methods of assigning foals to mares in the helicopter surveys of the free-ranging herds. The combination implants, inserted intraperitoneally, were effective for 2 or 3 years. As mentioned above in connection with estrogen alone, it appears that all treated mares returned to cycling, but follow-up did not extend to production of young. Although there are no other published reports on estrogen plus progesterone treatment of equids or other ungulates, results of studies of nonhuman primates indicate a high rate of reversal (Porton and DeMatteo, 2005). No behavioral data were collected, so effects on behavior or social organization are not available.

Intrauterine Devices

Intrauterine devices were first used in domestic animals (such as camels) perhaps thousands of years ago. IUDs were a nonhormonal alternative for women in the 1960s and early 1970s that fell out of favor in the late 1970s, mostly because of problems with the Dalkon Shield (Sivin, 1993). Later analyses of IUD use in women have shown the method to be both highly effective and safe (Chi, 1993; Sivin, 1993; Rivera and Best, 2002). The precise mechanism of action of IUDs is not well described but is thought to be low-grade inflammation of the uterine endometrium provoked by the presence of the foreign object. Thus, IUDs may more appropriately be considered antigestational devices in that endometrial inflammation is not conducive to embryo implantation. Although there have been few studies of IUD use in nonhuman animals, some species may be well suited to this method.

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Delivery Route, Efficacy, and Reversibility

Two studies have evaluated IUDs in domestic and captive feral horses. The first (Daels and Hughes, 1995) used a flexible, silastic O-ring, fabricated specially for the study, in six domestic mares; when compressed, it could be easily inserted into the cervix and later removed in the same way. During the breeding season after the IUDs were in place, none of the mares conceived, but all conceived after IUD removal during the next 2 years. Uterine health was monitored with palpation, ultrasonography, and vaginoscopy when samples were taken for uterine cytology and culture. Cytology and culture results were consistent with inflammation, which reversed within a week of IUD removal. It was concluded that the inflammatory response was sufficient to interfere with fertility. Mares that had IUDs in place continued to exhibit estrous cycles with the same frequency as control mares.

The second study (Killian et al., 2004), of 15 feral mares in a holding facility, used a commercially available copper-containing IUD, which is considered more effective because of the spermicidal action of copper ions (O'Brien et al., 2008). In a pilot study, the authors tested three types of copper-containing products on four mares and selected the copper T for the larger study of 15 mares. After 60 days with a stallion, 20 percent of the IUD-treated mares were pregnant compared with 75 percent of the control mares. After the second and third years, 71 and 86 percent were pregnant, respectively (Killian et al., 2006). The authors believed the pregnancies of the IUD-treated mares were due to loss of the relatively small IUDs, not to failure of efficacy, because no IUDs were found on ultrasound examination of the pregnant treated mares.

MALE-DIRECTED METHODS OF FERTILITY CONTROL

Potential methods of fertility control directed at male equids include castration, vasectomy (chemical or surgical), and immunocontraceptives. The mode of action and effects of each method are reviewed below.

Surgical or Chemical Sterilization

Sterilization of male equids can be accomplished through removal of the testes, permanent disruption of spermatogenesis, or blockage of the vas deferens to prevent the passage of sperm.

Castration

Castration, also referred to as gelding in equids, eliminates the organs that produces sperm, thereby making the male infertile. Surgical castration has been common husbandry practice for domestic equids for over 2,000 years.

Delivery, Efficacy, and Reversibility. Castration (gelding) is a routine operation for domestic male horses and is much less invasive or risky than the comparable surgery in mares. However, complications can occur at a rate of about 10 percent, including hemorrhage from the spermatic artery if not properly crushed; inadequate postoperative drainage that results in swelling, infection, or hydrocele (fluid accumulation); or even evisceration in rare cases (Blodgett, 2011).

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Surgical castration is, of course, permanent and is 100-percent effective in eliminating the source of sperm.

An agent for chemical castration (formerly Neutersol®, now Esterilsol™, Ark Sciences, New York City) developed for and extensively tested in domestic dogs might also be effective in stallions. A solution of zinc gluconate with L-arginine is injected into each testicle, where it causes permanent disruption of the seminiferous tubules, where spermatogenesis occurs. However, given the much larger volume of stallion testes, the technique might need modification and would require testing under controlled conditions before application in the field could be considered.

Efficacy of Esterilsol is not well established, even in dogs, in that the product is relatively new. Available data indicate that efficacy depends primarily on proper injection of the solution so that it is distributed adequately throughout the testis. It is claimed to be virtually painless (ACC&D, 2012).

Side Effects. Because castration removes the primary source of androgen production, male-type aggressive and sexual behaviors are usually reduced. Adrenal androgens (such as dehydroepiandrosterone) are still produced, but they are weaker and have much less effect on behavior than testosterone. Some geldings show less alteration in behavior after castration, potentially because of the adrenal androgen action but more probably because of individual differences in temperament, prior experience, or both and because of development of behavior patterns that are slow to disappear. Males that do not retain sufficient sex drive and aggressive competitiveness to acquire and maintain a harem could be outcompeted or supplanted by intact, fertile males.

The effects of chemical castration on testosterone production are not clear. The mechanism of action (spermicidal action of zinc gluconate) is supposed to spare the Leydig cells, which produce testosterone. However, the generalized scarring that occurs, and that is necessary for the permanent changes in testicular architecture to prevent further sperm production or release, could also affect Leydig cell structure and compromise hormone synthesis and release. The extent of the effect on testosterone production would determine the possible effects on male-type behavior.

Individual males vary in their behavioral response to castration—for example, in the loss of male-type behavior, such as aggression and sexual interest, depending on the age and sexual experience of the male. However, some or total loss of sex drive would be likely in castrated stallions, and this is counter to the often-stated public interest in maintaining natural behaviors in free-ranging horses. The effect that gelding a portion of the males in a herd would have on reproduction and behavior could not be predicted at the time this report was prepared. Aside from variability in how much male-type behavior is lost in gelded animals, the effects of gelding on reproduction and behavior in the population will also depend on the roles that the males selected for gelding (whether harem males or bachelors) hold in the population, their reproductive and social history, and possibly their age. Keeping a portion of the male population nonreproducing by gelding could increase aggression and competition in herds or decrease it. Similarly, reproductive success may be reduced or increased. With respect to effects at the population level, it is not clear how castration of males would be better than vasectomy, which does not affect testosterone or male-type behaviors. Ultimately, the growth rate of any population that includes reproductive horses of both sexes will be commensurate with the number of fertile females in the population.

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Vasectomy

Vasectomy, whether surgical or chemical, does not affect the production of sperm but does prevent ejaculation of sperm by blocking the epididymis (where sperm leave the testis) or the vas deferens (the duct that carries sperm to the urethra for ejaculation).

Delivery and Efficacy. A potential disadvantage of both surgical and chemical castration is loss of testosterone and consequent reduction in or complete loss of male-type behaviors necessary for maintenance of social organization, band integrity, and expression of a natural behavior repertoire. Vasectomy blocks passage of sperm without affecting testosterone synthesis or secretion, sparing androgen-supported natural behaviors. The most widely used vasectomy method is surgical, although there are several variations that are meant to increase efficacy, reduce production of sperm granulomas, or facilitate microsurgical vasectomy reversal (Esho and Cass, 1978; Frenette et al., 1986; Moss, 1992; Silber, 1989). After either chemical or surgical vasectomy, the average delay to passage of all remaining sperm from the vas deferens is about 6 weeks, so treatment should occur well in advance of the mares' breeding season to ensure infertility.

Surgical vasectomy in dominant stallions has been used successfully to control fertility in bands of free-ranging horses (Eagle et al., 1993; Asa, 1999). The vasectomy procedure was 100-percent effective in preventing foal production in stable bands that had no subordinate stallions, but some of the bands that had intact subordinate stallions contained foals. The stability of bands did not differ between treated and untreated groups. However, limiting treatment to dominant stallions leaves subordinate band stallions and bachelors fertile and thus reduces overall efficacy. In particular, bands that had subordinate stallions were vulnerable (Asa, 1999). The probability that subordinate stallions will mate is higher in bands that have a vasectomized dominant stallion because the females continue to have estrous cycles throughout the entire breeding season, whereas females with intact, fertile stallions are likely to conceive in the first month or so of the breeding season. Thus, females with vasectomized dominant stallions present many more opportunities for mating with a subordinate. For population control, a more effective approach would be to vasectomize a larger proportion of males, regardless of age or social status. The target number or proportion of males treated could be adjusted to achieve the level of population control recommended for each HMA.

Chemical vasectomy is a simpler, less invasive alternative to a surgical approach, but both require anesthesia. Several chemical agents have been assessed in domestic dogs and cats (Pineda et al., 1977; Pineda and Dooley, 1984). There are no published reports on chemical vasectomy in horses, but the procedure should not be difficult to adapt.

Reversibility. Both surgical vasectomy and chemical vasectomy should be considered permanent if properly done. Vasectomy reversal has been successful in humans in some cases (Silber, 1989), but it requires microsurgery by a highly skilled surgeon, so it would not be practical for field application. Spontaneous reversal has been reported after some surgical approaches—resulting from recanalization of the vas deferens (Esho and Cass, 1978)—so the choice of technique is critically important.

Side Effects. There are no reported side effects of vasectomy, a procedure that is considered safe and effective even in humans, in whom it has become commonplace. However, in free-ranging horse herds that have vasectomized males, females that do not conceive continue to undergo

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estrous cycles until the end of the breeding season and continue to attract and mate with males (Asa, 1999). Thus, the number of months that males compete for and defend females is increased, and this increases the risk of injury to males and diverts time from foraging that, in some environments, could compromise a male's body condition going into winter. Those problems did not occur in the single study of vasectomy for fertility control (Asa, 1999) but might be more likely under some conditions for some males.

Winter survival of males that do lose condition may be reduced. That is likely to have a number of consequences for a population's dynamics. A lost stallion would probably be replaced quickly by a bachelor male or the mares would be taken in by dominant stallions of other bands. However, the stability of the harems taken over by younger, less experienced males would be more likely to decline (Rubenstein, 1994), and this could reduce female fecundity via increased levels of male harassment. Turnover might enhance the genetic diversity of populations, in that more males would be contributing to the gene pool and thus enhancing effective population size.[10]

Steroid Hormone Treatments

High doses of androgen can suppress endogenous production of testosterone via negative feedback and have a suppressive effect on spermatogenesis. Turner and Kirkpatrick (1982) treated 10 free-ranging stallions with microencapsulated testosterone proprionate. Only 28.4 percent of bands that had treated stallions had foals compared with 87.5 percent of the untreated bands. Although increased concentrations of androgen could be expected to cause increased aggression, it was not reported. However, only territorial marking and sexual behaviors were analyzed. All stallions showed evidence of reversal in about 8 months. No side effects were noted.

GnRH Vaccines

As described in the section on the use of GnRH vaccines in females, treatment with GnRH vaccines interferes with the production of LH and FSH from the pituitary; in males, that results in failure of stimulation of testosterone, which is necessary for stimulation of spermatogenesis and expression of sexual behavior. However, the use of GonaCon or other experimental GnRH vaccines has not completely eliminated sperm production (Malmgren et al., 2001; Turkstra et al., 2005). Stout and Colenbrander (2004) reported that mature stallions treated with GnRH vaccines continued to produce sufficient semen to impregnate a mare.

Delivery Route, Efficacy, and Physical Side Effects

In possibly the first study of GnRH immunization in domestic stallions, Malmgren et al. (2001) evaluated an experimental GnRH vaccine used with the adjuvant Equimune® in four domestic stallions (one control, three treated) during the nonbreeding season. The vaccination protocol involved five shots at intervals of 2-4 weeks. All stallions showed a response, but one male had a significantly lower antibody response than the other two. Two of the treated stallions demonstrated decreases in testosterone and more pronounced decreases in testis size and semen

[10]Genetic diversity and effective population size are discussed further in Chapter 5.

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quality as well as changes in testicular histology, but these effects did not appear until 7-9 weeks after initial vaccination. There was no clear change in ejaculate volume.

Turkstra et al. (2005) evaluated two different adjuvants (Carbopol® and CoVaccine™ HT) with an experimental GnRH vaccine in previously hemicastrated stallions. Four animals were treated with Carbopol, and four animals were treated with CoVaccine HT. Stallions were treated during the breeding season with an initial vaccination, boosted at 6 weeks, and monitored for a total of 14 weeks after the initial vaccination. There were no injection-site reactions and no changes in body weight. The CoVaccine HT treatment was superior; treated stallions had undetectable testosterone from 2 weeks after the booster until the end of the study. Those stallions also had reduced sperm motility, but there were no adjuvant-related differences in semen volume, sperm concentration, or sperm count. Both adjuvants appeared to reduce testis size and alter testis histology in ways that would reduce fertility. The authors suggested that, aside from superior performance, CoVaccine HT is also desirable because time to effect was better defined.

Janett et al. (2009) evaluated the effects of Equity, given to five domestic stallions as three injections at intervals of 4-8 weeks, on testosterone concentrations, sexual behavior, and semen characteristics. Two stallions exhibited minor injection-site reactions that resolved in 2-3 days. Adverse effects on sperm quality were observed in four stallions, although there was individual variation in the strength and type of effect (lower sperm numbers, lower motility, and increased sperm defects), and one stallion had a weak immune response. Overall, those inhibitory effects lasted from 24 weeks to under 46 weeks.

Although not tested in stallions, GonaCon-KLH has been evaluated in a number of studies of male deer. Typical results include reduced testosterone concentrations and testis size (Killian et al., 2005; Miller et al., 2000, but see Gionfriddo et al., 2011a). Killian et al. (2005) found inactive Leydig cells and regressed seminiferous tubules that did not contain mature sperm in eight treated bucks. Gionfriddo et al. (2011b) found that 10 GonaCon-KLH-treated bucks had higher body-condition scores than untreated bucks.

One interesting finding in the Killian et al. (2005) study was that there was a high prevalence of pulmonary disease, the leading cause of mortality, in bucks in their Pennsylvania study site. The incidence of the disease was higher in treated bucks, but the authors reported that the microorganisms that cause the disease are endemic in captive deer herds in Pennsylvania. They speculated that vaccination with GonaCon could have lowered resistance to the disease.

Reversibility

In four stallions treated with Equity, testosterone remained suppressed for 24, 36, 45, and 46 weeks (excluding one low-responding stallion) (Janett et al., 2009). In a study of eight deer bucks that received different treatment protocols, Killian et al. (2005) reported that suppressive effects of GonaCon-KLH on male reproductive physiology appear to last for 3 years, with testicular function beginning to recover in year 4; however, the authors suggested that a low level of sperm production might have persisted.

Behavioral Side Effects

Malmgren et al. (2001) found that four stallions vaccinated with an experimental GnRH vaccine first began to demonstrate reduced sexual interest and behavior 4 weeks after the initial vaccination, and the reduction appeared to persist for about 13 weeks. Libido was reduced in four stallions treated with Equity, including one that did not respond with high vaccine titers.

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The fifth stallion had a strong immune response and significantly reduced testosterone concentrations but maintained very strong, sustained sexual behavior (Janett et al., 2009). Kirkpatrick et al. (2011) expressed concern about the application of GnRH vaccines in stallions because testosterone-supported behaviors, which are necessary for keeping bands together, are suppressed; however, no data or citations are provided for this claim. It appears from the available data that sexual behaviors may be suppressed to various degrees by individual animal, but the effect of the suppression on other behaviors has not been assessed.

In other species, Killian et al. (2005) reported that eight GonaCon-KLH-treated white-tail bucks had reduced libido and interest in estrous does; bucks might mount does but not completely. Miller et al. (2000) found similar effects with an experimental version of GonaCon-KLH in four white-tail bucks and remarked that the rutting season was not extended in treated bucks. The inability of GnRH vaccines to suppress FSH completely, although central to maintenance of sexual behavior in treated females, is not likely to affect males. The possible effects on male behavior are probably limited to suppression of LH, inasmuch as LH alone is needed to support testosterone production. Thus, an adequate vaccine dose that suppressed LH should be accompanied by elimination of testosterone, a situation similar to castration. Whether male-type behavior would continue without testosterone support depends on the temperament and prior experience of the male.

Gonadotropin-Releasing Hormone Agonists

As discussed in the section on their use in females, GnRH agonists first stimulate then suppress production of pituitary and gonadal hormones involved in reproductive function. The pituitary hormones, LH and FSH, are the same as in females, but in males the gonadal hormone affected is testosterone; without testosterone, spermatogenesis is not supported. The outcome can be likened to a potentially reversible chemical castration (Junaidi et al., 2009). Although effective in males of some species, GnRH agonist treatment has had mixed results in male ungulates. In domestic stallions given various GnRH agonist formulations, some studies reported transient stimulation followed by return to baseline or lower concentrations of LH and testosterone (Montovan et al., 1990; Boyle et al., 1991), whereas others showed enhanced LH secretion or sexual behavior (Roser and Hughes, 1991; Sieme et al., 2004). No suppressive effects of what were considered high doses were detected by Brinsko et al. (1998); this led them to conclude that stallions are remarkably resistant to reproductive suppression by GnRH agonist treatment. Nevertheless, the ability of some agonists at some doses to achieve even slight suppression suggests that more potent analogues or higher doses might be effective. Newer, more potent agonists have not yet been tested adequately in stallions.

Delivery Route and Duration of Efficacy

Recent formulations, such as Suprelorin, in slow-release implants are more practical for contraceptive treatment than osmotic pumps or injections. As described in the section “Female-Directed Methods of Fertility Control,” Suprelorin is produced in 6-month and 12-month formulations. Those durations of efficacy represent minimums, and suppression continues for about twice as long in most species.

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Reversibility

Suprelorin reversal rates have not been established for equids, but in male dogs the rate nears 100 percent. However, the rate has been lower in some other species,[11] so caution is recommended in treating a species for the first time.

Side Effects

The side effects of GnRH agonists are similar to those of castration, inasmuch as the treatment can be considered chemical gonadectomy. Because inhibition of spermatogenesis requires suppression of testosterone, any testosterone-supported secondary sex characteristics and behavior would be affected. However, as explained in the section on side effects of surgical castration, males with prior sexual experience may continue to show interest in estrous females but would probably not be able to compete successfully with untreated, intact males.

ADDITIONAL FACTORS IN EVALUATING METHODS OF FERTILITY CONTROL

The sections above included the information most relevant to understanding and choosing a method for fertility control: delivery route, efficacy, duration of effect, and possible side effects. There are, however, some additional effects that should be considered in evaluating the methods. For example, data on the effects of some contraceptive approaches on general health and longevity are accumulating. The energetic costs of pregnancy and lactation are high, and this burden is much greater on free-ranging females that must subsist on lower-quality forage than on domestic animals that have calorie- and nutrient-rich diets. Mares on Assateague Island treated with PZP that did not regularly produce foals were in better body condition and lived longer than females that were not contracepted and continued to reproduce (Turner and Kirkpatrick, 2002).

Several methods (such as vasectomy, PZP vaccines, and GnRH vaccines) are likely to be associated with a prolonged breeding season. That is, mares that are not pregnant continue to undergo estrous cycles until late summer or fall, when daylength is decreasing and no longer stimulates cycling (Sharp and Ginther, 1975). Although nonpregnant females that continue to cycle expend time and energy in courtship and mating, the expenditure is considerably lower than the energetic demands of pregnancy and lactation. Thus, any effect on health and well-being of females should be negligible. In contrast, the burden on males could be greater in that the length of the breeding season, and thus the time in which males compete for and defend estrous females, is prolonged. Time spent in defending and courting females also diverts males from grazing, and this could affect health and body condition under some conditions. However, no study has focused specifically on that issues, and it warrants further investigation.

Early studies of fertility control focused on steroid hormone treatments, mirroring approaches to contraception in humans (such as birth-control pills that contain synthetic estrogen and progestagen). However, serious concerns arose regarding the tissue accumulation of synthetic steroids (testosterone in males, estrogen and progestagen in females) because they become concentrated in fat and muscle (Lauderdale et al., 1977; Hageleit et al., 2000). The potential for those compounds to enter the food chain argues against their use in free-ranging wildlife.

[11] Association of Zoos and Aquariums Wildlife Contraception Center database. Accessed July 20, 2012.

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IDENTIFYING THE MOST PROMISING FERTILITY-CONTROL METHODS

The fertility-control methods discussed in this chapter vary considerably. The criteria most important in selecting promising fertility-control methods for free-ranging horses and burros are delivery method, availability, efficacy, duration of effect, and potential physiological and behavioral side effects. The relative importance of those criteria will probably vary with characteristics of the site (the HMA or HMA complex) and population characteristics of the equids at the site. The importance of a given criterion may also change.

The first criterion is delivery method. As they exist now, fertility-control methods can be distinguished by whether it is necessary to have an animal in hand for administration. In most cases, treatments must be delivered when animals are gathered. There are HMAs in which remote delivery (e.g., darting) is possible, but these seem to be exceptions, and investigators have reported increasing difficulty in darting animals repeatedly, as would be necessary with vaccines that require periodic boosters. In addition, some data suggest that hand injection of some contraceptives is more reliable than delivery by dart even if darting is possible for the method in question. Thus, given the current fertility-control options, remote delivery appears not to be a practical characteristic of an effective population-management tool, but it could be useful in some scenarios. However, alternative methods to gathering, such as trapping near water sources, should be considered. At the time the committee's report was prepared, no product for oral delivery was available that would be species-specific and gender-specific. Although altrenogest, an oral progestagen product, has been used successfully in domestic mares to control estrus, it requires daily dosing during the breeding season. There is no mechanism to assure delivery to mares only, so consumption by stallions, nontargeted wildlife, and domestic grazing livestock could have deleterious effects.

The second criterion, availability of the fertility-control product, includes not only the ability to obtain the product but skilled personnel to administer or conduct it correctly. The methods discussed above range from experimental products to well-established surgical procedures. Two contraceptive vaccines (liquid PZP and GonaCon) are registered with EPA for use in horses; other immunocontraceptives are available only for research application (see Box 4-1). An ideal population-management tool for horses and burros would be readily available in sufficient quantities to achieve population-level effects with little regulatory and administrative burden.

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BOX 4-1

Regulatory Considerations Regarding Immunocontraceptives

Licensing and registration of contraceptive products are necessary to ensure that safe and efficacious agents are used as tools for managing free-ranging horse and burro herds. In the United States, before 2006, the Food and Drug Administration Center for Veterinary Medicine was responsible for registration and licensing of such products, but the U.S. Environmental Protection Agency (EPA) has since assumed that responsibility (Eisemann et al., 2006). Extensive data are necessary for successful registration, including safety and efficacy for target species, effects on nontarget species impacts, effects of environmental residue, and human safety. Registration is a long and expensive enterprise that discourages licensing of products that have low expected sales. Government agencies and industry have largely discontinued pursuing registration for important products that are useful to a small consumer base because of the quantity of data required and the associated expense (Fagerstone et al., 1990). Because such products are not widely used and therefore have low profit margins, they cannot generate enough profit to finance the studies required or the annual registration maintenance fees (Fagerstone et al., 1990). The cost for registration of GonaCon™ has been estimated to be $200,000-$500,000 (K. Fagerstone, NWRC, personal communication, 2012). Unregistered products can be used in field studies, although permits for experimental field trials are required. At the time this report was prepared, liquid PZP and GonaCon were licensed. Application to EPA for licensing pelleted PZP-22 for free-ranging horses was being prepared.

The third criterion, efficacy, is important for calculating the number or percentage of animals that must be treated to reach the target population for an HMA. Efficacy also depends on the ability to administer the treatment to a sufficient percentage of animals to achieve population-management objectives. Fertility-control methods that are highly effective (such as vasectomy) in preventing fertility may have no effect on population growth if a sufficient number of animals cannot be treated. Thus, efficacy involves both the efficacy of the treatment at the level of the individual animal and the efficacy at the population level, determined by the ability to administer the treatment successfully. For example, studies have found that a substantial percentage of a population (more than 50 percent) must be effectively treated to achieve reductions in population size (e.g., Garrott and Siniff, 1992; Pech et al., 1997; Hobbs et al., 2000; Kirkpatrick and Turner, 2008). It is critical that information on efficacy be integrated with population modeling to determine how many individuals in a population must be treated to achieve population goals.

Duration of fertility inhibition has major practical importance. Shorter-acting methods require substantially more effort and financial resources to implement even if the cost of the contraceptive itself is low. Longer-acting methods are preferable to minimize requirements for personnel and financial resources and to decrease the frequency of animal handling. Longer-acting methods should be used more judiciously because they remove animals from the gene pool for a longer period, perhaps permanently.

Several types of side effects were covered in the sections on the different methods in this review. Potential pain associated with administration is one consideration, although the use of anesthetics, analgesics, or both during administration may address this problem (e.g., during vasectomy). The discomfort of injections and darting is transitory and is not generally considered unacceptable. The potential of a method to cause disease or debilitation is not acceptable. That IUDs may provoke undue uterine inflammation warrants caution and would require further testing before application in the field could be considered. In addition, evidence concerning loss rates of IUDs, especially during copulation, would be needed. The possibility that ovariectomy

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may be followed by prolonged bleeding or peritoneal infection makes it inadvisable for field application. Potential effects of GnRH vaccines and agonists on other tissues than the pituitary gonadotrophs have not been well studied or documented and warrant caution until further research has been conducted.

Any of the methods described may also affect behavior. Because all methods affect sexual function in some way, changes in expression of sexual and social behavior should be considered. The ideal method would not eliminate sexual behavior or change social structure substantially. Castration, ovariectomy, and the GnRH products (vaccines and agonists) eliminate or substantially reduce steroid hormone production and so have a potentially profound effect on the expression of sexual behavior. In contrast, vasectomy and the PZP vaccines result in a prolonged breeding season, with increased sexual interaction, because females continue to undergo estrous cycles but fail to conceive. That is not ideal because a prolonged breeding season can result in more fighting among males over access to females. However, the many studies of PZP vaccines and the single study of vasectomized stallions have not reported problems with increased aggression (e.g., more injuries or deaths among stallions).

Considering the above criteria, the methods judged most promising for application to free-ranging horses or burros are PZP vaccines, GonaCon vaccine, and chemical vasectomy. The advantages and disadvantages of each of these methods and their effects on behavior are shown in Tables 4-1 and 4-2, respectively. PZP vaccines are female-directed, chemical vasectomy is male-directed, and GnRH vaccines can be used to treat either males or females. Of the PZP vaccines, PZP-22 and SpayVac seem most appropriate and practical because of their longer duration of effect (especially PZP-22). They could be applied to herds immediately in a research framework, which is required because the products are not yet licensed. Research should address efficacy, duration, and side effects at the population and individual levels where possible. At the time the committee's report was prepared, there was no evidence to suggest that PZP-22 or SpayVac would have different effects from liquid PZP apart from reports of uterine edema in SpayVac-treated animals. Although GonaCon can be used and has been tested in males, the effects are similar to those of chemical castration. To achieve the suppression of spermatogenesis needed to ensure infertility, testosterone must be suppressed to at or near zero. As with surgical castration, although sexually experienced males may continue to express learned behavioral patterns, they would probably not be successful in competing with intact males. Because preserving natural behaviors is an important criterion, GonaCon seems more appropriate for use in females. Although vaccines against GnRH interfere with its action on the pituitary (stimulating FSH and LH), FSH secretion is partially independent of GnRH (Padmanabhan and McNeilly, 2001). FSH is not required for stimulation of testosterone; LH is sufficient. In females, however, FSH is important for stimulating growth of follicles, which secrete estradiol, the hormone that supports estrous behavior. The role of LH is in the final stages of follicle growth and in inducing ovulation, so blockage of LH is sufficient to prevent conception. Investigations of GonaCon treatment of mares have reported continued estrous behavior and secretion of estradiol consistent with at least partial FSH independence from GnRH control. Thus, to the extent that GonaCon preserves natural behavior patterns while effectively preventing reproduction, it is a promising candidate as a female-directed fertility-control method. However, further studies of its behavioral effects are needed. Chemical vasectomy is promising as an alternative to or in combination with treating females. However, as stated above, vasectomizing more than dominant males would be practical in application at the population

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level. The effects of surgical vasectomy, and presumably of chemical vasectomy, on sexual behavior closely parallel those of the PZP vaccines and possibly GonaCon.

TABLE 4-1 Advantages and Disadvantages of the Most Promising Fertility-Control Methods

Method	Advantages	Disadvantages
PZP-22 and SpayVac®[a]	Research and application in both captive and free-ranging horses	Capture needed for hand injection of PZP-22
	Allows estrous cycles to continue so natural behaviors are maintained	Extended breeding season requires males to defend females longer
	High efficacy	With repeated use, return to fertility becomes less predictable
	Can be administered during pregnancy or lactation	Out-of-season births are possible
Chemical Vasectomy	Simpler than surgical vasectomy	Requires handling and light anesthesia
	Permanent	Permanent
	No side effects expected	Only surgical vasectomy has been studied in horses, so side effects of the chemical agent are unknown
	Normal male behaviors maintained	Extended breeding season requires males to defend females longer and may result in late-season foals if remaining fertile males mate
	Should have high efficacy	Only surgical vasectomy has been studied in horses, so efficacy rate is unknown
GonaCon™ for Females		Capture may be needed for hand injection of initial vaccine and any boosters
	Effective for multiple years	Lower efficacy than PZP-vaccine products, especially after first year
	Sexual behavior exhibited	Sexual behavior may not be cyclic, inasmuch as ovulation appears to be blocked
	Social behaviors not affected in the single field study	Should not be administered during early pregnancy because abortion could occur
		Few data on horses

[a]PZP-22 and SpayVac® are formulated for longer efficacy and require further documentation of continued efficacy and of rate of unexpected effects.

SOURCE: Asa et al. (1980a), Kirkpatrick et al. (1990), Thompson (2000), Kirkpatrick and Turner (2002, 2003, 2008), Stout and Colenbrander (2004), Imboden et al. (2006), Turner et al. (2007), Killian et al. (2008a), Gray (2009), Nuñez et al. (2009, 2010), Gray et al. (2010, 2011), Powers et al. (2011), Ransom (2012).

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TABLE 4-2 Behavioral Effects of Fertility-Control Methods

Behavior	PZP[a,b]	GonaCon™ for Females	Vasectomy
Male sexual	Increase or no change reported	No change reported	Longer breeding season
Female sexual	Increase or no change reported	Decrease or no change reported	Longer breeding season
Social structure	Possible decrease in band stability	No change reported	No change reported
Activity budget	Females may graze less	No change reported	No change reported
Aggression	Males may defend females longer	No change reported	Males defend females longer
Spatial relationships	Females may spend more time near male	No change reported	No change reported

[a]Includes results of studies of both liquid and pelleted (PZP-22) formulations; not all studies reported results in all the behavioral categories, and not all studies detected changes.
[b]There are no published reports on behavioral effects of SpayVac®.
SOURCE: Rubenstein (1994), Turner et al. (1996), Asa (1999), Powell (1999, 2000), Thompson (2000), Stout and Colenbrander (2004), Imboden et al. (2006), Killian et al. (2008b), Gray (2009), Nuñez et al. (2009), Ransom et al. (2010), Gray et al. (2010, 2011), Madosky et al. (2010, in review), Powers et al. (2011).

Although all three methods extend the breeding season, the implications of this effect after vasectomy are more serious because the likelihood of late-season mating and late births would be greater. Foals born later have less time to grow and accumulate fat stores for winter, and this jeopardizes their survival. The more intact males there are in a population, the more likely late-season birth would be because mares would have a greater chance of encountering and mating with a fertile male as the season progressed. Thus, vasectomy might be more appropriate in populations in which a relatively large percentage of males could be treated. The strategy of treating only dominant stallions should be avoided.

Late-season births could occur in mares treated with one of the vaccine products if reversal occurred during the breeding season, but because most free-ranging mares give birth every other year rather than yearly, conceptions and births should become re-established in spring or early summer. For mares that are able to maintain a pregnancy and give birth annually, reversal late in the season could have long-term consequences for all her future foals in that the 11-month gestation and the one or two ovulatory cycles needed to conceive can result in an about 12-month repeating cycle (see Garrott and Siniff, 1992).

Given that chemical vasectomy appears to be an effective means of reducing male reproduction with side effects that are likely to be minimal and not socially different from controlling female fertility, strategies that simultaneously control male and female fertility are likely to be most biologically and economically cost-effective. Because of the polygynous nature of horse and burro societies, the effect of chemically vasectomizing any one dominant harem-holding or territorial stallion will have a greater effect than contracepting any one fertile female.

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Moreover, because eventual male turnover is ensured, any long-term problems associated with chemical reproductive interventions are likely to be more reliably self-correcting in males than in females. When that safety factor is added to the problem of procuring large supplies of PZP vaccine in the short term, strategies of dual control allow large-scale and aggressive interventions that modeling (see Chapter 6) suggests will be necessary for regulating population growth in humane and ecologically sound ways.

Most of the PZP-vaccine research in horses (as reviewed in this chapter) has used the older, shorter-acting formulation that requires two initial injections and annual boosters. That formulation was the one licensed for use in horses at the time of the committee's study. The longer-acting formulations (PZP-22 and SpayVac) were not licensed in the United States, so they were restricted to use for research purposes and not available for wide-spread application for management purposes. Similarly, GonaCon was registered with EPA for use in free-ranging horses in January 2013. Many state veterinary licensing agencies require that a vasectomy be performed by a licensed veterinarian, although the surgery is straightforward, but the simpler chemical vasectomy had not been systematically evaluated in horses, so testing in captive horses would be needed before widespread application in the field.

CONCLUSIONS

On the basis of the peer-reviewed literature and direct communication with scientists who are studying fertility control in horses and burros, the committee considers the three most promising methods of fertility control to be PZP-22, GonaCon, and chemical vasectomy. Chemical vasectomy requires capture and handling, which could be straightforward in areas where BLM regularly gathers horses. It is more problematic in areas where it could be difficult or impossible to capture a sufficient number of animals for treatment to achieve a population effect. In addition, the efficacy of the two vaccines is higher if they are hand-injected rather than delivered by dart. Even in the case of liquid formulations of the vaccines that can in principle be delivered by dart, adequate delivery cannot be ensured. In addition, darting typically entails following animals by helicopter, which could be as stressful as gathering. Alternative methods for gaining closer access to animals for delivering injections should be sought for areas where gathering is not practical or possible.

The vaccines can be effective for multiple years, but chemical vasectomy should be considered permanent. In cases in which reversibility is important and repeated treatment is practical, one of the vaccines would be preferable, with the caution that treatment for more than a few years may prolong recovery of fertility. A single treatment that induces lifetime infertility could be preferable in other situations.

Even if a large fraction of a population's males are chemically vasectomized and the sterility is permanent, the effects of such an extensive intervention on the dynamics of the population will be self-correcting. If gathers are an average of 5 years apart, younger males rising through the ranks as bachelors or adopting alternative routes to adulthood (Rubenstein and Nuñez, 2009) will be adding new genes to the pool at an increasing rate. Given that virtually all burro and some horse populations exhibit low levels of genetic heterozygosity, virtual elimination of local male fertility for short periods to allow translocations of males that have desired genetic characteristics into the population may be warranted. Such large-scale local chemical vasectomies would allow managers to enhance genetic diversity and reduce inbreeding

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of populations at risk. Moreover, it would be a self-correcting process as younger males that have the original genetic constitution mature and compete for reproductive opportunities with translocated males. Managing genetic diversity through translocation is discussed more thoroughly in the next chapter.

All three methods should preserve the basic social unit and expression of sexual behavior, although there have been conflicting reports on various effects of the vaccines on social interactions and on the cyclicity of estrous behavior. The major effect of the methods is that the typical breeding season would be extended for females that do not conceive (the implications are discussed at length above). No method has yet been developed that does not have some effect on physiology or behavior. However, the effects of not intervening to control or manage population numbers are potentially harsher than contraception; in the absence of natural predators, population numbers are likely to be limited by starvation (see Chapter 3 for discussion of the effect of density-dependent factors). Even if there were a method that had no effect other than preventing the production of young, the absence of young would alter the age structure of the population and could thereby affect harem dynamics. The most appropriate comparison that should be made in assessing the effects of any method of fertility control is with the current approach, gathering and removal. That is, to what extent does the prospective method affect health, herd structure, and the expression of natural behaviors relative to the effects of gathering? Three methods (PZP-22, GonaCon, and chemical vasectomy) are considered the most promising for managing fertility in free-ranging horses and burros because they have the fewest and least serious effects on those parameters. In addition, although their application requires handling the animals—gathering—that process is no more disruptive than the current method for controlling numbers, and it lacks the further disruption of removal and relocation to long-term holding facilities. Considering all the current options, the three methods, either alone or in combination, offer the most acceptable alternative for managing population numbers. However, further research is needed before they are ready for widespread deployment for horse population management.

The current major gaps in knowledge about PZP-22, SpayVac, and GonaCon include a thorough understanding for each vaccine of percentage and duration of efficacy and the extent of its reversibility. GonaCon should be examined to evaluate the extent to which treated females continue to exhibit sexual behavior, which is important for maintaining natural social interactions. A study is needed to assess the efficacy and safety of potential agents for chemical vasectomy before it is used in free-ranging stallions during gathers.

In light of the extensive research that has been conducted with liquid PZP, the likelihood that PZP-22 or SpayVac will produce new or unexpected effects, other than an extended duration of action, is small, and this should reduce the scope of research that would be needed. Furthermore, given the decades of research on the earlier liquid formulation of PZP and its successful application in numerous free-ranging horse herds, liquid PZP can be used in many herd areas now. It might be applied not only in herds that are amenable to darting but during gathers for horses that are turned back onto the range. Even without a booster in the months just after a gather, any later inoculation will serve as a booster and initiate a period of infertility (J.W. Turner, University of Toledo, personal communication, August 2012). Thus, liquid PZP could serve as an interim fertility-control method until one of the other longer-acting methods is available.

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5

Genetic Diversity in Free-Ranging Horse and Burro Populations

This chapter reviews the relationship between genetic diversity and the long-term health of free-ranging horse and burro herds. It does that by reviewing genetic studies conducted on 102 horse Herd Management Areas (HMAs) and 12 burro HMAs under the jurisdiction of the Bureau of Land Management (BLM) and comparing the results with those of studies of other species and herds for evidence of an optimal level of genetic diversity that might be used as a management target. It also examines the idea that BLM's free-ranging horse and burro herds can be considered a metapopulation, or a "population of populations that are spatially discrete but connected through natural or assisted immigration" (Levins, 1969). Metapopulation theory can be used to suggest directions for management activities that might be undertaken to attain and maintain the level of genetic diversity that is needed for continued survival and reproduction and for adapting to changing environmental conditions.

THE CONCEPT AND COMPONENTS OF GENETIC DIVERSITY

Genetic studies provide essential data for the management of populations, including estimates of the levels and distribution of genetic diversity, assessments of ancestry, and the detection of genetically distinct populations. At the population level, genetic diversity can be measured as the mean number of variants of a gene (alleles) or as the proportion of individuals that have different variants of a gene (heterozygosity). Theoretical and empirical studies have demonstrated substantial fitness costs associated with the loss of genetic diversity in both free-ranging and captive populations (Lacy, 1997; Saccheri et al., 1998; Crnokrak and Roff, 1999; Slate et al., 2000; Brook et al., 2002; Keller and Waller, 2002; Spielman et al., 2004). In small populations or populations that suffer size bottlenecks,[1] allelic diversity is lost relatively quickly through random genetic drift, but heterozygosity is less affected. In small populations that are isolated, inbreeding is inevitable and occurs within only a few generations. Whereas inbreeding does not change allele frequencies, it results in a change in the proportion of individuals that carry two alleles at a locus that are identical by descent and decreases heterozygosity. Thus, it is

[1]A population bottleneck is a large reduction in population size over one or more generations.

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important to measure and monitor allelic diversity, observed and expected heterozygosity (H_o and H_e), and coefficients of inbreeding (F_{is}) in managed populations.

Genetic diversity in a population results from a number of evolutionary forces: mutation, natural selection, gene flow, and genetic drift. Although mutation is the ultimate source of all genetic variation, mutation rates of most genes are low and cannot replenish diversity quickly once it is lost (Lande, 1995). The effects of natural selection depend on whether it is directional, stabilizing, or balancing selection.[2] Regardless of the kind of natural selection exerted on a population, when a population is small, only strong selection will affect the level of diversity (Frankham et al., 2010). In contrast, the recruitment of even a small number of unrelated breeding individuals into a population (gene flow) can increase genetic diversity or prevent its loss. Genetic drift—random change in allele frequencies between generations—is a strong force in small populations and can result in rapid loss of genetic diversity (Frankham et al., 2010).

A related issue is the detection of populations that are genetically distinct because of low gene flow and are thus functioning independently (Moritz, 1994). In such isolated populations, genetically based adaptations to local environmental conditions may arise. If management actions involve translocations (movement) of individuals among populations, genetic data will help to guide the choices of donor and recipient populations.

RESEARCH ON GENETIC DIVERSITY IN FREE-RANGING POPULATIONS SINCE 1980

In the late 1970s, when the National Research Council Committee on Wild and Free-Roaming Horses and Burros reviewed the state of the science, nothing was known about the genetics of free-ranging equids. The committee's 1980 report found that "no information exists about these populations concerning . . . the amount of genetic variation within populations, the amount of genetic differentiation between populations, and the pattern of genetic relatedness ('phylogeny') of the wild populations and the domestic breeds" (NRC, 1980, p. 93). Furthermore, no information on the amount of genetic variation within or between breeds of domestic equids existed (NRC, 1980). Therefore, that committee recommended that genetic studies be conducted to assess the genetic health of the herds. The lack of information regarding the ancestry and lineages of free-ranging equids was also identified as a concern.

As a result, BLM awarded a grant to the University of California, Davis (UC Davis) for a study of free-ranging horse genetics. From December 1985 to October 1986, researchers collected 975 blood samples from five horse populations under BLM management in Oregon and Nevada. A total of 19 genetic loci known to be polymorphic[3] in domestic horses were screened (seven red-cell antigens and 12 isoenzyme and serum proteins) and used to estimate levels of genetic diversity and differentiation among herds and to investigate herd ancestry. The results, which were reviewed by the Committee on Wild Horse and Burro Research and published in the

[2]Natural selection can take three forms in a population. In directional selection, the frequency of an allele increases because of its greater fitness (its ability to help the individual survive and reproduce). Stabilizing selection decreases the frequency of alleles that have lower fitness, that is, alleles that hinder an individual's chances to reproduce. Directional and stabilizing selection can continue until a beneficial allele is fixed in the population or the detrimental allele is eliminated. In balancing selection, more than one variant of a gene is maintained in the population, and individuals carrying more than one variant of a gene may have a genetic advantage in their environment.

[3]Containing more than one allele.

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National Research Council's report *Wild Horse Populations: Field Studies in Genetics and Fertility* (NRC, 1991), indicated that free-ranging herds did not differ from domestic herds with respect to levels of genetic diversity (heterozygosity and allelic diversity) and that differentiation among herds was less than that among breeds of domestic horses. With regard to herd ancestry, the results were consistent with the hypothesis that herds originated from escaped or released domestic horses.

Studies by E. Gus Cothran at the University of Kentucky and Texas A&M University have been conducted since 2000 to monitor genetic diversity in individual free-ranging horse herds and assess their genetic similarity to domestic horse lineages. The earliest of these studies used the same types of genetic loci used by the UC Davis researchers (17 isozyme and serum proteins), but more recent studies have used 12 highly polymorphic microsatellite DNA loci[4] (Goldstein and Pollock, 1997). The more recent studies have made substantial progress in comparing existing populations with exemplars of New World and Old World domestic breeds and have yielded valuable information about herd ancestry and lineages. Furthermore, although the 1980 National Research Council report identified a lack of information on the genetic variation of both free-ranging horse and burro herds, the UC Davis study did not include samples from burros. Cothran has studied 12 burro herds with nine microsatellite loci. This chapter reviews the results of Cothran's studies, comparing them with published results on genetic diversity of free-ranging donkey populations in Spain and Sicily (Aranguren-Mendez et al., 2001, 2002; Guastella et al., 2007; Bordonaro et al., 2012).

THE RELEVANCE OF GENETIC DIVERSITY TO LONG-TERM POPULATION HEALTH

The probability of natural gene flow in free-ranging horses and burros varies among herds. In some herds, management actions have included removals that had unknown effects on the levels and distribution of genetic diversity. Isolation and small population size, in combination with the effects of genetic drift, may reduce genetic diversity to the point where herds suffer from the reduced fitness often associated with inbreeding. That would compromise the ability of herds to persist under changing environmental conditions.

Inbreeding

Inbreeding depression, defined as a reduction in fitness due to the loss of diversity and the expression of deleterious genes that can accompany inbreeding, can be difficult to detect, especially in wild populations, and the relationship between inbreeding depression and extinction risk is not clear (Lacy, 1997). Crnokrak and Roff (1999) reviewed the literature on wild populations known to be inbreeding to determine what levels of inbreeding depression were occurring and whether they had important fitness effects. They found that most estimates of inbreeding depression (169 estimates in 35 species and 137 traits) were high enough to be biologically important, and most of the traits that they surveyed were directly related to fitness; this allowed them to conclude that inbreeding depression is detectable 54 percent of the time in

[4]Microsatellite loci contain tandem repeats of one to six base pairs and are commonly used as molecular markers to detect genetic variation and relatedness among individuals in a population.

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species known to be inbred. Keller and Waller (2002) established that inbreeding depression occurs in the wild, is measurable, and can influence population viability. They cited literature on agricultural systems that demonstrated that the cost of a 10-percent increase in inbreeding leads to a 5- to 10-percent loss of fitness. In fact, Lacy (1997) could find no evidence that any mammalian species is unaffected by inbreeding.

In addition to diseases related to genetic mutations, a species may demonstrate conditions or abnormalities and reduced fitness due to inbreeding. Some of the evidence on inbreeding depression or correlations between low genetic diversity and fitness traits in ungulates is reviewed below. There is evidence in horses that inbreeding avoidance occurs in the harem band as fathers and step-fathers avoid copulating with related young mares (Berger, 1986; Berger and Cunningham, 1987). However, that does not preclude inbreeding at the population level inasmuch as both sons and daughters disperse from the natal group and may associate later in life as adults.

Reproductive Physiology, Reproductive Success, and Offspring Survival

Inbreeding results from reproduction by two related parents. If the ancestries of the parents are known with a high degree of certainty, a pedigree can be constructed, and the coefficient of relatedness (the inbreeding coefficient, *F*) of the offspring can be calculated on the basis of the relatedness of the parents. In free-ranging populations, however, relatedness among breeding individuals is rarely known but can be estimated by using biparentally inherited DNA markers such as microsatellite loci (Eggert et al., 2010) or single-nucleotide polymorphisms (SNPs; Li et al., 2011). The use of genetic markers to estimate pairwise relatedness between individuals can be problematic primarily because of incomplete sampling, the overall low variance in relatedness among individuals in natural populations, and the need for large numbers of markers to produce precise estimates (Csillery et al., 2006; Pemberton, 2008; Li et al., 2011). Genetic estimates of inbreeding coefficients at the population level can also be problematic; they have been found to be strongly affected by the size, history, and genetic diversity of the founders (Ruiz-Lopez et al., 2009). Thus, although there are potential problems with both pedigree-based and molecular genetics-based estimates of inbreeding, both can provide information about inbreeding that is useful for population management.

Data on inbred ungulates suggest a negative relationship between inbreeding and reproductive health. In Cuvier's gazelle, Gomendio et al. (2000) found an inverse relationship between inbreeding levels and ejaculate quality. The Texas state bison herd, which was founded by only five individuals in the 1880s, has statistically significantly lower genetic diversity than herds in Yellowstone and Theodore Roosevelt National Parks. Halbert et al. (2004) found semen abnormalities in four of eight tested bulls from the Texas state herd. In Przewalski's horse mares, Collins et al. (2012) found a significant association between mean urinary estrogen over an ovulatory cycle and mean kinship, a measure used to quantify relatedness between individuals in a population (Lacy et al., 1995). Mares that had higher mean kinship had lower estrogen concentrations.

In a study of sequential ejaculates from Shetland pony stallions, van Eldik et al. (2006) found that higher inbreeding coefficients based on pedigree data correlated with lower sperm quality in the form of lower percentages of progressively motile and morphologically normal sperm. Those effects were apparent even at relatively low inbreeding levels ($F = 0.02$) and worsened with increasing inbreeding. In contrast, Aurich et al. (2003) studied single ejaculates

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from Noriker draught horse stallions and found no correlations between semen quality and heterozygosity at microsatellite loci.

Luis et al. (2007) analyzed the genetic structure of the Sorraia horse breed, which has populations in Germany and Portugal and is characterized by relatively high levels of inbreeding ($F = 0.363$). They found low genetic diversity compared with other breeds and stated that further analysis showed that inbreeding levels correlated negatively with adult fertility and juvenile survival (C. Luis, Universidade de Lisboa, Portugal, unpublished results). In addition to abnormalities in semen quality, the Texas state bison herd was characterized by lower natality and higher calf mortality than other captive bison herds (Halbert et al., 2004). In a study of red deer on the Isle of Rhum, Scotland, Slate et al. (2000) found that lifetime breeding success in both females and males (as measured by the number of calves produced) correlated positively with heterozygosity at nine microsatellite loci. Finally, in a study of 12 species of ungulates maintained in zoos, Ballou and Ralls (1982) demonstrated that infant mortality was higher in inbred than in noninbred offspring in 11 of 12 species of ungulates and that inbreeding was the only possible explanation for the observed differences.

Disease

Sasidharan et al. (2011) found that populations of mountain zebra affected by sarcoid tumors, which are known to have a partially genetic basis, had lower genetic polymorphism, lower expected heterozygosity, and lower gene diversity and higher values of internal relatedness and homozygosity than populations that were not affected by these tumors. Although the trends were clear, the differences were not statistically significant. Ragland et al. (1966) described an outbreak of sarcoids in horses in which affected animals were related and originated from a highly inbred family line.

Congenital Defects

Zachos et al. (2007) conducted a genetic analysis of a herd of about 50 red deer known to have descended from no more than eight individuals. The genetic diversity shown by data that the authors provided did not appear to be significantly lower than that in other red deer populations, but in this population a number of cases of brachygnathy,[5] which is believed to be associated with inbreeding in deer (Renecker and Blake, 1992), have been observed.

In horses, the condition known as club foot is defined as "a flexural deformity of the coffin joint resulting in a raised heel; not to be confused with the club foot deformity of humans" (Siegal, 1996). Although the condition is suspected to have a genetic basis, to the committee's knowledge this has not been confirmed. Club foot has been reported in free-ranging horse herds, but it is not a life-threatening or "limited-use" condition.

Clinical Issues Related to Genetics in Horses

Aside from concerns about the deleterious effects of inbreeding, there are concerns related to the genetics and health of horses. Similar concerns may exist for burros, but the committee could find no publications about clinical issues related to genetics.

According to Brosnahan et al. (2010) and Finno et al. (2009), 10 or 11 conditions in horses are known to be caused by genetic mutations. All are single-gene, autosomal mutations

[5]Brachygnathy, also known as parrot mouth, is the underdevelopment of the lower jaw.

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inherited in a Mendelian fashion (Brosnahan et al., 2010). Although all are considered rare, they have had important effects on major breeds. Some of the conditions are lethal, but others are not, so the mutations can spread in herds, especially when inbreeding occurs. Commercial testing is available for all except the mutation involved in lavender foal syndrome. Very few of the conditions present clinical signs that would be unambiguous and discernible during a gather of horses that includes large numbers of unknown animals that are grouped for relatively short periods (e.g., days) and are not under constant, individual observation. However, because many of the conditions can be diagnosed via genetic screening of blood or hair samples, surveillance of the genetic mutations underlying them is possible in HMAs. Screening of samples from gathered horses could be used to generate frequencies of the alleles involved in these disorders, and the frequencies could be monitored during later gathers in order to determine whether a particular HMA has a higher occurrence of a given mutation that might affect the fitness of the herd. The conditions that seem to be immediately discernible on observation are discussed below on the basis of clinical data provided by Brosnahan et al. (2010) and Finno et al. (2009).

Junctional epidermolysis bullosa is a trait known to affect Belgians, other draft breeds, and American Saddlebred horses. The condition is most often observed in foals, which demonstrate irregular, reddened erosions and ulcerations on the skin and mouth over pressure points. Ocular and dental abnormalities co-occur in some cases. Another notable manifestation of the condition is complete sloughing of the hooves in foals, which is terminal.

Overo lethal white foal syndrome or *ileocolonic aganglionosis* presents in the form of an all white or nearly all white hair coat in foals and an underlying intestinal obstruction. Affected breeds include American Paint Horse, Quarter Horse, and rarely Thoroughbreds. Diagnosis of the condition is difficult because of the wide variation in phenotype in these breeds and associated ambiguous language related to color patterns. The condition is terminal.

Grey horse melanoma is found in many breeds and is manifested as a gray coat in conjunction with dermal melanomas. The melanomas themselves are not typically life-threatening, but they may metastasize to other organs.

Arabian horses are the primary breed affected by *lavender foal syndrome* or *coat color dilution lethal*. Affected animals' coats appear silver, pink, or lavender. Other clinical signs include seizures, dorsiflexion of the head and neck, hyperaesthesia, and recumbency. Progressive neurological dysfunction is also observed. The condition is terminal. Testing is not available commercially but was in development at the time of the committee's study.

Hereditary equine regional dermal asthenia is known to affect Quarter horses and horses from a Quarter horse lineage. Signs include seromas, hematomas, open wounds, scars, and sloughing of the skin. In addition, the skin is loose and is easily separated from the underlying fascia. In areas of hair regrowth, white hairs are typical of this condition. Skin lesions can be treated, but euthanasia is the typical outcome. Testing is available.

For most of those clinical conditions, an aberration in coat color pattern is the most discernible and unambiguous cue. Although limb deformities or abnormal gait patterns are clinical signs in some conditions, they may be due to nongenetic factors. Regardless of the underlying causes, phenotypic data have not been recorded and integrated into the genetic management of free-ranging herds. Recording the occurrence of phenotypic data associated with diseases and clinical issues along with information on the age and sex of the affected animals would allow BLM to monitor the distribution and prevalence of a number of genetic conditions that have direct effects on herd health.

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Genetics and Population Viability

The maintenance of genetic diversity in a population is a function of the genetic effective population size (N_e; Wright, 1931, 1938), which is defined as the size of an idealized population that would experience the same magnitude of random genetic drift as the population of interest (Conner and Hartl, 2004) and can be estimated with genetic or demographic data. Populations that have experienced fluctuating sizes between generations, unequal sex ratios, or high variance in reproductive success are likely to have effective population sizes that are lower than the number of animals present; Frankham's (1995) review of effective population size estimates in wildlife concluded that they are usually at least an order of magnitude lower.

It was originally thought that an effective population size of at least 50 was necessary to avoid short-term inbreeding depression, but empirical work suggests that if maintenance of fitness is important, effective population sizes much larger than 50 are necessary. Theoretical studies suggest that the figure could be closer to 5,000 for several reasons. First, new genetic variation from mutations is added to a population more slowly than originally thought (Lande, 1995). Mutations with large effects tend to be detrimental and are removed from the population by natural selection, so the overall mutation rate does not accurately predict the infusion of new genetic variation. Second, the effects of inbreeding depression are likely to be more severe in stressful environments (Jimenez et al., 1994; Pray et al., 1994). Finally, slightly deleterious mutations may accumulate in smaller populations and lead to a decline in fitness (Lynch and Gabriel, 1990; Charlesworth et al., 1993; Lande, 1994).

A related concern is whether there is a general rule that would help managers to decide how large a population needs to be to remain genetically and demographically viable in the long term (Flather et al., 2011a,b). Flather et al. (2011a) argued that a general rule of thumb is not scientifically defensible given the variation among species, their evolutionary history, the habitats that they occupy, and the threats to their survival. However, they agreed with previous suggestions that multiple populations totaling thousands, rather than hundreds, of individuals will probably be necessary for long-term viability of species.

At the time of the committee's study, the total population of horses on BLM land exceeded 31,000. When that population is considered as a whole, concerns regarding minimum viable population (MVP) size are not important. However, this population exists in many smaller, fragmented units. Only a small fraction of the HMAs or HMA complexes contain more than 1,000 horses, so no single HMA or complex could be considered to have an MVP size for the long term, although the analyses cited above suggest that horse populations on HMAs or HMA complexes that are larger than 1,000 do have a greater than 50-percent probability of survival for 100 years. In addition, it does not appear to be realistic to attempt to manage each HMA or HMA complex with a goal of a minimum of 5,000 animals. Therefore, management of the HMAs as a metapopulation, in the form of natural and assisted movement of animals between HMAs, will be necessary for long-term persistence of the horses at the HMA or HMA-complex level. Movement of animals will need to be guided by a number of genetic, demographic, behavioral, and logistical factors, discussed later in this chapter.

In contrast with horses, the total population of free-ranging burros is estimated at only about 5,000 and is therefore at what scientists would consider an MVP size. These animals exist in fragmented units, each of which has a population size well below the MVP size; as in the case of horses, it is unrealistic to consider increasing the population in each unit to 5,000. Genetic monitoring and movement of burros between HMAs is therefore more necessary than it is for

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horses to maintain the overall population for the long term. The same factors that would inform movements of horses would apply to movements of burros.

IS THERE AN OPTIMAL LEVEL OF GENETIC DIVERSITY IN A MANAGED HERD OR POPULATION?

In a survey of genetic diversity levels in mammals, Garner et al. (2005) found an average heterozygosity value of 0.677 ± 0.010 in healthy populations. For 16 species, they compared healthy populations with ones that had experienced a demographic challenge and found a strong association between demographic threats and the loss of heterozygosity (healthy mean, 0.715 ± 0.240; demographically challenged mean, 0.525 ± 0.040). They also found evidence of differences in genetic diversity among families within orders of mammals. Genetic diversity in free-ranging horses and burros in HMAs should be compared with genetic diversity detected in other free-ranging and domestic herds to determine the health of a herd or population, depending on the management goal.

Genetic Diversity in Free-Ranging Horses

Table 5-1 compares estimates of genetic diversity of free-ranging populations (Sable Island, eastern Canada; Colonial Spanish horses known as the Marsh Tacky, found in South Carolina, the Florida Cracker, and populations on Shackleford Banks, Corolla, and Ocracoke Islands, North Carolina; southern European native horse breeds; and Assateague Island, Maryland), domestic breeds, and the endangered Sorraia horse breed (Portugal and Germany), which was founded in 1937 with three stallions and seven mares. The studies have shown that the mean observed heterozygosity was below that observed in healthy mammal populations for the Sorraia and Colonial Spanish horse populations and for some domestic breeds. Observed heterozygosity was on a par with that in healthy mammal populations of free-ranging horses on Sable Island and Assateague Island, breeds from Canada and Spain, some domestic breeds, and some southern European native breeds.

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TABLE 5-1 Estimates of Genetic Diversity of Free-Ranging and Domestic Horses

Population	Allelic Diversity	Observed Heterozygosity	F_{is}	Reference
Sable Island	5.60 ± 1.35 SD	0.647 ± 0.035 SD	0.070	Lucas et al., 2009
Sorraia	3.32 ± 0.95 SD	0.450 ± 0.212 SD	-0.061 to 0.018	Luis et al., 2007
Domestic breeds from Canada and Spain	5.50 ± 0.42 SE to 8.25 ± 0.57 SE	0.66 ± 0.02 SE to 0.79 ± 0.04 SE	-0.046 to 0.083	Plante et al., 2007
Southern European native horse breeds	5.75 ± 1.54 SD to 8.08 ± 1.93 SD	0.687 ± 0.170 SD to 0.772 ± 0.099 SD	Not estimated	Solis et al., 2005
Domestic breeds (10 breeds, 191 individuals)	3.6 ± 0.3 SE to 4.5 ± 0.4 SE	0.494 ± 0.057 SE to 0.626 ± 0.058 SE	Not estimated	Vilà et al., 2001
Colonial Spanish horse populations (five)	4.00 ± 1.27 SD to 7.73 ± 2.05 SD	0.54 ± 0.18 SD to 0.74 ± 0.10 SD	-0.069 to 0.058	Conant et al., 2012
Assateague Island	7.4 ± 1.8 SD	0.794 ± 0.102 SD	Not estimated	Eggert et al., 2010

NOTE: SD = Standard deviation; SE = Standard error.

Genetic Diversity in Horses Managed by Bureau of Land Management

Genetic studies have been conducted by E. Gus Cothran for many of the HMAs (Table 5-2). The results of the studies have shown that genetic diversity varies among HMAs. Allelic diversity values range from 2.583 (Liggett Table, OR) to 8.000 (Warm Springs, OR, and Paisley Desert, OR), observed heterozygosity values range from 0.497 (Cibola-Trigo, AZ) to 0.815 (Hog Creek, OR), and inbreeding coefficient values range from -0.230 (Nut Mountain, CA) to 0.133 (Lahanton Reservoir, NV). The lowest allelic diversity and heterozygosity found in the HMAs are consistent with those in the endangered Sorraia breeds and the Colonial Spanish horse populations, all of which are small, isolated herds.

The management goal, as stated in the BLM's *Wild Horses and Burros Management Handbook* (BLM, 2010), is to keep the observed heterozygosity (H_o) of all herds no lower than one standard deviation below the mean in the BLM herds. In the 2012 Cothran reports, the free-ranging feral horse mean H_o was listed at 0.716 with a standard deviation of 0.056, and the value below which a herd was considered at critical risk was listed in the BLM handbook as 0.66 for DNA estimates and 0.31 for blood group estimates. By those standards, herds in eight HMAs listed in Table 5-2 are at risk because of low heterozygosity. If the same criterion is applied to allelic diversity (mean number of alleles [MNA]), the goal would be 4.97 alleles/locus (mean, 6.06; standard deviation, 1.09), and an additional HMA would fall below the acceptable level. An examination of Table 5-2 reveals that herds in 34 HMAs have observed heterozygosity or allelic diversity values between the mean and the value at which a herd is considered at critical

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risk and should be managed and monitored routinely to detect decreases in diversity or improvements as the result of management actions. One HMA—Liggett Table, OR—has low heterozygosity, extremely low allelic diversity, and a small appropriate management level (AML). Its low inbreeding coefficient is surprising, in that it is inconsistent with expectations under those conditions. The Cothran report for this HMA notes that one horse was destroyed because of an unspecified congenital defect.

Each of the Cothran reports includes information on the percentage of variants (microsatellite alleles) that have frequencies below 0.05 because these rare variants are the ones most likely to be lost if population size declines or not all individuals reproduce equally. It is important to note that although some microsatellite loci have been implicated in human disease (Wooster et al., 1994), the dinucleotide (2-bp repeat motif) microsatellite loci used in the Cothran studies are found in regions of DNA that are unlikely to directly affect the fitness of individuals. In those studies, microsatellite loci were used as proxies to test for overall levels of genetic diversity and to assess levels of inbreeding. Managing for the preservation of microsatellite alleles that are rare in an HMA would not be expected to increase fitness, and this approach is not recommended in any of the Cothran reports.

Evidence of Strong Associations with Spanish Bloodlines

Phenotypic similarities and historical records have suggested that several HMAs have high concentrations of old Spanish blood and thus may be assigned high priority for conservation. Cothran's studies have addressed that, using both blood group polymorphisms, which reveal alleles that have strong associations with Spanish bloodlines, and microsatellite loci. Because the blood group polymorphisms provide clear evidence and the microsatellite loci do not, the results that he presented to the committee were based only on blood group data. He found evidence of Spanish blood in the Cerbat Mountains, AZ; Pryor Mountains, MT; and Sulphur, UT, HMAs. The Cerbat Mountains herd is largely isolated, but the reports show that the Pryor Mountain and Sulphur herds both have Spanish blood mixed with that of non-Spanish breeds. The Kiger, OR, herd, which contains morphologically distinct horses, may have had some Spanish ancestry, but it is not possible to distinguish between that and indirect ancestry through possible Quarter Horse introductions in the same area. The Lost Creek, WY, herd also has some evidence of Spanish ancestry that may be indirect.

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TABLE 5-2 Genetic Diversity in Free-Ranging Horses in Herd Management Areas Determined by Using 12 Microsatellite Loci

Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Cerbat Mountains	AZ			90					Evidence of Spanish blood
Cibola-Trigo	AZ	24	2005	150	0.497	0.490	-0.014	4.17	04/15/08
Arizona mean value					*0.497*	*0.490*	*-0.014*	*4.17*	
Bitner	CA	21	2012	25	0.734	0.713	-0.029	5.92	05/15/12
Buckhorn	CA	31	2010	85	0.806	0.749	-0.076	6.42	10/20/10
Carter Reservoir	CA	60	2009	35	0.689	0.688	-0.001	6.33	10/04/10
Centennial	CA	69	2001	168	0.665	0.709	0.062	6.92	11/19/01
Chicago Valley	CA			12					
Coppersmith	CA	53	2009	75	0.708	0.703	-0.007	6.33	10/05/10
Fort Sage	CA			29					
Fox Hog	CA	115	2012	220	0.717	0.730	0.018	7.42	05/18/12
High Rock Canyon	CA	35	2012	120	0.774	0.773	-0.001	7.75	05/17/02
Massacre Lakes	CA			35					
New Ravendale	CA			25					
Nut Mountain	CA	47	2011	55	0.770	0.752	-0.230	7.33	05/14/12
Piper Mountain	CA			17					
Red Rock Lakes	CA			25					
Round Mountain	CA			10					
Twin Peaks - Gilman	CA	13	2011	758	0.724	0.764	0.052	6.67	04/28/11
Twin Peaks - S Observ	CA	52	2011	758	0.710	0.754	0.058	7.67	04/28/11
Twin Peaks - Skedaddle/Dry Valley	CA	28	2011	758	0.673	0.744	0.096	6.92	04/28/11
Wall Canyon	CA	14	2012	25	0.708	0.709	0.001	6.00	05/23/12
California mean value					*0.723*	*0.732*	*0.005*	*6.81*	
Little Book Cliffs	CO	29	2002	150	0.745	0.721	-0.034	6.25	05/28/03
Piceance-East Douglas Creek	CO	32	2006	235	0.635	0.640	0.007	4.67	06/01/10
Sand Wash Basin	CO	50	2001	362	0.730	0.723	-0.009	6.50	04/16/02
Spring Creek Basin	CO	15	2007	65	0.689	0.702	0.018	5.08	06/21/10
Colorado mean value					*0.700*	*0.696*	*-0.005*	*5.63*	
Black Mountain	ID	25	2010	60	0.720	0.704	-0.023	6.42	03/03/11
Challis	ID	46	2002	253	0.743	0.735	-0.010	6.42	09/15/03

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Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Four Mile	ID	25	2003	60	0.740	0.691	-0.071	5.75	06/14/04
Hard Trigger	ID	30	2010	130	0.764	0.733	-0.042	6.50	03/01/11
Sand Basin	ID	25	2003	64	0.782	0.726	-0.077	6.33	06/14/04
Saylor Creek	ID	50	2010	50	0.767	0.748	-0.025	6.42	12/17/10
Idaho mean value					*0.753*	*0.723*	*-0.041*	*6.31*	
Pryor Mountains	MT	103	2009	120	0.757	0.762	0.007	6.58	09/02/10 Evidence of Spanish blood
Montana mean value					*0.757*	*0.762*	*0.007*	*6.58*	
Antelope	NV			324					
Antelope Valley	NV	28	2011	259	0.765	0.756	-0.012	6.75	06/13/11
Augusta Mountains	NV	29	2011	308	0.770	0.756	-0.018	6.58	04/26/11
Bald Mountain	NV	97	2009	215	0.759	0.775	0.021	7.58	08/13/10
Black Rock East	NV	31	2012	93	0.710	0.753	0.057	7.00	05/30/12
Black Rock West	NV	19	2012	93	0.675	0.654	-0.032	5.67	05/30/12 Monitor closely and consider introducing two to four new mares
Buffalo Hills	NV	51	2009	314	0.724	0.729	0.008	7.00	08/05/10
Calico Mountains	NV	40	2012	333	0.748	0.723	-0.035	6.92	05/24/12
Callaghan Austin Allot	NV	40	2009	237	0.742	0.780	0.049	7.25	08/12/10
Callaghan East Allot	NV	40	2009	incl	0.765	0.791	0.033	7.75	08/11/10
Clan Alpine	NV			979					
Desatoya	NV	25	2003	180	0.703	0.707	0.005	6.00	05/05/04
Diamond	NV			151					
Diamond Hills North	NV			37					
Diamond Hills South	NV			22					
Dogskin Mountains	NV			15					
Eagle	NV			210					
Fish Creek	NV	23	2005	180	0.790	0.758	-0.042	7.00	06/03/08
Fish Lake Valley	NV			54					
Flanigan	NV			125					
Fort Sage	NV			36					
Fox Lake Range	NV			204					
Garfield Flat	NV			125					
Goshute	NV	28	2011	123	0.765	0.748	-0.022	6.50	06/15/11
Granite Peak	NV			18					
Granite Range	NV	40	2012	258	0.760	0.737	-0.032	7.08	05/24/12

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Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Horse Mountain	NV			95					
Hot Creek	NV			41					
Jackson Mountains	NV			217					
Kamma Mountains	NV			77					
Lahontan	NV	28	2004	10	0.595	0.687	0.133	5.50	07/01/04
Lava Beds	NV			148					
Little Fish Lake	NV	40	2005	39	0.703	0.748	0.060	6.75	05/30/08
Little Humbolt	NV	23	2010	80	0.743	0.742	-0.001	6.58	12/09/10
Little Owyhee Fairbanks	NV	10	2004	298	0.775	0.704	-0.101	5.42	02/29/08
Little Owyhee Lake Creek	NV	10	2004	298	0.764	0.713	-0.072	5.67	02/29/08
Little Owyhee Twin Valley	NV	10	2004	298	0.760	0.737	-0.031	5.83	02/29/08
Maverick-Medicine	NV			276					
Montezuma Peak	NV	46	2010	4	0.737	0.707	-0.043	6.33	12/16/10
Montgomery Pass	NV			100					
Nevada Wild Horse Range	NV			500					
New Pass/Ravenswood	NV	52	2007	566	0.780	0.771	-0.013	7.42	07/07/10
Nightengale Mountains	NV			126					
North Monitor	NV			8					
North Stillwater	NV	50	2008	205	0.670	0.722	0.072	6.75	07/07/10
Owyhee	NV			231					
Palmetto	NV			76					
Pancake	NV			493					
Paymaster	NV	49	2010	38	0.748	0.702	-0.066	5.83	12/10/10 High incidence of club foot
Pilot Mountain	NV			415					
Pine Nut Mountains	NV	26	2003	179	0.670	0.687	0.026	6.08	04/27/04
Red Rock (Bird Springs)	NV	23	2006	27	0.786	0.743	-0.059	6.08	06/18/09
Reveille	NV	51	2010	138	0.753	0.715	-0.054	6.50	12/17/10
Roberts Mountain	NV	29	2008	150	0.730	0.740	0.013	6.42	07/15/10
Rock Creek	NV	28	2010	250	0.738	0.745	0.010	6.00	12/17/10
Rocky Hills	NV	64	2009	143	0.759	0.774	0.019	7.33	08/06/10
Sand Springs West	NV			49					
Saulsbury	NV	25	2007	40	0.773	0.768	-0.007	6.83	06/17/10
Seven Mile	NV	27	2005		0.756	0.748	-0.011	6.58	06/03/08
Seven Troughs	NV			156					
Shawave Mountains	NV	28	2003	73	0.783	0.762	-0.027	6.50	06/04/04
Silver King	NV			128					

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Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Snowstorm Castle Ridge	NV	10	2004	140	0.659	0.718	0.082	5.42	02/29/08
Snowstorm Dryhill	NV	9	2004	140	0.750	0.616	-0.218	4.25	02/29/08
South Shoshone	NV	52	2008	100	0.761	0.770	0.012	7.33	07/21/10
South Stillwater	NV	42	2003	16	0.705	0.716	0.015	5.58	04/07/04
Spruce-Pequop	NV	26	2011	82	0.750	0.709	-0.058	5.75	06/16/11
Stone Cabin	NV	50	2007	364	0.763	0.775	0.015	7.67	06/16/10 Some incidence of club foot
Tobin Range	NV			42					
Triple B	NV			518					
Warm Springs Canyon	NV	28	2010	175	0.729	0.719	-0.014	7.17	11/04/10
Wassuk	NV			165					
Wheeler Pass	NV	26	2007	66	0.756	0.763	0.008	7.08	06/16/10
Whistler Mountain	NV			24					
Nevada mean value					*0.739*	*0.734*	*-0.008*	*6.49*	
Bordo Atravesado	NM	27	2011	60	0.787	0.749	-0.051	6.08	04/25/11
Carracas Mesa	NM			23					
New Mexico mean value					*0.787*	*0.749*	*-0.051*	*6.08*	
Beaty's Butte	OR	32	2010	250	0.747	0.763	0.020	6.67	11/04/10
Cold Springs	OR	24	2010	150	0.806	0.754	-0.068	6.00	11/11/10
Coyote Lake/Tule Springs	OR	50	2011	390	0.792	0.766	-0.034	7.33	05/09/12
Hog Creek	OR	14	2003	50	0.815	0.739	-0.103	6.00	05/13/04
Jackies Butte	OR	40	2011	150	0.750	0.742	-0.010	7.17	04/30/12
Kiger	OR	40	2011	82	0.671	0.695	0.034	5.83	03/29/12 Morphologically unique Spanish blood not confirmed
Liggett Table	OR	17	2010	25	0.500	0.448	-0.115	2.58	11/12/10 Horse destroyed for unspecified defect
Murderers Creek	OR	71	2009	35	0.696	0.707	0.015	6.25	09/23/10
Paisley Desert	OR	83	No year	150	0.743	0.780	0.047	8.00	E. G. Cothran, Texas A&M University, email communication, December 21, 2011
Palomino Buttes	OR			64					
Pokegama	OR			50					
Riddle Mountain	OR	21	2011	56	0.679	0.657	-0.034	5.50	03/29/12
Sand Springs	OR	15	2011	200	0.772	0.759	-0.017	6.67	05/08/12
Sheepshead/Heath Creek	OR	48	2011	302	0.790	0.787	-0.004	7.25	05/09/12
South Steens	OR	31	2010	304	0.758	0.741	-0.023	6.92	10/19/10

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Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Stinkingwater	OR	24	2010	80	0.726	0.680	-0.067	5.50	04/07/10
Three Fingers	OR	50	2011	150	0.710	0.753	0.058	7.250	04/30/12
Warm Springs	OR	83	2010	202	0.766	0.778	0.015	8.00	04/05/11
Oregon mean value					*0.733*	*0.722*	*-0.018*	*6.43*	
Bible Spring	UT			60					
Cedar Mountain	UT	20	2002	390	0.742	0.726	-0.021	6.08	09/23/03
Chloride Canyon	UT			30					Low diversity and dwarfism per 2001 Blawn Wash HMA report
Choke Cherry	UT			30					
Confusion	UT			115					
Conger	UT			80					
Four Mile	UT			60					
Frisco	UT			60					
Kingtop	UT			40					
Mount Elinor	UT			25					
Muddy Creek	UT	33	2001	125	0.619	0.638	0.029	5.33	01/03/02
North Hills	UT	28	2002	36	0.807	0.710	-0.136	6.00	09/09/02
Onaqui Mountain	UT	40	2005	210	0.298	0.282	-0.053		6/3/2008 Values for blood groups
Range Creek	UT	26	No year	125	0.663	0.707	0.061	5.25	E. G. Cothran, Texas A&M University, email communication, December 21, 2011
Sulphur Herd N	UT	53	2009	250	0.682	0.732	0.067	6.33	07/29/10 Evidence of Spanish blood
Sulphur Herd S	UT	41	2009	250	0.679	0.715	0.050	5.83	07/29/10 Evidence of Spanish blood
Swasey	UT			100					
Tilly Creek	UT	25	2002	50	0.609	0.617	0.013	5.08	04/29/03
Utah mean value					*0.637*	*0.641*	*0.001*	*5.70*	
Adobe Town	WY	103	2010	800	0.776	0.776	0.000	7.75	04/21/11
Antelope Hills	WY	25	2004	82	0.747	0.733	-0.018	6.33	03/05/08
Conant Creek	WY	22	2004	100	0.680	0.656	-0.035	5.50	03/06/08
Crooks Mountain	WY			85					
Dishpan Butte	WY	30	2004	100	0.768	0.743	-0.034	6.33	03/06/08
Divide Basin	WY	60	2011	600	0.785	0.787	0.003	7.75	05/15/12
Fifteen Mile	WY			160					
Green Mountain	WY			300					

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Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Little Colorado	WY	45	2011	100	0.761	0.768	0.009	6.67	05/07/12
Lost Creek	WY	30	2009	82	0.775	0.788	0.017	6.67	10/14/10
McCullough Peaks	WY	50	2004	140	0.755	0.715	-0.055	6.33	07/06/06
Muskrat Basin	WY	27	2004	250	0.731	0.727	-0.006	6.00	03/06/08
Rock Creek Mountain	WY			86					
Salt Wells Creek East	WY	33	2003	365	0.760	0.782	0.027	7.83	05/06/04
Salt Wells Creek West	WY	25	2003	365	0.763	0.745	-0.025	6.58	05/06/04
Salt Wells Creek -Marvel Gap	WY	25	2010	365	0.813	0.775	-0.050	6.67	04/11/11
Stewart Creek	WY	30	2009	175	0.750	0.751	0.002	6.42	10/18/10
White Mountain	WY	60	2011	300	0.701	0.715	0.020	7.58	04/30/12
Wyoming mean value					*0.755*	*0.747*	*-0.010*	*6.74*	
Comparison from Cothran reports:									
Mean horse HMAs					0.716	0.710	-0.012	6.06	
Standard deviations					0.056	0.059	0.071	1.09	

NOTE: Blue shading indicates observed heterozygosity or MNA values below the mean minus one standard deviation. Gray shading indicates values below the mean, N = number of animals sampled, AML = appropriate management level, H_o = observed heterozygosity, H_e = expected heterozygosity under Hardy-Weinberg equilibrium, F_{is} = inbreeding coefficient, MNA = mean number of alleles per individual. For Herd Management Areas listed without genetic data, neither data nor reports were provided to the committee for review.
SOURCE: Data from genetic analyses of Herd Management Areas provided by E. Gus Cothran. To access the data, contact the National Research Council's Public Access Records Office at paro@nas.edu.

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Genetic Diversity in Free-Ranging Burros

Far less research has been conducted on genetic diversity in free-ranging donkeys and burros than in horses. Aranguren-Mendez et al. (2001) studied five endemic Spanish donkey breeds using 14 polymorphic microsatellite loci. Their results indicated little differentiation among breeds and moderate genetic diversity within breeds (allelic diversity, 8.7 ± 4.4 alleles/locus; H_e, 0.637–0.684). In a similar study, Guastella et al. (2007) studied three Sicilian donkey breeds, including the endangered Pantesco breed, using 11 microsatellite loci. They also found low differentiation among breeds and moderate genetic diversity (allelic diversity, 4.1–6.5 alleles/locus; H_e, 0.500–0.618). However, they detected high levels of inbreeding in one of the breeds (F_{is}, 0.230). In a later study using 14 microsatellite loci, Bordonaro et al. (2012) confirmed low diversity (allelic diversity overall, 6.07 ± 0.72 alleles/locus; H_e, 0.581 ± 0.059) in the Sicilian breeds. Although the diversity in the Spanish breeds was within the confidence limits of levels in healthy mammalian populations (Garner et al., 2005), the lower allelic diversity and heterozygosity in the Sicilian breeds approached the levels in unhealthy populations.

Genetic Diversity in Burros Managed by the Bureau of Land Management

Genetic studies of 12 burro HMAs have been conducted by Cothran and compared with his previous studies of domestic burro populations. The loci used for burros include nine of the 12 used for the free-ranging horse studies. Summary data for samples collected from domestic burro populations and genotyped in the Cothran laboratory are provided in Table 5-3.

All burro HMAs on which genetic data were obtained had diversity measures below 0.66, the value used for horse HMAs, and all had values lower than those reported for the Spanish and Sicilian donkeys. Five of the 12 HMAs had diversity values at least one standard deviation below the mean value obtained from the four domestic donkey breeds.

Cothran's reports do not provide information regarding the provenance of the four domestic donkey breeds that he used for comparison, nor does he provide dates on which they were sampled. However, his results suggest that domestic donkeys in the western United States have lower genetic diversity than Spanish and Sicilian donkey breeds in that both allelic diversity and heterozygosity measures are lower. Only 12 of the 28 HMAs have had genetic studies of free-ranging burros. Of the remaining 16 HMAs, seven had AMLs over 50 and nine had AMLs under 50. All but one of the reports on burros provided to the committee involved samples collected during 2001-2005.

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TABLE 5-3 Genetic Diversity in Free-Ranging Burros in Herd Management Areas Determined by Using Nine Microsatellite Loci

Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Alamo	AZ			160					
Big Sandy (Wikieup)	AZ	10	2004	139	0.490	0.510	0.038	3.667	10/30/08
Black Mountain (Kingman)	AZ	25	2004	478	0.551	0.553	0.003	4.111	10/30/08
Cibola-Trigo 2	AZ	28	2004	285	0.453	0.506	0.104	4.000	11/06/08
Havasu	AZ	19	2004	166	0.487	0.498	0.021	3.889	11/06/08
Lake Pleasant	AZ			208					
Arizona mean value					*0.495*	*0.517*	*0.042*	*3.917*	
Chemehuevi	CA	52	2003	121	0.354	0.427	0.171	3.222	07/15/03
Chocolate Mule	CA	55	2002	133	0.298	0.394	0.243	3.444	01/24/03
Lee Flats	CA	2	No year	15	0.278	0.278	0.000	1.778	E. G. Cothran, Texas A&M University, email communication, December 21, 2011
Twin Peaks	CA	39	2011	116	0.487	0.526	0.075	3.444	10/5/12
Waucoba-Hunter Mountain	CA			11					
California mean value					*0.354*	*0.406*	*0.122*	*2.972*	
Blue Wing	NV	28	2003	28	0.252	0.268	0.059	2.556	08/03/04
Bullfrog	NV	49	No year	91	0.492	0.502	0.199	3.889	E. G. Cothran, Texas A&M University, email communication, December 21, 2011
Gold Butte	NV			98					
Gold Mountain	NV			78					
Goldfield	NV			37					
Johnnie	NV			108					
Lava Beds	NV			16					
Marietta Wild Burro Range	NV			104					
McGee Mountain	NV			41					
Red Rock (Bird Springs)	NV			49					
Seven Troughs	NV	22	2005	46	0.245	0.339	0.277	2.667	11/13/08
Stonewall	NV			8					
Wheeler Pass	NV			35					
Hickison Summit	NV			45					
Nevada mean value					*0.330*	*0.370*	*0.178*	*3.037*	
Warm Springs	OR			25					

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Herd Management Area	State	N	Year Sampled	AML	H_o	H_e	F_{is}	MNA	Cothran Report Date - Comments
Canyon Lands	UT			100					
Sinbad	UT	30	No year	70	0.466	0.430	-0.084	3.000	E. G. Cothran, Texas A&M University, email communication, December 21, 2011
Comparison with Cothran reports:									
Mean-domestic		4			0.450	0.550	0.153	4.143	
Standard deviation					0.094	0.120	0.195	1.386	
Mean -burro HMAs		12			0.408	0.441	0.093	3.333	
Standard deviation					0.107	0.096	0.105	0.677	

NOTE: Gray shading indicates observed heterozygosity or MNA values below the mean minus one standard deviation. N = number of animals sampled, AML = appropriate management level, H_o = observed heterozygosity, H_e = expected heterozygosity under Hardy-Weinberg equilibrium, F_{is} = inbreeding coefficient, MNA = mean number of alleles per individual. For Herd Management Areas listed without genetic data, neither data nor reports were provided to the committee for review.

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Optimal Genetic Diversity in Herd Management Areas

Although the BLM *Wild Horses and Burros Management Handbook* (2010) does not differentiate between horses and burros, the target heterozygosity value for both clearly was derived from horse studies. The current method of maintaining free-ranging horse HMAs at observed heterozygosity (H_o) values that are no lower than one standard deviation below the mean will become problematic. When this value is recalculated with repeated surveys, it will decrease as allelic diversity is lost from herds when animals die or are removed to maintain AMLs (see Chapter 7). Unless there is gene flow between HMAs, inbreeding in individual HMAs is inevitable and will result in lower genetic diversity and individual fitness. The goal is to maintain as much as possible of the standing genetic diversity, so the mean heterozygosity and allelic diversity as they stand today are more appropriate targets over a reasonable timeframe (such as 100 years).

Monitoring of genetic diversity may be easiest if samples are collected during each gather. Blood samples may be collected from a representative sample of horses for analysis, and the first survey results can be used to determine a baseline value. If that value is below the mean of the BLM horse HMAs, that HMA should be identified as a target for translocation of horses from other HMAs (see "Translocation for Genetic Restoration" below). Samples should be collected from each HMA for genetic monitoring at least once every 5 years. If genetic diversity (either heterozygosity or allelic diversity) is statistically significantly lower than that detected in the previous survey, the HMA should be assigned high priority for genetic management.

The target level of diversity for free-ranging burros is unclear but appears to be based on levels in four domestic donkey breeds of unknown provenance previously studied by Cothran. Although they provide a local comparison, a more appropriate comparison would be with the free-ranging Spanish donkey breeds studied by Aranguren-Mendez et al. (2001).

The committee found that Cothran had conducted multiple genetic studies for several HMAs since 2000. Besides providing estimates of current genetic diversity, the second report on each of those HMAs discussed changes in diversity since the previous one. That valuable information allows BLM to evaluate the effectiveness of management actions aimed at preserving genetic diversity. To maintain the free-ranging horse and burro HMAs at the prescribed AMLs with the genetic diversity needed for long-term genetic health, continued monitoring and active management will be required.

MANAGEMENT ACTIONS TO ACHIEVE OPTIMAL GENETIC DIVERSITY

The goal of genetic management is to maintain as much as possible of the standing genetic diversity of a population and thereby provide the raw material needed to respond to environmental changes. Chapter 4 outlines a variety of techniques for controlling and reducing fertility in free-ranging horses and burros so that numbers can be kept at prescribed levels. Although dramatically limiting individual fertility will reduce a population's size, it will also reduce its genetic effective population size, and this will have effects on genetic diversity.

Many HMAs are spatially isolated, and others are contiguous. Some of the contiguous HMAs have been grouped into complexes by BLM (see Figure 1-2); this suggests that they are exchanging migrants and may be considered a single unit. Within each of the HMAs, BLM could accomplish the goal of conserving genetic diversity through intensive management, as has been

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done for the herds at Assateague Island and Shackleford Banks. Alternatively, BLM could consider the HMAs as a single population and use the principles of metapopulation management to guide its actions.

Effects of Fertility Control on Genetic Diversity

Changing the proportion of breeding males and females can have important effects on genetic diversity through reductions in effective population size. First, contracepting large numbers of females in the population will increase variance in family size in that many more females than normal will fail to produce offspring. Because N_e is inversely proportional to variance in family size, any increase in the number of nonreproducing but surviving females will decrease effective population size. Second, any movement of the sex ratio of breeders from 1:1 will also decrease effective population size. That effect can be subtle in polygynous species, such as horses and burros, inasmuch as the number of breeding males is usually less than the number of breeding females. Thus, although reducing the number of breeding females through female contraception may move the ratio closer to 1:1, the reductions in total numbers of breeders and increases in the variance in family size may still lead to an overall reduction in N_e.

Alternatively, if population size is reduced by decreasing the number of males, it might not reduce N_e depending on the pool of bachelor males available to become harem stallions. If the pool is large, it will leave the number of breeders and variance in family size unaffected.

It is important to consider those effects in the planning phase of management actions. A modeling approach (see Chapter 6) will allow managers to consider the effects of population-size reduction by using fertility-control methods and other important factors.

Individual-Based Genetic Management

Maximum retention of genetic diversity in each HMA (or HMA complex) and in the population as a whole could be achieved if horses and burros were managed as individuals. That entails knowing all individuals in the population unit, their relationships, and their reproductive performance over time. The detailed population monitoring and record-keeping required to accomplish this has been possible in some barrier-island horse populations, including Assateague Island (Eggert et al., 2010) and Shackleford Banks. This level of management would entail an important departure from a truly wild population that is subject to natural selection, a distinction that would need to be made clear to all interested parties. It would also differentiate the management of free-ranging horses and burros from that of other species in the landscape, with the exception of cattle. The committee believes individual-based genetic management might be possible in some HMAs in which habitat conditions and local or BLM knowledge of individual animals make it possible to track individuals (for example, Pryor Mountains).

In addition to monitoring the genetics (via pedigree) and demographics of the population, individual-based genetic management would require actively controlling reproduction of individual animals so that they contribute to the gene pool equally and rare alleles or genotypes are not lost. The barrier islands of Assateague and Shackleford Banks provide some models of attempts to maximize genetic diversity in free-ranging animals through targeted contraception. Nuñez (2009) summarized the evolution of the contraceptive management programs on those islands. Software tools for keeping track of animal pedigrees, analyzing genetic relationships,

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and monitoring population demography were developed for captive populations of animals in zoos; their application to the Assateague Island population was described by Ballou et al. (2008) and Eggert et al. (2010). In HMAs in which known individual animals can be reliably contracepted, either temporarily or permanently, this type of genetic management is possible. In HMAs in which following individual animals and managing their individual reproductive performance is not feasible, a less labor-intensive approach to genetic management is possible with the use of translocations.

Translocation for Genetic Restoration

HMAs exist in a mosaic of ecological habitats, anthropogenic effects, political jurisdictions, free-ranging horse and burro protection status, and property-ownership arrays. The likelihood of natural migration between HMAs is affected by many factors. Two of the most important are the distance over which dispersing animals must travel to reach other HMAs and the quality of the intervening habitat. Hampson et al. (2010) used GPS collars to study travel distances in two populations of free-ranging horses (12 horses) in Australia over 6-7 days at two sites that differed in vegetation and water abundance. There were no differences in daily travel distances between the two sites, but there was a wide range: 8.1-28.3 km. The mean daily travel distance was 15.9 km (18.2 km for males, 14.8 km for females). Some animals in the study were observed walking for 12 hours to reach water. Hampson et al. (2010) cited data from previous studies that showed travel distances of 17.9 km/day by free-ranging horses in Australia, 8.3 km/day by wild asses and 3.5 km/day by Przewalski's horses in Mongolia, and 15 km per 12 hours by female zebras.

Given the distances between many pairs of HMAs, that movement of horses and burros for genetic or demographic reasons would probably need to be facilitated by BLM. The practice of moving individual animals between populations for genetic restoration, or translocation, is justified scientifically. Perhaps the most famous case is that of the Florida panther (*Puma concolor coryi*). Details on the background of that population, the issues and decision-making processes involved in the genetic restoration, and the outcomes may be found in Hedrick (2001), Pimm et al. (2006), Johnson et al. (2010), and Benson et al. (2011). Briefly, this subspecies of puma was reduced to a population of about 25 in the early to mid-1990s and demonstrated lower genetic diversity than other North American puma populations (Culver et al., 2000) and a number of traits that suggested that the influences of inbreeding and genetic drift had completely or nearly fixed genes for potentially deleterious traits that were previously rare. Introduction of female Texas panthers (*Puma concolor stanleyana*) into the population in 1995 resulted in the production of offspring (Land and Lacy, 2000) that lacked several of the deleterious traits (Shindle et al., 2000; Hedrick, 2001; Johnson et al., 2010). Offspring, particularly females, had survival rates almost twice those previously observed in the population (Pimm et al., 2006; Benson et al., 2011) and increases in survival rates were correlated with increased heterozygosity (Benson et al., 2011). Despite these successes in population growth and apparent health, Johnson et al. (2010) pointed out that the future of the Florida panther will require continuing intensive management, including regular infusions of new genetic material, in the face of anthropogenic threats, habitat loss, infectious diseases, and continued inbreeding.

Other case studies of translocation providing genetic and demographic benefits include African lions (Trinkel et al., 2008), adders (Madsen et al., 1996, 1999, 2004), and prairie chickens (Westemeier et al., 1998). Studies by Seddon et al. (2005), Vilà et al. (2003) and

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Adams et al. (2011) described the favorable effect of a single natural immigrant into a wolf population. The case studies are supported by laboratory studies that have demonstrated genetic benefits, fitness benefits, or both of the infusion of new genetic material into small, inbred populations (e.g., Spielman and Frankham, 1992; Ebert et al., 2002; Saccheri and Brakefield, 2002).

Selection of Animals for Translocation

As early as the 1930s, it was established that inbreeding depression in small, isolated populations could lead to loss of fitness and increased risk of extinction (Wright, 1931). Wright's analyses led him to conclude that even small amounts of gene flow between isolated small populations could offset the adverse effects of genetic drift and inbreeding. That conclusion gave rise to a large body of work aimed at determining exactly how much gene flow, in the form of immigrants per generation, was necessary to offset the adverse effects of genetic deterioration. A rule of thumb of one immigrant per generation emerged (Kimura and Ohta, 1971; Lewontin, 1974; Spieth, 1974) and has been widely adopted in conservation practice. More recently, that rule of thumb has been challenged on the basis of the simplistic assumptions that were used in deriving it (e.g., Mills and Allendorf, 1996; Vucetich and Waite, 2000). At the time this report was prepared, it seemed likely that in real-world applications, one immigrant per generation would be an absolute minimum. Mills and Allendorf (1996) outlined a number of scenarios in which the number of immigrants per generations should probably exceed one, including scenarios in which at least one of the following is the case.

- Inbreeding depression is believed to be occurring already.
- Immigrants are closely related to each other or to the receiving population.
- Effective population size is much lower than the number of animals present.
- Social, behavioral, ecological, or logistical factors prevent single animals from immigrating successfully.
- Immigrants are at a disadvantage in probability of survival and reproduction.
- The receiving population has been isolated for many generations.
- Extinction risk due to demographic or environmental variation is deemed to be very high unless there is aggressive supplementation.

The authors concluded that up to 10 immigrants per generation might be necessary to effect genetic restoration in those situations. Vucetich and Waite (2000) extended the analyses by modeling variation in population fluctuation and suggested that more than 20 immigrants per generation may be necessary if high population fluctuation leads to drastically reduced effective population size.

In addition to the number of animals to translocate, the interval for doing so must be determined. There are important practical and logistical considerations involved, but the translocation of animals for genetic restoration is usually thought of as being conducted on a per-generation basis. Therefore, one starting point is to determine the generation time of free-ranging horses. Eggert et al. (2010) constructed a pedigree for the Assateague Island horse population on the basis of molecular analyses and herd records and derived an estimate of 10 years. Goodloe et al. (1991) also derived an estimate of 10 years for horses on Cumberland Island, Georgia. Similarly, historical pedigree data on zoo populations of wild equids in North America all have generation time estimates of about 10 years (range 9.6 years in Somali wild ass to 10.4 years in

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Hartmann's zebra[6]). Thus, it would be valid to consider 10 years as an appropriate interval for translocating animals between populations for genetic restoration. On the basis of the literature, it appears that translocation of 10 animals between populations every 10 years would be appropriate.

BLM is already experienced in the capture and transport of animals for population management, and the protocols for translocation would be similar to those currently used for gathers; only the destination of the removed animals would differ. Although the movement of animals among HMAs has the potential to facilitate the spread of pathogens (Champagnon et al., 2012), the probability of that could be minimized through observation and advance testing of source and target herds. Below is an outline of some factors to consider in selecting animals for translocation for genetic management.

Genetic Factors. Because the goal of translocation is to supplement the genetic diversity in a herd and reduce the probability of inbreeding, it is advisable to select animals that are unrelated to the target herd. In most cases, pedigree information on free-ranging horse and burro populations will not be available, so absolute genetic relationships among individual animals will be unknown. The use of genetic information, however, will make it possible to choose individual animals that have moderate levels of differentiation from the target population.

The term *outbreeding depression* is used to describe a decrease in fitness due to hybridization between individuals from populations that have differentially adapted genomes (Frankham et al., 2011). Frankham et al. (2011) used empirical data and modeling to develop a decision tree for predicting the probability of outbreeding depression. Their tree proved robust when crosses that had known outcomes were used, and it suggested that outbreeding depression is likely when the populations being crossed are of different species, exhibit fixed chromosomal variants, have not exchanged genes in 500 years, or inhabit different environments. None of those risk factors seems to apply to free-ranging horses and burros in HMAs. Environments may differ between HMAs, but Frankham et al. (2011) suggested that environmental differences need to be substantial enough to select for different traits among populations. They recommended paying particular attention to the needs and resources to which a species is most sensitive and to the range of variation in important features of the environments under consideration. The adaptability of the horse and its associated ability to live in various environments appears to lessen the concern about environmental differences between possible translocation sites.

By using the genetic data generated for the evaluation of level of genetic diversity, it is possible to estimate the level of differentiation among HMAs. The fixation index (F_{st}) is a measure of genetic distance, or population differentiation, that is based on genetic polymorphisms (Wright, 1931). Polymorphic microsatellite loci constitute a powerful tool for predicting which populations are so similar (low F_{st} value) that translocating animals will probably not be successful in supplementing genetic diversity and which are so different (high F_{st} value) that genetic compatibility between individuals may not be optimal and may reduce the probability of successful translocation. Matrices of pair-wise F_{st} values for horse and burros based on genetic data from HMAs are in Appendix F and could be used to identify the mixtures that might be most successful because they exhibit moderate F_{st} values.

New genetic variation needed by an HMA does not necessarily need to come from another HMA. Mares in long-term holding facilities could also be used as sources of genetic diversity if necessary, assuming that they present no novel disease risk for free-ranging horses

[6]Association of Zoos and Aquariums website, www.aza.org. Accessed April 16, 2012.

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and burros. The genetic tools described above can be used to identify free-ranging horses and burros on other public lands, in private sanctuaries, and in long-term holding facilities that could be used to infuse new genetic variation into an HMA.

Behavior and Social Factors. Given the harem social structure of free-ranging horses and the fact that this structure means that more sexually mature females than sexually mature males are breeding at any one time, it appears that the most rapid way to infuse new genetic material into an HMA via translocation would be to move young, sexually mature mares between HMAs. Young mares new to an HMA are likely to be courted by bachelor males and to be open to forming consortships with them. Older mares would also probably be bred relatively quickly, but they may be more selective in forming consortships with bachelor males. Ideally, translocated mares would already be familiar with one another, if possible originating from the same harem. Kaseda et al. (1995) found that mares that had long-term bonds to harem stallions had higher reproductive success than mares that wandered between bands regularly or that had shorter bonds to stallions. Linklater et al. (1999) also found that single mares that were dispersing between bands had lower fecundity, reproductive success, and body condition; had higher parasite levels; and received more aggression from bachelor males than mares in established harems. Moving established groups of females may buffer some of those adverse effects, but it is possible that translocating bonded females without a harem stallion will lead to dissolution of bonds between mares (Rubenstein, 1994).

A second option and one that might further lessen adverse effects is to move intact harems if the harem members and associated stallions can be reliably identified during gathers. That would immediately add new genetic material to the site, but there would be a longer delay in getting that material into the gene pool because foals born into the harem would have to grow up, disperse, and interbreed with members of the resident population.

A third option would be to move bachelor males. This option carries the most risk with respect to getting new genes into the resident population. Stallions that have harems may be quite successful in spreading their genes rapidly via breeding with multiple mares, but obtaining a harem is not easy, and bachelor males may not survive to realize breeding opportunities.

Immediate and long-term infusion of new genetic material may be most likely if intact harems or groups of young mares (immediate) are translocated with a number of males (long term).

Burros are characterized by a less cohesive social structure in which the only long-term relationships are between females and their dependent offspring. Thus, there would be fewer challenges in integrating new females into a burro population, so females would be the first choice for translocation of animals for genetic restoration of burro populations. Males would also be viable candidates for genetic restoration, but introduced males would have to compete with resident males for access to breeding females.

Fertility Control and Implications for Translocation

Introductions of males or females are likely to have different consequences in that adding new females will increase numbers exponentially over time. If population regulation involves female contraception, adding new fertile females could be counterproductive, so adding novel males may be the best way to increase genetic diversity without increasing population size. However, to ensure that the new males become breeders, either a large number would need to be translocated or some of the resident males would need to have their fertility reduced.

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Alternatively, if curtailing male fertility is the preferred means of population regulation, either a smaller number of novel males can be added to replace a disproportionate number of resident males that are made sterile, or novel females can be added inasmuch as whenever one of the few remaining resident males breeds, he will sire offspring that have genes from the novel females.

Which type of translocation is best to use will depend on a variety of factors, many of which can be tested with a modeling approach in the planning phase (see Chapter 6). Population size, fertility-control methods, and the effects of translocation on N_e will need to be considered. Although translocating males may require fewer total introductions when population size is being regulated because male additions increase the population growth arithmetically rather than exponentially, novel males may find it difficult to obtain harems (horses) or territories (burros), which are prerequisites for siring many offspring. Many tradeoffs will require sensitivity to context in designing effective translocation strategies that enhance genetic diversity without upsetting existing population regulatory strategies.

CONCLUSIONS

Genetic diversity is an important component of the health of free-ranging horses and burros on HMAs, in that it provides the raw material needed to respond to environmental changes. Maintenance of genetic diversity is a function of the effective population size (N_e), which is probably at least an order of magnitude lower than the number of animals present. Factors that reduce N_e include unequal sex ratios, variance in family sizes, and high variance in population sizes between generations. In small, isolated herds, inbreeding is inevitable and will occur within only a few generations. It is important to measure and monitor allelic diversity, observed and expected heterozygosity (H_o and H_e), and coefficients of inbreeding (F_{is}) in HMAs to detect the loss of diversity before the reduction in fitness that has been observed in many inbred populations becomes a problem.

In recognition of the importance of monitoring genetic diversity, and as recommended in previous National Research Council reports, BLM has collaborated with outside scientists since 1985 to monitor herd-specific diversity on the basis first of isozyme and serum proteins and later of nuclear microsatellite loci. The committee recommends that BLM continue to monitor genetic diversity as part of the routine management of both horse and burro HMAs. The BLM *Wild Horses and Burros Management Handbook* does not clearly state which HMAs should be monitored and how often studies should be repeated. The committee recommends routine monitoring at all gathers and collection and analysis of a sufficient number of samples to detect losses of diversity.

Genetic concerns involve both the potential for the reduced fitness associated with inbreeding and the effects of mutations that can cause phenotypic conditions that affect the fitness of a herd. The Cothran studies are excellent tools for BLM to use in managing herds to reduce the incidence of inbreeding, but they do not provide information about the effects of specific genes known to cause genetically based conditions. To the committee's knowledge, no tests have been conducted to detect the presence of genetic mutations associated with those types of conditions. The committee recommends that BLM document the incidence of coat color or other morphological anomalies that may indicate the presence of deleterious mutations during all gathers. For herds in which phenotypic data suggest the presence of genetically based disorders,

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the committee recommends testing and consultation with geneticists and equine veterinarians to devise appropriate management actions.

Monitoring of genetic diversity in burro HMAs has been conducted in only one herd since 2005. Genetic diversity in burro herds is lower than that in Spanish and Sicilian breeds, including endangered breeds, and many of the AML numbers are low to very low. The committee recommends that BLM resume the genetic monitoring of burro HMAs. Although the available literature does not report clinical issues in burros, the committee recommends that BLM routinely monitor and record the incidence of any morphological anomalies that may indicate the deleterious effects of inbreeding.

The committee recognizes that genetic management of some HMAs is complicated by other considerations. For herds that have strong associations with Spanish bloodlines—such as those of the Cerbat Mountain, AZ; Pryor Mountains, MT; and Sulphur, UT—or herds that contain unique morphological traits—such as the Kiger, OR, herd—BLM will need to balance concerns about maintaining breed ancestry with the need to maintain optimal genetic diversity. Herds that remain isolated over the long term will inevitably lose genetic diversity inasmuch as maintaining or slightly increasing herd sizes will not offset the effects of genetic drift. The public is interested in these herds, and it is particularly important that BLM seek opportunities to discuss the complexity of the situation with interested parties. It is true that the existence of a few genetic markers may indicate Spanish origin, but the remainder of the genome may not; rather, it may reflect horses that are well adapted to local conditions. If the latter is the case, isolation of the herd to maintain purity may be mistaken and may lead to unnecessary loss of genetic diversity. The committee recommends that BLM examine in more depth the genetic constitution of these herds and share the findings with the public so that informed decisions about the sustainability of the populations can be made (see Chapter 8).

The committee recommends that BLM consider some groups of HMAs to constitute a single population and manage them by using natural or assisted migration (translocation) whenever necessary to maintain or supplement genetic diversity. Although there is no magic number above which a population can be considered forever viable, studies suggest that thousands of animals will be needed for long-term viability and maintenance of genetic diversity. Very few of the HMAs are large enough to be buffered against the effects of genetic drift, and herd sizes must be maintained at prescribed AMLs, so managing the HMAs as a metapopulation will reduce the rate of reduction of genetic diversity in the long term.

Finally, the committee recommends that BLM stay abreast of advances in population genetics and genomics. New laboratory and data-analysis tools promise to reduce costs while providing more powerful methods for monitoring genetic diversity and resolving breed relationships. The 12 nuclear microsatellite loci that are currently used for estimating genetic diversity and genetic differentiation among herds were chosen largely from those approved by the International Society of Animal Genetics for their informativeness in equine genotyping. Thus, they are useful tools for estimating overall genetic diversity and population divergence. However, the small number of loci and the uncertainty about their evolution limit their power to resolve relationships among closely related lineages, such as equid breeds. Recently, the Illumina 50K SNP Beadchip, an equine SNP genotyping array with over 50,000 polymorphic loci, was developed and found to be informative in several equid species (McCue et al., 2012). The Equine Genetic Diversity Consortium successfully used that array to assess the effects of inbreeding and natural selection in 36 breeds from around the world, to infer relationships among breeds, and to detect signals of ancestral admixture (Petersen et al., 2012a). Genomic tools are also being used

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to detect the genetic underpinnings of traits that are under positive natural selection (Petersen et al., 2012b) and mutations that are responsible for genetically based diseases, such as lavender foal syndrome (Brooks et al., 2010). Genomic analysis can provide much finer resolution of questions about breed associations and will soon be the method of choice for population-level analysis.

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Population Models and Evaluation of Models

The Bureau of Land Management (BLM) *Wild Horses and Burros Management Handbook* states that the WinEquus model,[1] developed by Stephen Jenkins at the University of Nevada, Reno, "will be used during gather or herd management area planning to analyze and compare the effects of proposed wild horse management" and "to identify whether any of the alternatives would be likely to 'crash' the population based on a number of stochastic factors (varying environmental conditions)" (BLM, 2010a, p. 28). This chapter briefly reviews the purpose and utility of modeling population dynamics and the kinds of models that have been applied to free-ranging horse and burro populations. It then examines models that have been developed specifically for the BLM Wild Horse and Burro Program. After reviewing their strengths and weaknesses, the chapter concludes with an overview of alternative modeling approaches that can be useful for managing the free-ranging equid populations on the western rangelands.

UTILITY OF POPULATION MODELS

Models of population dynamics (hereafter, referred to as population models) are useful tools for understanding, explaining, and predicting the dynamics and persistence of biological populations. From a management perspective, such models can be used for assessing the status of a population, diagnosing causes of population declines or explosive growth, prescribing management targets, and evaluating the prognosis of a population's likely responses to alternative management actions (Caswell, 2001). For example, population modeling played an important role in reversing the decline of the endangered loggerhead sea turtle population in the United States (Crouse et al., 1987; Crowder et al., 1994; Caswell, 2001). Until the 1980s, sea turtle conservation efforts had focused on the protection of nests, eggs, and hatchlings on nesting beaches. Analysis of stage-structured population models revealed that the sea turtle population growth rate was proportionately most sensitive to changes in survival and that reducing mortality of subadult and adult turtles at sea would be a more efficient way of increasing population growth rate than protecting nests and hatchlings on nesting beaches. Informed in part by those

[1]The WinEquus program can be found at http://wolfweb.unr.edu/homepage/jenkins/.

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findings, regulations were imposed to require turtle excluder devices (TEDs) in shrimp trawls in the sea turtle range. Although controversial initially, the use of TEDs was later endorsed by a National Research Council committee (NRC, 1990) and is thought to have had a substantial favorable effect on loggerhead sea turtle populations (Caswell, 2001).

Models of population dynamics can also help to predict populations' responses to environmental changes, such as global climate change. Global climate change is predicted to influence arctic sea ice adversely, and this could affect the population dynamics and persistence of species that depend on sea ice environments. For example, polar bears depend on arctic sea ice for feeding and breeding. By integrating field data, climate-change models, and population models, Hunter et al. (2010) predicted that the polar bear population in the southern Beaufort Sea would experience a drastic decline because of a reduction in sea ice extent by the end of the 21st century.

Population models are also useful tools in the management of overabundant species. For example, the American bullfrog is an introduced species on Vancouver Island and is adversely affecting biodiversity on parts of the island. A modeling study by Govindarajulu et al. (2005) reported that the management strategy of targeting removal of tadpoles may not be effective because partial removal of tadpoles could lead to higher tadpole survival owing to reduced density-dependent effects. Their results revealed that culling metamorphs in fall would be most effective in controlling bullfrog populations. A theoretical study by Zipkin et al. (2009) suggested that control of overabundant species by harvest (or removal) could backfire because populations of species characterized by early maturity and high fecundity may experience rapid growth after harvest or removal as a result of density-dependent overcompensation. Other examples of the application of population models include assessing the influences of culling and fertility control on the population dynamics of an overabundant elk population (Bradford and Hobbs, 2008) and controlling the fertility of the koala on koala-forest dynamics (Todd et al., 2008), evaluating the efficacy of euthanasia versus trap-neuter-return for management of free-roaming cats (Andersen et al., 2004) and the efficacy of fertility control in a white-tailed deer population (Merrill et al., 2003), discerning mechanisms underlying a recent rapid population growth in yellow-bellied marmots (Ozgul et al., 2010), predicting effects of El Niño on the dynamics and persistence of the Galapagos penguin population (Vargas et al., 2007), assessing harvest impact on the persistence of dugongs (Heinsohn et al., 2004), and projecting the impact of anticipated climate change on the dynamics and persistence of emperor penguin populations (Jenouvrier et al., 2009).

POPULATION MODELS APPLIED TO HORSES AND BURROS

Population models have been applied to free-ranging horse populations to address a variety of ecological and management questions. The modeling frameworks used have ranged from simple, unstructured models to complex spatially explicit, individual-based simulation models. In the United States, Garrott and Taylor (1990) were among the first to report estimates of age-specific survival, reproductive rates, and population growth rates in a free-ranging horse population. Since then, several population modeling studies have been conducted, including those by Garrott et al. (1991, 1992), Garrott and Siniff (1992), Coughenour (1999, 2000, 2002), Gross (2000), Ballou et al. (2008), and Bartholow (2007). Outside the United States, population dynamics in free-ranging or semi–free-ranging horse populations have been studied and modeled

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in Australia (Walter, 2002; Dawson, 2005; Dawson and Hone, 2012), Argentina (Scorolli and Lopez Cazorla, 2010), New Zealand (Linklater et al., 2004), and France (Grange et al., 2009). Relatively few studies have examined demography and population dynamics of free-ranging asses or free-ranging burros either inside or outside the United States (Freeland and Choquenot, 1990; Choquenot, 1991; Saltz and Rubenstein, 1995; Saltz et al., 2006).

From a management perspective, free-ranging horse population modeling efforts have focused on management strategies to reduce population size and growth rate (Garrott and Siniff, 1992; Garrott et al., 1992; Gross 2000). The primary foci have been to determine the number (or proportion), sex, and age of animals to be removed or made infertile to achieve a target population size or growth rate and to determine the frequency of removal or fertility-control treatments necessary to achieve management objectives.

Motivated by a controversy regarding the sex of animals to be targeted for fertility control, Garrott and Siniff (1992) conducted a simulation study to determine the population effects of male-directed fertility control in free-ranging horses. They concluded that male-oriented contraception would result in only modest reductions in population growth rate and potentially would disrupt seasonal foaling patterns. In one of the first and most comprehensive modeling efforts, Garrott et al. (1992) used an age-structured population model and evaluated population effects and costs associated with five management alternatives: selective removal, nonselective removal, and three different fertility-control treatments. Their results revealed pros and cons of each management alternative but suggested that a female-directed fertility-control program can reduce the number of horses that need to be removed to keep the horse numbers within an acceptable range and can reduce associated costs of management activities.

Gross (2000) developed an individual-based model to simulate free-ranging horse population dynamics and genetic diversity and to evaluate the efficacy of alternative management strategies. The model operated on a yearly time step,[2] followed each animal from birth to death, and was parameterized with (that is, based on) demographic data from the Pryor Mountain herd. Sex, age, reproductive status, and genetic constitution of each animal were explicitly considered, and such processes as breeding, recruitment, contraception, and removal were simulated. Genetic diversity was modeled by simulating Mendelian inheritance at 10 independent loci. Management strategies implemented included removals, contraceptive treatments, or both. Management strategies were "simulated by applying rules based on current population size, post-treatment population objective, sex and age of animals to be treated, the minimum number of horses in each sex/age class that were to be unaffected by the treatment, and for removals, the length of time since a previous removal" (Gross, 2000, p. 321). Model output included the number of animals by sex and age classes, the age and sex of animals removed, the age of animals given contraceptive treatment, and measures of genetic diversity for each year of simulation. Gross concluded that management strategies based on removal and fertility control were most effective in achieving management goals but advocated strategies that rely less on removal and more on fertility control; he also highlighted the importance of management actions to delay age at first reproduction and increase generation length to reduce population growth. The model was somewhat unique in that it tracked individual animals throughout their lives and simulated breeding and genetic diversity.

[2]In simulation models, the model user projects population size (or some other variable of interest) from one time "step" to the next, for example from year 1 to year 2 and then from year 2 to year 3 and so on. The length of the time step (e.g., day, month, or year) is specified by the model user.

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Coughenour (1999, 2000) used a spatially explicit ecosystem model to simulate the ecosystem dynamics in the Pryor Mountains, of which free-ranging horses were a component. Coughenour's model (SAVANNA; Coughenour, 1993) operated on weekly time steps and was driven by monthly weather data. The model simulated net primary productivity, litter decomposition and nitrogen cycling, animal forage intake and energy balance, and population dynamics of free-ranging horses and sympatric bighorn sheep. Horse populations were represented as age-sex classes, and birth and death rates were allowed to be affected by horse nutritional status, which in turn was affected by forage availability. The model was run to simulate a variety of management alternatives, including density-dependent self-regulation, that is, food-limited carrying capacity (see Chapter 3). Coughenour concluded that without culling horses have the capacity to increase to higher densities and can persist at quasiequilibrium with available forage, although vegetation cover would be reduced in many areas and horses would generally be in poorer condition and exhibit higher mortality (see Chapter 3). The model was unique in that it was process-oriented and explicitly linked free-ranging horse population dynamics with climate, vegetation, and ecosystem processes.

More recently, Bartholow (2007) used WinEquus (reviewed below) to simulate costs and demographic effects of removal and contraception in four horse populations managed by BLM: Challis, Little Book Cliffs, McCullough Peaks, and Pryor Mountains. Alternative scenarios simulated included status quo of selective removal, adoption, and sanctuary; changing the frequency and efficiency of roundups; and status quo plus a variety of contraceptive applications. Bartholow (2007) concluded that prudent use of contraceptives could lead to reductions in costs of management activities of up to 30 percent.

Ballou et al. (2008) used the program VORTEX[3] (Miller and Lacy, 2005) to simulate population-dynamic and genetic effects of alternative management scenarios for horses on Assateague Island (managed by the National Park Service). Specifically, they examined the rate of population decline, the time to reach the management target, and the level of inbreeding under the existing contraceptive strategy and under an adaptive contraceptive strategy. They concluded that the continued use of the current fertility-control strategy would further reduce the population growth rate, cause a major shift in age structure in favor of older animals, and lead to a low percentage of females that have reproductive opportunities.

VORTEX was not developed specifically for horses, but it has many features that could be useful for modeling free-ranging horse population dynamics. It is an individual-based simulation model that allows users to evaluate potential effects of deterministic forces (e.g., density dependence) and stochastic forces (e.g., demographic and environmental stochasticity and catastrophes) on the dynamics and persistence of age-structured wildlife populations (Lacy, 2000; Miller and Lacy, 2005). The program allows users to create and analyze alternative management scenarios easily. The program has been in existence for many years, is fully and adequately documented, offers an easy-to-use graphical user interface, and has been one of the most popular population-viability analysis software packages (see Miller and Lacy [2005] for a bibliography of publications that use VORTEX).

Age-structured or stage-structured matrix population models (Caswell, 2001) have often been used to explore questions relevant to free-ranging horse management. For example, Hobbs et al. (2000) used a female-only, density-dependent, stage-structured matrix model for theoretical exploration of questions pertaining to the effects of culling and fertility control on ungulate population dynamics. Only recruitment was assumed to be density-dependent. The effect of

[3]VORTEX can be downloaded at http://www.vortex9.org/vortex.html.

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fertility control was modeled by partitioning females of reproductive age into fertile and infertile categories, and removal was modeled by including a removal term that was a function of per capita removal rate. Zhang (2000) also used a density-dependent matrix model for theoretical analysis of the efficacy of fertility control and culling for wildlife population control. Similar population modeling frameworks have been used to evaluate the effect of fertility control on overabundant white-tailed deer populations in the United States (Merrill et al., 2003) and to simulate koala-forest dynamics in Australia (Todd et al., 2008). Although generally flexible, powerful, and amenable to theoretical explorations (Caswell, 2001), matrix models do not permit explicit consideration of such factors as allelic diversity, mating system, individual variation, and behavioral interactions, which can affect free-ranging horse population dynamics.

POPULATION-MODELING FRAMEWORK USED BY THE BUREAU OF LAND MANAGEMENT

The committee was asked to evaluate the strength and limitations of the population model used by BLM and the types of decisions that could be appropriately supported by the model. As mentioned previously, when the report was prepared, BLM used the population simulation model WinEquus.

WinEquus uses an individual-based approach—that is, each animal is tracked individually as opposed to the use of aggregated age-sex or stage classes—to simulate population dynamics and management of free-ranging horses in the framework of age-structured and sex-structured population models. Given appropriate data, it can incorporate the effects of environmental and demographic stochasticities, density dependence, and management actions and can simulate population dynamics for up to 20 years (Jenkins, 2011).

The basic data requirements include initial age and sex distributions, sex-specific and age-specific survival probabilities, age-specific foaling rates, and parameter values needed to implement density dependence, environmental stochasticity, and, if desired, management options (removal, contraception of females, or both). By default, WinEquus assumes a detection (or sighting) probability of 90 percent for typical BLM inventory surveys and increases the number of horses counted in each age-sex class accordingly. The assumption of 90-percent detection probability originated in a paper published by Garrott et al. (1991) that draws from a small sample of western herds with adequate data and likely represents an optimistic estimate of the typical proportion of horses detected in routine surveys (see Chapter 2). However, the user can disable that option in such a way that initial age and sex distributions are treated as exact and no adjustments for detection probability are made. Environmental stochasticity is incorporated by sampling survival and foaling rates from the logistic distribution with user-specified parameter values. However, there are no specific linkages among parameters of logistic distribution, climatic variability (e.g., variability in rainfall and winter severity), and vital rates (e.g., birth and death rates). Survival of both foals and adults are assumed to be perfectly correlated by default; however, the user can specify any correlation from -1 to +1 between survival and foaling rates if desired. Because the program uses an individual-based simulation approach, the effect of demographic stochasticity (random variation among individuals in survival and foaling rates) is automatically incorporated. By default, density dependence is not considered; however, the user may choose for foal-survival probability to be density-dependent, in which case WinEquus adjusts foal-survival probability as a nonlinear function of population density in such a way that

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the finite population growth rate is 1.0 (births equal deaths) when population density reaches the carrying capacity (Jenkins, 2011). Management scenarios offered by the program include no management, removal only, female fertility control only, and both removal and female fertility control.

The user can specify various parameter values relevant to the selected management alternatives, including a gather schedule, target population size, population size above which removal is implemented, percentage of animals of different sex and age classes to be removed, effectiveness of fertility control over time, and percentage of mares of different ages to be treated with fertility-control agents. The program output includes time series and summaries of population size, information regarding the age and sex composition of the simulated population trajectories, and information on annual population growth rates. The output also includes summary information on results of management such as number of gathers, number of horses removed, and number of mares treated with fertility-control agents; this information can be used to assess the economic costs of management alternatives although the current version of the program does not offer options for calculating economic costs.

The committee evaluated WinEquus and concluded that it does what the author claims that it can do. It offers an easy-to-use user interface, provides default parameter values (age-specific foaling rates, age-specific and sex-specific survival rates, and sex and age composition), and allows users to choose management options to be simulated. A user manual was not available for the current version (Version 1.40) of the program, but the help files offer useful guidance. Results can be saved as text files for further analyses or viewed on a computer monitor. Under the assumptions of the model and given appropriate data, WinEquus can adequately simulate horse population dynamics under alternative management actions (no treatment, removal, female fertility control, and both removal and female fertility control). The committee found one peer-reviewed journal article that used WinEquus for modeling free-ranging horse population dynamics under alternative management scenarios (Bartholow, 2007).

How the Bureau of Land Management Uses WinEquus

As noted previously, the BLM handbook calls for the use of the WinEquus population model for Herd Management Area (HMA) planning that involves management interventions. Guidelines for the use of WinEquus have been developed and summarized by BLM for the Wild Horse and Burro Program staff in a document titled “How to Use and Interpret the WinEquus Population Modeling Program” (BLM, email communication, February 17, 2012). The document offers step-by-step instructions for specifying parameters and alternative management scenarios, running the model, and viewing or saving results.

The committee reviewed gather plans and environmental assessments of proposed management actions related to a sample of about 10 HMAs or HMA complexes and requested additional information from BLM administrators to aid in interpretation of information presented in the documents to evaluate how BLM uses WinEquus (see Appendix D). As stated variously in gather plans and environmental assessments, population modeling using WinEquus appeared to have two objectives: to evaluate potential population effects of alternative management actions and to determine whether any of the alternatives would crash the population or cause extremely low population numbers or growth rates. At least one gather plan (BLM, 2010b) reported that one of the objectives of population modeling was to assess the effects of different management

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alternatives on the genetic health of the herd, but WinEquus has no capability for simulating genetic diversity, so it cannot be used to address issues related to genetic health.

Presentations of WinEquus results in the HMA gather plans and environmental assessments examined by the committee normally included a brief narrative in the body of the document and further details and graphic presentations of simulations in an appendix. Notably absent from most of the presentations was adequate information on the input parameter values used and the modeling options. Results of population simulations with WinEquus depend heavily on a large number of decisions that must be made by the user when setting up a simulation. As previously described, the decisions include data on or assumptions about animal abundance, sex and age structure, survival and foaling rates, parameters needed to model environmental stochasticity, and parameters associated with density dependence if it is incorporated into a simulation. In addition to model parameters that establish attributes of the population and the demographic processes to be simulated, the user must provide parameter values for management alternatives, which may include efficacy of fertility treatment, percentage of mares of different ages to be treated, percentage of horses to be removed by sex and age, and removal schedule. There are a large number of combinations of the input parameter values that, in turn, dictate model output. Default parameter values (estimated using data collected from the Garfield Flat, Granite Range, and Pryor Mountain HMAs) and options available in the program can be used; however, it was often not stated whether or which set of default parameter values were used. Results of WinEquus simulations cannot be adequately interpreted without knowledge of input parameters and the many decisions made by the user in setting up the simulations.

Despite the importance of describing clearly and explicitly how WinEquus simulations were structured and the input parameter values used for each modeling exercise, there appeared to be no standardization of the amount of information presented in gather plans and environmental assessment documents. Many planning documents provided vague descriptions of input parameter values. For example, the Black Mountain gather plan stated that “data used in the statistical analysis of the Black Mountain and Hardtrigger HMAs was extrapolated from the census, and age and sex structure of the November 2010 CTR [capture, treat, release] gather” (BLM, 2012a, p. 79). Without further information, it is impossible to know how the data referred to in that statement were used to parameterize the WinEquus model or the actual values of any input parameters that might have been derived from the data. An exception in that respect was the High Rock Complex gather plan (BLM, 2011a), which provided a fair amount of relevant detail regarding input parameter values (with appropriate citations) and WinEquus options used. It specifically stated that demographic parameters for the Granite Range herd (a default option) were used, provided values of contraception and removal parameters, and stated that age and sex composition based on data from the High Rock HMA collected during 2006 were used in the results reported. However, many BLM planning documents reviewed by the committee, such as the Cold Spring HMA gather plan (BLM, 2010c), failed to provide any information regarding input parameter values or WinEquus options.

The lack of relevant information regarding input or management parameters in gather plans or environmental assessments has attracted public attention. For example, multiple public comments were related to some aspects of input parameters or modeling options for the Twin Peak HMA gather plan (BLM, 2010d). In response to one such comment, BLM stated that “the model and parameters therein were developed by Stephen H. Jenkins of the Department of Biology, University of Nevada at Reno. Reference: Wild Horse Population Model, Version 3.2 User’s Guide, Stephen H. Jenkins, University of Nevada, 1996” (BLM, 2010e, p. 24). That

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response is vague and uninformative but seems to imply that the simulations relied on one of the default parameter options available in WinEquus. Although it was rarely stated explicitly in planning documents, the committee concluded that one of the default age-specific survival and foaling rate datasets (Granite Peak, Garfield Flat, and Pryor Mountain HMAs) is typically used for WinEquus simulations. It was unclear whether or to what extent the chosen (default) datasets were representative of a specific HMA or HMA complex because no information that addressed this issue is typically provided in planning documents. In response to the committee's queries, BLM noted that default parameter values were used because HMA-specific data were not available, and it offered lack of funding to collect HMA-specific data as justification. The committee recognized that limitation, but nearly all HMAs or HMA complexes are periodically gathered and substantial numbers of horses removed, sexed, aged, and placed into holding facilities. Those data, with sex- and age-composition data obtained in previous gathers and estimates of abundance from periodic population surveys (see Chapter 2), can provide some site-specific data that can be used in assigning values to parameters in WinEquus, and it is the committee's impression that this information may have been used in most WinEquus simulations. However, that is an assumption; it was not explicitly stated in most gather plans or environmental assessments.

Results of population modeling reported in gather plans or environmental assessments varied substantially, but they generally included graphic or numerical summaries of typical population trajectories, of statistics on population size at the end of the simulation period (usually 11 years), of descriptions of the realized population growth rate during the simulation period, and of the numbers of horses gathered, removed, and treated with a fertility-control agent under alternative management actions. Most gather plans and environmental assessments, however, simply copied and pasted WinEquus output and gave no explanation or interpretation of the results being reported. Although management options recommended or implemented appeared to be generally consistent with results of population modeling, most of the gather plans conveyed nothing about whether or how results of population modeling were used to make management decisions. In rare instances, how results of population modeling were used in management decisions was explicitly stated; for example, the Challis HMA gather plan specifically stated that the number, age, and sex of animals proposed for removal were based on the results of population modeling (BLM, 2012b).

The committee queried BLM to gain additional insight into how results of WinEquus simulations were used in management decisions to determine whether there was a general agency policy on the use of WinEquus results. One BLM field office responded that "[results of population modeling] were not used to make direct management decisions regarding age or sex of horses to return to the range as these decisions were made based on horses actually captured and commensurate with our selective removal criteria" (BLM, email communication, March 20, 2012). A similar question had been submitted to BLM officials by a member of the public during public comment period for the Twin Peak environmental assessment. It elicited the response that "these modeling prediction numbers are not used for making specific management decisions, however these numbers are useful in making relative comparisons of the different alternatives and of the potential outcomes under different management options" (BLM, 2010e, p. 34). Thus, whether or how results of WinEquus analyses were used in management decisions at the HMA or HMA-complex level is unclear because of the inconsistency in statements found in the planning documents reviewed by the committee.

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The committee was also asked to determine the type of management decisions that can be appropriately supported by using WinEquus. Such a determination would require the committee knowing how BLM uses, or would like to use, WinEquus to make management decisions, specific questions to be addressed and management alternatives to be evaluated, and the availability of data needed to assign values to parameters in the model. As noted above, the committee could not determine with certitude whether or how BLM uses results of WinEquus population modeling in making management decisions. Specifically, it was difficult to determine whether results of population modeling were used to make management decisions or were offered as justification for management decisions that were made independently of modeling results. Furthermore, in the absence of at least some site-specific (or otherwise representative) data and relevant information regarding input parameters and WinEquus options, results of population modeling exercises would be difficult for a critical reader to accept as pertinent and meaningful. Nonetheless, given appropriate data, WinEquus can be used to simulate free-ranging horse population dynamics without management interventions or under alternative management regimes that are available in the program (removal only, female fertility control only, and both removal and female fertility control).

Strengths and Weaknesses of WinEquus

The committee understood that WinEquus was developed to fulfill BLM's need for easy-to-use software for simulating horse population dynamics and its need for management scenarios that can be used by its staff with minimal training. WinEquus appears to fulfill those needs. The easy-to-use graphical user interface makes it easy to enter baseline demographic data manually or to choose from default datasets available in the program. When a management option is selected, the program offers intuitive data-input windows for relevant parameters. Likewise, the program makes it relatively painless to input a scale parameter to implement environmental stochasticity on age-specific survival and foaling rates or to implement density-dependent effects on foal survival rate. Ease of use, the ability to simulate population effects of management options (female fertility control, removal or both), and informative outputs were viewed as strengths of WinEquus. However, some modeling options that are not available in WinEquus would potentially be useful to BLM's Wild Horse and Burro Program (see "Alternative Modeling Approaches" below).

THE WILD HORSE MANAGEMENT SYSTEM MODEL

The Humane Society of the United States (HSUS) has suggested to BLM that it use the Wild Horse Management System (WHMS) model as an alternative in the management of free-ranging horses and burros. The model was developed by EconFirst Associates, LLC, initially with HSUS's financial support. Charles W. de Seve, the company's president, gave two presentations to the committee (de Seve, 2011a, 2012) explaining how the model simulates free-ranging horse population dynamics, management actions, and associated costs.

According to de Seve (2011b), the WHMS is "a set of linked computer models to help control wild horse populations on the western rangelands managed by the Bureau of Land Management." The model is described as a "dynamic management tool useful to guide BLM's

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activities toward the dual objectives of humane population control and cost containment." It has four components.

- **Dynamic population simulation model:** This component is a stochastic population simulation model that projects age and sex composition annually for up to 12 years. A sub-model projects age and sex composition of horses in the holding facilities;
- **Economic costing model:** This component calculates annual costs of horse management on the range and in holding facilities;
- **Management intervention and optimization model:** This module is described as a supervisory module that controls parameter input, simulation runs, and reports results; and
- **Population and range database system:** The database structure includes "current and historical data by range on age-sex counts, gathers, removals, releases and fertility control." It is argued that the database "…is designed to improve the limited management data that are currently available" (de Seve, 2011b).

Economic costing and optimization options offered by the WHMS model could be useful to BLM. For example, the reverse-optimization technique in that model could be used to identify the most effective use of limited funds for managing horses given the simulated population dynamics of the horses, the effects of removals and contraception on horse population dynamics, and the economic costs of removals, contraception, and holding facilities. Other useful features of the model include the ability to model single or multiple HMAs and a built-in database-management system. It is claimed that the population dynamics submodel is the same as that used in WinEquus, but the committee could not verify that. The description of many aspects of the model provided in the handout and presentations was generally unclear or otherwise vague. The committee did not have access to the program or its user manual, so it could not objectively evaluate the WHMS model developed by EconFirst Associates, LLC, or verify the many claims made about its capabilities. The committee cautions that BLM should not adopt a complex model, such as the WHMS model, without a thorough evaluation of its program and appropriate documentation by independent experts.

ALTERNATIVE MODELING APPROACHES

The adequacy of a population model depends on a number of factors, including how (and for what purpose) BLM plans to use it, characteristics and processes that are considered important enough to be included, management alternatives that are to be simulated, and availability of data to assign to parameters. If BLM plans to use a population model for short-term population projection and to evaluate potential effects of the management alternatives (female fertility control, removal, or a combination of the two), WinEquus is probably sufficient to support current needs. However, BLM's Wild Horse and Burro Program faces unique challenges, and population models are potentially valuable tools in devising and implementing both short-term and long-term management plans. Although the committee recognizes that a perfect model does not exist, it is instructive to consider features that would help BLM to meet its unique challenges.

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Basic Features

At the basic level, a good population model would accurately reflect free-ranging horse or burro life-history, social structure, and mating system. It would also incorporate factors and processes that can affect population dynamics, including environmental and demographic variability or stochasticity, and density dependence. Climatic variability can substantially affect population growth through its effects on forage availability and subsequently, survival and reproduction. Explicit linkages between weather data and demographic vital rates would markedly increase the realism of simulated scenarios. Chapter 3 reveals that several vital demographic rates can be potentially influenced by increased competition for forage at high population densities, especially if the populations are allowed to increase to food-limited carrying capacity. Thus, options to allow those vital rates to be density-dependent, and perhaps the inclusion of alternative functional forms for density-dependent effects, might be useful. There are, however, surprisingly few studies of mechanisms that generate density-dependent responses in free-ranging horse and burro populations, and data-based estimates of parameters that define relationships between population density, climatic variables, and demographic vital rates were not available at the time of the committee's study. Until such data on free-ranging horses and burros become available, incorporating the aforementioned features would necessitate extrapolating insights gained from detailed demographic studies of other species, and caution should be exercised when making such extrapolations.

The committee understands that fertility control may become a major tool for management of free-ranging horses. Whereas WinEquus allows simulation of female fertility control, male fertility control cannot be simulated with the current version of it. As described in Chapter 4, male fertility control, perhaps via such minimally invasive methods as chemical vasectomy, remains a viable management option. Fertility control that targets both males and females may be more effective in reducing population growth than a strategy that targets only one sex. In addition, fertility control can trigger unintended consequences such as increased survival and longevity, changes in ages at first and last reproduction, and alteration of populations' age structure (see Chapter 4). Many HMAs and HMA complexes hold fairly small numbers of horses, and Chapter 5 suggests that genetic diversity remains a concern. Maintenance of genetic diversity is especially important in the context of global climate change because further loss of genetic diversity may compromise free-ranging equids' ability to respond to global climate change evolutionarily. Thus, the capacity to model population effects of fertility control that targets both males and females (and the ensuing compensatory responses) and options that allow simulation of allelic diversity (e.g., Gross, 2000; Lacy, 2000) might prove useful for short-term population management and the long-term goal of maintaining genetic diversity and evolutionary potential.

The earth's climate is changing (IPCC, 2007). Most models of global climate change predict that the mean and variance of rainfall and temperature will be affected and that the frequency of extreme climatic events, such as severe drought, will increase. Thus, global climate change will undoubtedly affect free-ranging horses and burros because it will affect the arid environment that horses and burros inhabit (McLaughlin et al., 2002; Saltz et al., 2006; IPCC, 2007). Population models that would allow simulation of climate-change effects and catastrophic events (e.g., disease outbreaks) would be helpful in the long run.

Asymptotic and transient sensitivity analyses (sensitivity of asymptotic population growth rate, projected population size or probability of extinction to vital demographic rates and other input parameters) are useful tools and have been used in setting priorities for research and

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making management decisions (Crowder et al., 1994; Caswell, 2001, 2005, 2007). WinEquus and other models developed for free-ranging horses do not offer options for sensitivity analysis. Options to perform transient and asymptotic sensitivity analyses would be helpful to BLM's Wild Horse and Burro Program.

A "Metapopulation" Perspective and Budgetary Considerations

BLM's Wild Horse and Burro Program manages free-ranging horse and burro populations on public rangelands, but it also manages captive populations of horses that have been removed from the rangelands. Horses and burros removed from public rangelands are processed in short-term holding facilities where a subset of animals are made available for adoption by the public and unadoptable horses are transferred to long-term holding facilities, where they are maintained indefinitely. Each of those populations has its own characteristic dynamics, and all three are linked inasmuch as BLM moves horses among the populations on the basis of management policies and actions, budgets, and other considerations that influence maintenance of the captive horses and burros. A major dilemma for the Wild Horse and Burro Program over the last decade has been the rapid increase in the number of horses removed from public rangelands that cannot be placed into private ownership through the Adopt-a-Horse Program and must be maintained in long-term holding facilities.

WinEquus and most other models developed for free-ranging horses are focused on capturing the dynamics of individual free-ranging horse populations and the influence of removals and various contraceptive interventions to alter growth rates of free-ranging horse herds (Garrott, 1991; Garrott et al., 1991, 1992; Garrott and Siniff, 1992; Gross, 2000; Roelle et al., 2010). An alternative model structure that could complement those efforts would use a metapopulation type of model that captures the dynamics of the free-ranging, short-term holding, and long-term holding populations and the movement of horses among these three populations—in essence, a model that captures the dynamics of all horses managed by the Wild Horse and Burro Program. Such a model could

- Elucidate the basic processes operating in the Wild Horse and Burro Program and help to address BLM's current programmatic challenges.
- Project the changes in the numbers of horses maintained in short-term and long-term holding facilities and the budgets that would be required under current and potential future management alternatives.
- Include economic costing, and possibly cost-optimization and population-optimization, options.
- Project the longevity of horses in the long-term holding facilities to plan for the long-term budgetary requirements to maintain them.
- Project changes in the number of horses in each subpopulation and the entire metapopulation[4] and budgets that would be required if best available contraceptive tools are more aggressively used to reduce the growth rates of free-ranging populations as outlined in the 2011 Wild Horse and Burro Program strategic plan (BLM, 2011b).

[4]A metapopulation is a collection of smaller subpopulations that are connected through movement of individual animals.

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- Explore additional combinations of management actions that may help to meet the challenges of stabilizing the budget of the Wild Horse and Burro Program and to address the multiple goals of the program. If BLM finds that current management alternatives cannot meet program objectives within the budgetary constraints, it may be necessary to explore additional alternatives.

The WHMS model described above presumably has some of those capabilities and the capacity to calculate the economic costs incurred by keeping animals in holding facilities. However, the committee could not verify that because it did not have access to the WHMS software program.

An Ecosystem Modeling Approach

The population dynamics of free-ranging horses and burros are inextricably linked to ecosystem processes through their interactions with vegetation and other herbivore species, including livestock. Horse and burro populations respond to the quantity and quality of vegetation used as forage; their herbivory and trampling affects vegetation composition, quantity, and quality. Vegetation dynamics are in turn linked to climate, hydrology, nutrient cycling, and decomposition of plant matter in the soil. Ultimately, equid population dynamics are driven by forage abundance and forage dynamics. Forage abundance affects forage intake, which affects animal body condition, which then affects survival and foaling rates. Survival and foaling rates affect horse and burro abundance, which affects forage abundance.

An ecosystem modeling approach (Coughenour, 1999, 2000, 2002; Weisberg et al., 2006) would capture these linkages between horse and burro population dynamics and ecosystem dynamics. It would go beyond the simple representations of fixed parameter values for survival and foaling rates, stochastic variation in the values of the parameters as represented in some models, or even correlative or regression-based linkages to climatic variables. Such a modeling framework would explicitly consider how or why horse and burro population sizes vary in response to forage, climate, and competition from other herbivore species over time and across the landscape.

Density-dependent population controls could be represented mechanistically. In contrast with the traditional approach of invoking a carrying capacity term such as the “K” term in a logistic or theta-logistic population growth model (see section “Density-Dependent Factors” in Chapter 3), density dependence would be represented by simulating competition for forage among equids and other wildlife and livestock and the effects of forage limitation on body condition and the subsequent effects of body condition on population processes. As the herbivore population increases, available forage per animal decreases, average forage intake rate decreases in response to the decreased forage biomass, body condition begins to decline in response to decreased intake, survival and foaling rates decrease, and population growth slows.

Density-independent population controls could also be represented mechanistically. The primary source of density-independent controls is climatic controls on forage biomass. An ecosystem model therefore would represent plant-productivity responses to climate in a realistic fashion. A second major source of density-independent population fluctuations for horse and burro populations occupying higher elevations and more northerly latitudes is variation in winter severity, particularly snow cover (Berger, 1986; Garrott and Taylor, 1990). Snow cover affects forage availability and energetic costs of foraging for large herbivores because of the need for animals to displace snow while moving and foraging (Parker and Robbins, 1984; Parker et al.,

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1984). To simulate that effect, the model would have to simulate snow cover and its effect on forage intake rate. A third major source of density-independent population fluctuations for horses and burros occupying more southerly latitudes is variation in the availability of drinking water. Because such climatic variables as precipitation, temperature, snow cover, and water are not affected by population density of horses and burros, their effects on forage abundance and, later, on forage intake, body condition, survival, and foaling rates are density-independent.

Horses and burros are mobile and wide-ranging animals, capable of moving large distances daily. Consequently, they derive forage from landscapes that are spatially heterogeneous with respect to climate, soils, topography, water, and vegetation. It matters where horses and burros are on the landscape because forage biomass is spatially heterogeneous. If horses and burros have access to portions of the landscape that have increased forage, their forage intake will increase, with favorable effects on population dynamics as described above. Conversely, if they do not have access to forage areas because, for example, these areas are too far from a drinking-water source, there will be negative consequences for population growth. Thus, an ecosystem model would represent spatial variations in soil and climate and their effects on forage productivity. It would represent spatial variations in densities of horses or burros as they select habitats that have suitable forage, topography, water, snow, and vegetation cover. It would also represent spatial variations in forage offtake, inasmuch as this affects the spatial distribution of forage. Forage, drinking water, snow, and animal distributions are, of course, temporally variable. Some parts of the landscape can function as “key resource areas” that provide critical forage and drinking water during times of drought when most of the rest of the landscape is devoid of these resources. Consequently, an ecosystem model would need to be spatially explicit (that is, it would represent the spatial distributions of forage, water, and equids on the landscape); it should also represent the seasonal and annual changes in climatic variables and the spatial distribution of horses or burros and key resources to predict equid population responses to variability in their environments accurately.

Spatially explicit ecosystem models are useful for a mechanistic understanding of critical linkages involved in climate-vegetation-consumer dynamics and to capture spatial heterogeneity at various levels of ecological organization adequately. Such models would also be required for exploring short-term and long-term effects of global climate change and can be used to simulate the effect of management actions. On the basis of the committee’s evaluation of how BLM uses population models, basic outputs provided by WinEquus appear to satisfy the agency’s needs. However, spatially explicit, process-driven ecosystem models would provide capabilities for assessing population responses to climate, spatial distributions of accessible forage and water, density dependence, and consequences for vegetation as described in Chapter 7.

CONCLUSIONS

The committee views population models as tools that can be useful but are never perfect. The usefulness of the information obtained from population modeling is directly related to the reliability of the data that are used to assign values to parameters in a model and depends on how adequately the model structure reflects the life-history of the study organisms and whether and to what extent deterministic and stochastic factors and management actions that affect the study population are considered. Models that capture free-ranging horse or burro life-history, genetics, social structure, and behaviors adequately or that simulate ecosystem processes are likely to be

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more complex and require more parameters than simpler models, but HMA managers are often constrained by a lack of that information. Consequently, it is difficult for the committee to recommend specific modeling frameworks.

A suitable modeling framework, or suite of models, would have to simulate life history; social behavior; mating system and genetics; forage limitation; use of forage, water, and space; and effects of alternative management actions throughout horse or burro life spans to meet the challenges outlined in the preceding paragraphs and to incorporate appropriately the factors and processes that influence free-ranging equid population dynamics. Possibly, different models could be used to address different aspects of the overall problem. As discussed previously, BLM's current practice of using default datasets for population modeling is relatively uninformative and potentially misleading in that free-ranging horse and burro populations are distributed over a wide geographic area that encompasses varied climatic conditions and ecoregions, states of rangeland vigor, and herd management histories. All those factors almost certainly interact to influence demographic vital rates and other model parameters that would be needed to reflect horse or burro population dynamics in any HMA or HMA complex accurately. Efforts should be made to ensure that future modeling exercises use data from the target HMA or HMA complex or a sentinel population that closely resembles the target population being modeled.

The free-ranging horse and burro populations under BLM management are unusual in that they are composed of a multitude of HMAs or HMA complexes, horses and burros in short-term holding facilities, and horses in long-term holding facilities; animals are moved among the free-ranging population and short-term and long-term holding facilities. In addition, horses exhibit strong social organization, and age-sex composition is likely to be important in modeling the projected outcomes of management actions. BLM faces management constraints and must work within the 1971 Wild Free-Roaming Horses and Burros Act (92 P.L. 195 as amended), budgetary constraints, and other congressional or administrative restrictions, which leave the agency with few management options (primarily fertility control and removal). As summarized in Chapter 4, some fertility-control treatments are suitable only for males and others are suitable only for females. Furthermore, some fertility-control measures sterilize treated animals for life, whereas others are effective only for a limited period and have changing degrees of efficacy over time. To make the matter more complicated, both fertility control and removal (the two management options available to BLM at the time of the committee's review) can alter individual and population demographic attributes, social organization, behavior, and genetic diversity. As discussed in Chapter 5, loss of genetic variation remains a concern in connection with free-ranging horse and burro populations and cannot be ignored. In light of those complexities and budgetary constraints, population models could serve as helpful tools.

Although the committee appreciated BLM's efforts to use population models in its Wild Horse and Burro Program, it also identified several shortcomings. Those included a lack of transparency regarding how values were assigned to model parameters in WinEquus and what information was used to determine those values, how (or whether) results were used in management decisions, and failure to make full use of the available capabilities of WinEquus. When the same default datasets are used to model population dynamics of most or all HMAs or HMA complexes, results will necessarily be similar (give or take the effect of environmental stochasticity and initial age and sex structure). It is therefore not surprising that most gather plans and environmental assessments arrived at identical conclusions regarding the potential effects of the management alternatives considered.

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It may not be possible to collect site-specific demographic data because of budgetary constraints, but such site-specific data may not be necessary. Detailed study and monitoring of free-ranging horse populations in a few HMAs that are representative of the HMAs or HMA complexes in a given habitat or ecoregion (see Chapter 2) could, in the long-run, provide detailed and representative demographic data. In the interim, a default dataset that is most representative of the target HMA with site-specific sex-structure and age-structure data could be used. However, a clear description of input parameters, including those needed for various management alternatives, and a detailed description of and justification for the WinEquus options selected would help the general public to determine the reliability of modeling results. Furthermore, a clear explanation of whether or how results of population modeling were used would be helpful.

The committee noted that BLM's population-modeling efforts have focused on the near-term (about 10-year) projection of population size. This modeling (and management) focus is understandable given the mandate that herd size be kept between upper and lower appropriate management levels. In the long run, however, management strategies aimed at reducing population growth to a modest rate (such as 5 percent per year) with methods described in Chapter 4 (e.g., a more aggressive fertility-control program targeting both males and females) might be most effective. Such a strategy would ensure that unpredictable variation in the environmental factors and catastrophic events and uncertainty in the effects of management interventions would not reduce populations to below acceptable size. Because only a small number of horses would have to be removed annually if the growth rate is modest, quick placement of removed horses could be possible. In addition, excessive reliance on a removal-based management strategy could backfire because removal can lead to rapid population increases due to density-dependent compensation (Zipkin et al. 2008, 2009). Compensatory (or overcompensatory) responses to removal may be contributing to the high growth rate realized by the free-ranging horse populations in many HMAs (see Chapters 2 and 3). Population models could identify an optimal mix of management interventions that would help to achieve management objectives in the face of (over)compensatory responses to removal, both in the short term and the long term.

Under the management regimes reviewed by the committee, BLM will have to remove free-ranging horses from western rangelands indefinitely unless very aggressive fertility-control programs are implemented (Garrott, 1991; Eagle et al., 1992; Garrott and Siniff, 1992; Gross, 2000; Bartholow, 2004, 2007). As briefly discussed in Chapter 2, there may be more horses in the short-term and long-term holding facilities than on the range. An average of more than 8,000 horses are moved from the free-ranging population to holding facilities annually, and almost 60 percent of the Wild Horse and Burro Program's budget was allocated to the care and maintenance of captive animals in fiscal year 2012 (BLM, 2012c). The amount of money needed to care for horses in the long-term holding facilities will continue to increase and, in the long run, could consume the entire budget allocated to the Wild Horse and Burro Program. Thus, BLM may have to consider other management options, including male fertility control. Chapter 3 suggests that self-regulation via density-dependent and density-independent processes is possible if populations are allowed to increase to higher numbers. Virtually all population-modeling efforts under the auspices of BLM have been focused on HMAs or HMA complexes; a modeling study evaluating the entire free-ranging horse population on the range and in holding facilities was not available at the time the report was prepared.

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A comprehensive modeling study that evaluates population dynamics of horses in the western rangelands and in holding facilities and the costs and consequences of management alternatives, including those not currently available to BLM, would help in evaluating whether and to what extent stated management objectives are achievable under the current or projected funding situations and regulatory restrictions. Such a study could help to identify the most effective or cost-effective management options to achieve the objectives or achievable goals given available funding and policy constraints. However, the committee notes that usefulness and reliability of results of modeling exercises depends not only on the adequacy of the model itself but on the quality of data used to parameterize the model. As noted previously (see Chapter 2), data on representative sentinel herds can be used to obtain rigorous and representative estimates of demographic and management parameters. Monitoring of sentinel herds can also provide data that can be used to test models, that is, to evaluate how well predictions of the models under alternative management scenarios match observations. Models can be modified or updated as one learns from the management experiments and estimates of demographic and management parameters are refined. Consequently, the committee recommends that future modeling efforts be based on rigorous and reliable estimates of demographic and management parameters in an adaptive-management framework.

Adaptive management is an iterative decision-making process in the face of uncertainty (Williams et al., 2007; Nichols et al., 2011). It aims to reduce uncertainty by monitoring the state of the system, learning, and adjusting management decisions accordingly. Models of system behavior are an important component of adaptive management (Nichols et al., 2011). In the long run, free-ranging horse and burro population dynamics and management are best modeled in an adaptive-management framework (Williams et al., 2001, 2007; Nichols et al., 2011). Chapters 7 and 8 provide details regarding how an adaptive-management framework might be applied to free-ranging horse and burro population management.

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7

Establishing and Adjusting Appropriate Management Levels

The Wild Free-Roaming Horses and Burros Act of 1971 (92 P.L. 195), as amended by the Public Rangelands Improvement Act of 1978 (95 P.L. 514), requires the Bureau of Land Management (BLM) to "determine appropriate management levels for wild free-roaming horses and burros on [designated] public lands." The legislation makes BLM responsible for deciding how these appropriate management levels (AMLs) of free-ranging horses and burros should be achieved within the agency's multiple-use mandate, including consideration for wildlife, livestock, wilderness, and recreation. BLM is also directed to manage for a thriving natural ecological balance, to prevent deterioration of the range, and to use minimal management for free-ranging horses and burros.

An AML has been interpreted by BLM as being a population size with upper and lower bounds for each individual Herd Management Area (HMA). Options listed in the legislation for keeping horses and burros within set population levels include removal of animals from the range, destruction of animals,[1] sterilization, and natural controls on population levels, although the legislation does not limit BLM to these actions or specify acceptable types of sterilization or natural controls. Much of the controversy surrounding the management of free-ranging horses and burros focuses on the appropriate limit, if any, for the numbers of these animals on the range and how to keep free-ranging equid populations within a prescribed limit. From submitted public comments and statements made by members of the public at information-gathering meetings, it was clear to the committee that stakeholders vary in their opinions about how AMLs are established and what constitutes an AML. Because AMLs are a focal point of controversy, how they are established, monitored, and adjusted should be transparent to stakeholders and supported by scientific information.

The committee was asked to

- Evaluate BLM's approach to establishing or adjusting AMLs as described in the *Wild Horses and Burros Management Handbook* (BLM, 2010).

[1]The destruction of healthy, unadoptable free-ranging horses and burros has been restricted by a moratorium instituted by the director of BLM since 1982 and by the annual congressional appropriations bill for the Department of the Interior since 1988.

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- Determine, on the basis of scientific and technical considerations, whether there are other approaches to establishing or adjusting AMLs that BLM should consider.
- Suggest how BLM might improve its ability to validate AMLs.

To accomplish its assignment, the committee first investigated the basis of the *Wild Horses and Burros Management Handbook* approach to setting AMLs. The investigation included gaining an understanding of legislative definitions and interpretations that BLM has used to develop its AML policies. The committee then evaluated BLM's approach to setting AMLs as described in the handbook. Finally, the committee explored alternative, improved approaches that BLM could consider in setting and validating AMLs.

Scientific methods can be used to assess the condition of rangeland and its ability to sustain foraging and browsing animals. However, decisions regarding what kinds of animals should occupy the land, how many species should be in an area, how the land should be used, and what the balance of different uses of the land should be are questions of policy, not science. The committee's task in this chapter is to explore the science behind the establishment and adjustment of appropriate management levels.

THE HISTORY OF APPROPRIATE MANAGEMENT LEVELS

The *Wild Horses and Burros Management Handbook* was written in response to a critique by the Government Accountability Office (GAO) stating that, as of 2008, BLM had not provided formal guidance to its field offices on how AMLs should be established and that there was a lack of consistency in setting AMLs in the agency (GAO, 2008). The following summarizes the legislative context for establishing and adjusting AMLs. It then draws conclusions about the challenges inherent in establishing and adjusting AMLs on the basis of the committee's review of the legislation.

The Legislative Setting for Establishment of Appropriate Management Levels

The Public Rangelands Improvement Act of 1978 amended the 1971 act to state that information from rangeland inventory and monitoring, land-use planning, and court-ordered environmental impact statements should be used to determine whether horses are exceeding AMLs. The 1978 *Code of Federal Regulations* (*CFR*) asserted that BLM should ascertain the optimum number of free-ranging equids supported by an area and that enough forage should be allocated to horses and burros to maintain them at that number in healthy conditions while considering an area's soil and watershed conditions, wildlife, environmental quality, and domestic livestock (43 CFR §4730.3 [1978]). The concept of defining AMLs by the optimum number of horses that maintains a thriving natural ecological balance and avoids deterioration of the range was reaffirmed in *Dahl v Clark* supra 592 (1984) and by the Department of the Interior's Interior Board of Land Appeals (IBLA) (Animal Protection Institute of America, 109 IBLA 112, 119 [1989]).

Under its enabling legislation, the 1976 Federal Land Policy and Management Act (94 P.L 579), BLM is required to manage public lands under the principles of multiple use and sustained yield. The agency's objectives are

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> 1) to periodically and systematically inventory public lands and their resources and their present and future use projected through land-use planning processes; 2) to manage public lands on the basis of multiple use and sustained yield; 3) to manage public lands in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values; 4) where appropriate, to preserve and protect certain public lands in their natural condition; 5) to provide food and habitat for fish and wildlife and domestic animals; 6) to provide for outdoor recreation and human occupancy and use; and 7) to manage, maintain and improve the condition of the public rangelands so that they become as productive as feasible for all rangeland values in accordance with management objectives and the land use planning process. (BLM, 2001, p. I-1)

Those objectives originate with the Taylor Grazing Act of 1934 (73 P.L. 482), as amended and supplemented by the Federal Land Policy and Management Act of 1976, and the Public Rangelands Improvement Act of 1978. In addition, managers of free-ranging horses and burros must also be mindful of or necessarily follow (depending on the particular law) the guidance in the Wilderness Act of 1964 (88 P.L. 577), the National Historic Preservation Act of 1966 (89 P.L. 665), the Clean Water Act of 1972 (92 P.L. 500), the Endangered Species Act of 1973 (93 P.L. 205), and the Forest and Rangeland Renewable Resources Planning Act of 1974 (93 P.L. 378), and others. Managers of free-ranging horses and burros must balance a litany of complex and even conflicting considerations when setting and maintaining AMLs in the context of those laws. A Senate conference report that accompanied the Wild Free-Roaming Horses and Burros Act states

> The principal goal of this legislation is to provide for the protection of the animals from man and not the single use management of areas for the benefit of wild free-roaming horses and burros. It is the intent of the committee that the wild free-roaming horses and burros be specifically incorporated as a component of the multiple-use plans governing the use of the public lands. (U.S. Senate, 1971, p. 3)

Historically, BLM efforts to identify the appropriate number of free-ranging equids that should inhabit each HMA have been challenging and controversial, even after the term *optimum* was replaced in the *CFR* with the charge to "consider the appropriate management level for the herd, the habitat requirements of the animals, [and] the relationships with other uses of the public and adjacent private lands" while continuing to manage free-ranging horses and burros on designated HMAs (43 CFR §4710.3-1 [1986]). Previous reviews of BLM's setting of AMLs consistently reported that established AMLs were not based on thorough assessments of range conditions. The U.S. District Court for the District of Nevada, IBLA, and GAO all noted that AMLs of many HMAs in the 1970s and some in the 1980s were based on administrative decisions rather than information about the carrying capacity of the range (Dahl v Clark, 1984; 109 IBLA 119; GAO, 1990). The agency acknowledged in its 2003 strategic plan (updated in 2005) that diverse methods had been used to establish AMLs (BLM, 2003, revised 2005). In general, more consistent data collection has also been recommended for grazing management (Veblen et al., 2011).

Even though AML determination has been harmonized to derive from an agency-wide land-use planning process, diversity is still an issue because each state office conducts habitat

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assessment in its own way (BLM, 2003, revised 2005). In addition to a critique that formal guidance on setting AMLs had not been given to field offices, the 2008 GAO report noted that as late as 2002, AMLs had not been set for two-thirds of HMAs.

Major Challenges in Defining Appropriate Management Levels in Prescribed Legislation

The committee identified three overarching challenges that permeate any consideration of how to set or adjust AMLs. These challenges stem from the historical and legislative background of AMLs and the institutional and environmental context of BLM in considering the setting and adjustment of AMLs.

First, although biological and physical measurements are used to estimate the capacity of rangelands to support free-ranging horses and burros, the allocation of forage among multiple users is a policy decision.

Second, the legislation includes requirements that seem contradictory. As reviewed in Chapter 1, the 1971 act (as amended) calls for horses and burros to be managed "as an integral part of the natural system of the public lands" and that "all management activities shall be at the minimal feasible level" but also requires the protection of a thriving natural ecological balance, which encompasses other species—especially threatened, endangered, and sensitive species—and avoidance of range deterioration caused by overpopulation. As a result, horses and burros are limited to specified areas, populations are controlled, and herds are largely protected from starvation and drought. Thus, the stipulations for their management are different from those for wildlife, which can be hunted or left to self-regulate naturally, and for livestock, which can be removed from the range by their owners at BLM request.

Equids have been able to inhabit western rangelands for hundreds of years without human intervention despite weather, predation, and disease. On most HMAs, horse populations have demonstrated an ability to reproduce at a rate sufficient to sustain themselves and, in most cases, to increase in abundance. However, their reproductive success may cause them to migrate or disperse in search of more resources or to have undesirable effects on soils and vegetation, both of which can bring them into conflict with other land uses. Population processes involved in food-limitation, climatically driven variations in food and water, fire, predation, or natural barriers that limit access to additional food can, in some circumstances, effectively operate to regulate populations without human intervention (see Chapter 3). However, allowing horses or burros to self-regulate by permitting them to starve or to suffer from disease outbreaks is unacceptable to a large portion of the public (see section "Consequences and Indicators of Self-Limitation" in Chapter 3) and herbivory-induced changes in soils and vegetation may be unacceptable to some. Restricting horses and burros to designated HMAs can interfere with processes involved in self-regulation when dispersal or migratory movements are disrupted, when key resource areas are made unavailable (see Chapter 3), or when natural predators are lacking (see section "Effects of Predation" in Chapter 3). Management interventions may become necessary as surrogates for self-regulation processes. Interventions likely involve removals because hunting, euthanasia, and sale for slaughter are not currently acceptable options.

Setting AMLs in light of conflicting mandates leads to expensive and controversial approaches to management of rangeland herbivores, including gathering and removing horses and burros, fertility control, manipulation of genetic attributes, adoption, and feeding or pasturing horses. Each of those actions takes management of free-ranging horses and burros

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further from the ideal of minimal management as envisioned in the original legislation, regardless of how they represent attempts to work within the institutional and legal framework that shapes and constrains the protections for free-ranging horses and burros.

Third, although the legislation calls for setting AMLs to maintain a thriving natural ecological balance and to prevent rangeland deterioration, these terms are uninformed by science and open to multiple interpretations; precise definitions would improve the ability to use them as goals for management. For example, the concept of a thriving natural ecological balance does not provide guidance for determining how to allocate forage and other resources among multiple uses, which ecosystem components should be included and monitored in the "balance," or when a system is considered to be out of balance. It brings up arguments over whether such a balance exists in nature or is even possible. Avoiding rangeland deterioration and setting of land health standards may be seen as a problem of developing specific ecological measurements and standards or as a matter of arriving at a consensus about how rangelands should be maintained. A standard, broadly agreed-on definition of rangeland deterioration and how to measure it has proved an elusive goal for decades.

EVALUATION OF THE HANDBOOK APPROACH

The BLM *Wild Horses and Burros Management Handbook* was written to respond to GAO's criticism that BLM had not provided guidance to its field offices on how AMLs should be established. To understand how AMLs were set without a specific protocol, the committee surveyed 40 HMAs (Box 7-1). Beever and Aldridge (2011) provided a comprehensive review of criteria used by BLM managers to establish AMLs.

BOX 7-1

Reasons Given by Managers for Setting and Adjusting Appropriate Management Levels

The committee recognized that, by and large, AMLs for individual HMAs had been set before the publication of the handbook in June 2010 and that little time had passed for adjustments to be made between the publication and when the committee's survey questions (Appendix D) were distributed to 40 HMAs in January 2012. The committee wanted to gain an understanding of how AMLs had been established and adjusted before publication of the handbook. The 40 HMAs in the survey were the same as those sampled for population-estimate and survey-method information (Appendix E, Table E-3).

Survey respondents reported considerable variation at the HMA level in the approaches used for assessment and monitoring on HMAs. Establishment of HMAs generally occurred through consultation with state departments of fish and game for habitat and wildlife assessment, as called for in the legislation; use of state or regional BLM standards for rangeland (or public land) health as the "Standards for Land Health" stipulated as a goal in the handbook (BLM, 2010, p. 59); and reliance on the number of horses and cattle on the range at the time of HMA establishment to determine a goal for population levels, and in some cases to establish a ratio of number of horses to number of cattle as a framework for adjusting numbers.

The committee asked BLM managers who had been surveyed how they allocated forage among horses, cattle, and wildlife. Only a few fully addressed the question, and their responses were diverse. Use at the time of AML establishment was the most common answer, along with use of the original numbers at the time of the establishment of the HMA, the number specified in accordance with a resource management plan, the outcome of a land-use planning process, or a combination of the three. For example, in one HMA, the allocation between free-ranging horses and livestock was based on the original AMLs in the resource management plan, maintaining the original ratio of forage use for livestock and horses so that livestock and horses were reduced at the same rate. In this HMA, forage allocations were

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not increased because all the areas were stocked at or above carrying capacity. In another state, managers reported that in consultation with their department of fish and wildlife, the biologists at BLM made forage allocations to the native and exotic ungulates. Often, the forage allocated for existing livestock grazing privileges in an HMA was subtracted from total forage availability to determine the amount available to wildlife and horses.

Participating districts reported that measures of range condition and trend, upland utilization (amount of forage grazed, also termed "actual use" away from water), noxious weeds, and other types of rangeland and vegetation monitoring were considered relevant to adjusting and setting AMLs. One district used "negatively impacted vegetation functionality" as part of the justification to adjust an AML. Such considerations were frequent among reasons listed by managers for resetting or reaffirming AMLs. No data were provided on the metrics used to make the decisions, although some managers referred to other reports and multiple-use directives that were used in arriving at decisions. Monitoring of range and animal conditions; threatened, endangered, and sensitive species; and habitat was also conducted as part of setting, maintaining, or adjusting AMLs according to the survey. Most respondents to the committee's survey reported that rangeland monitoring studies (upland utilization, upland and riparian trend, and noxious-weeds monitoring) were being used to assess and evaluate forage availability in HMAs.[2]

On one HMA in another state, the AML was set after an intensive 5-year monitoring program. Data that were used included actual use, range condition and trends, utilization, precipitation, range sites, observations, and frequency of concentration areas for free-ranging horses. To change the AML again, the district reported that it would need to conduct a similar monitoring program that would include re-examining the entire HMA and potentially reallocating forage for all animals.

One district reported that in the 1975 HMA planning process, forage-production calculations from 1952 were used to estimate how many animals could be supported on BLM-managed land in the HMA. That carrying capacity was revised in 1975 because of rangeland seedings conducted in the HMA in 1974. BLM then identified the forage allocated to existing livestock grazing privileges in the HMA and subtracted that amount to calculate forage available to horses and wildlife. The state Department of Fish and Wildlife was consulted to determine the forage required by wildlife. Forage allocations to livestock, wildlife, and free-ranging horses were made commensurate with the available forage within a reasonable distance from water and in consultation with the state wildlife agency.

Managers in one state reported limiting forage use to 55 percent of production. No details were provided as to how annual plant production was determined.

The committee received the most comprehensive response to the question of allowable use from managers who used forage production maps from 1958 to estimate total forage production and determined the forage available on the basis of 50-percent utilization rate. The biologists reported currently using monitoring studies to assess and evaluate forage allocations in the HMAs.

Because horses are on the range year-round but cattle are not, temporal separation has been used to distinguish horse and cattle effects on water holes and other features. Surveyed managers of districts in California, Oregon, and Wyoming cited effects on watersheds and riparian areas, riparian utilization, riparian trend, and insufficient or unreliable water as causes for adjustment. "Timing and duration of flow" was also provided as a reason for changing AMLs.

Managers of the 40 surveyed HMAs reported that AMLs often had been adjusted or reaffirmed

[2]"All Bureau of Land Management grazing allotments are periodically evaluated to assess rangeland health and evaluate the trend in rangeland condition and the influence grazing management has on the multiple rangeland resources associated with these allotments. [As an example, one district] employs two methods of evaluating grazing allotments. The first strategy involves a one-time field assessment by an Interdisciplinary Team composed of various BLM resource specialists. This team completes an assessment based on observations of vegetation and soil conditions. The second, and most commonly used strategy, involves a formal allotment evaluation process. During this process, an interdisciplinary team composed of various resource specialists evaluates resource conditions and creates management recommendations for the allotment. The end product of this process is an allotment evaluation document which summarizes resource conditions and trend and makes recommendations for future grazing management and range improvements on the allotment. Typically allotment evaluations occur every five to 10 years depending on the resource concerns for a given allotment." (Sharp, no date, p. 1)

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since 1971. For example, on one HMA, AMLs were changed 13 times from 1979 to 2007. Reasons for the changes were related either to four essential habitat components (forage, water, cover, and space) or to the political process. Examples of reasons included emergency gathers after extensive wildland fire, free-ranging horse distribution data, absence or inadequacy of winter range available for horses, climate and weather, and change in space available to free-ranging equids (for example, because of land closures, land trades, land-use planning efforts, boundary discrepancies, or a "checkerboard" jurisdictional pattern adjoining HMAs). Responders also cited splitting current herds into smaller groups, adverse effects of horses on cultural resources, improving vegetation conditions, enhancing wildlife habitat, and updating management plans as reasons for adjusting AMLs.

The handbook seeks to rectify the lack of guidelines for setting AMLs by making recommendations for their establishment and adjustment in several sections. Most specifically, Appendix 3 of the handbook defines AMLs and provides guidelines for setting them.

> AML decisions determine the number of WH&B [wild horses and burros] to be managed within an HMA or complex of HMAs. AML is expressed as a population range with an upper and lower limit. The AML upper limit is the number of WH&B which results in a TNEB [thriving natural ecological balance] and avoids a deterioration of the range. The AML lower limit is normally set at a number that allows the population to grow to the upper limit over a 4-5 year period, without any interim gathers to remove excess wild horses and burros. (BLM, 2010, p. 67)

Table E-1 in Appendix E shows the upper limit set for HMAs as of May 2012. The handbook states that an AML should be evaluated or re-evaluated "when review of resource monitoring and population inventory data indicates the AML may no longer be appropriate" (BLM, 2010, p. 18). Reasons that may warrant a re-evaluation include changes in the environment; newly federally protected threatened, endangered, or sensitive species; and other relevant data.

The handbook prescribes processes for the decision-making aspects of setting and adjusting AMLs. Chapter 2 of the handbook, on land-use planning, suggests that the process of setting and adjusting AMLs should take place as part of comprehensive planning, should be based on monitoring and evaluation, and should follow required decision-making procedures.

> AML may be adjusted (either up or down) through the site-specific environmental analysis and decision process required by the National Environmental Policy Act of 1970 (NEPA) (P.L. 91-190). An analysis under NEPA is also required to establish a population range (upper and lower limit) for AMLs initially established as a single number. Development of a LUP [land-use plan] amendment or revision is not generally required. (BLM, 2010, p. 10)

The handbook states that an LUP should provide a process for adjusting AMLs once they are established. The process varies from one LUP area to another. If an LUP does not provide a process for adjusting AMLs, it may need to be revised or amended so that AML adjustments can be made.

In the committee's view, the setting of an AML within a NEPA planning process when allocating resources among uses is in concert with the recognition that tradeoffs and values are parts of management decisions. The NEPA process provides for public comment and review and increases public participation in environmental decisions although the relationship is consultative rather than collaborative, tends to be bureaucratic, and does not foster deliberation (Hourdequin

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et al., 2012). In any case, the decision-making process should be clearly distinguished from the data-gathering and analysis that provide the information used in decision-making. The committee's focus is on the scientific analysis that feeds into decisions that ultimately must reflect social values, compromise, and economic realities.

A multitiered analysis process is stipulated by the handbook for establishing and adjusting AMLs. Tier One instructs managers of free-ranging horses and burros to "determine whether the four essential habitat components (forage, water, cover and space) are present in sufficient amounts to sustain healthy [wild horse and burro] populations and healthy rangelands over the long-term" (BLM, 2010, p. 67). Assessing the amount of sustainable forage available for the animals' use is required by Tier Two. Tier Three concerns the genetic health of populations. Tiers One and Two are germane to this chapter; issues pertaining to Tier Three are discussed in Chapter 5.

The Tier One evaluation as described in the handbook for four habitat factors—forage, water, cover, and space—determines whether the features necessary to support horse and burro basic needs are present. It considers water, forage, space, and cover as limiting factors and requires evaluation of whether they are sufficient. Because of the inherent climatic variability of typical rangelands, the handbook recommends evaluating rangelands under conditions when they are likely to be low in forage production. Tier Two considers forage availability and quantity in detail. This section first reviews the handbook's approach to water, cover, and space and then discusses its approach to forage. Forage availability is described in greater detail because it must be measured and used as a primary method for determining the number of herbivores that the range will support in Tier Two of the handbook-prescribed analysis. The section concludes with a review of problems related to terms and consistency in the handbook.

Water

In keeping with its approach of using limiting factors to evaluate habitat suitability for horses and burros, the handbook instructs managers that the amount of available water is to be calculated on the basis of the driest part of the year (BLM, 2010). However, the handbook does not expand beyond the limiting-factors concept and provides little information about the importance of water in sustaining populations or about specific protocols for water monitoring and assessment. Water quantity and availability are to be assessed, but the handbook does not discuss poor water quality (such as nutrient content, sediment load, and water temperature). One BLM district reported in the committee's survey that in its 1975 HMA plan process, water was identified as a limiting factor for summer use in drought years; as a result, forage allocations to livestock, wildlife, and free-ranging horses were then made with specific attention to water supplies and carrying capacity. One concern of the committee would be the age of the data because water supplies, developments, and land use have often changed and are subject to further alterations because of climate change. Another concern would be the possibility of conflict arising from competition between BLM and state agencies with responsibilities for water management. For example, the Nevada Division of Environmental Protection is responsible for water-quality standards and monitoring in the state. To prevent overlapping or competitive efforts, cooperative interaction between that office and BLM would be valuable.

Although riparian condition has been used as one of a suite of criteria to justify removal of free-ranging equids, the handbook provides relatively little specificity on the criteria to use in

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such decisions. Areas near water should be considered foci of concentration for horses and burros and monitored accordingly. Analyses of habitat use by free-ranging horses in sagebrush (*Artemisia* spp.) communities reported that horses seek riparian habitats (Crane et al., 1997). Free-ranging horses typically range farther from water sources than domestic cattle but need more water than forage alone can provide in most seasons and locations. Free-ranging horses can travel to water every 3 days to twice a day, and numerous factors affect their drinking frequency, for example, ambient temperature, succulence of existing vegetation, wind speeds, and activity levels (Pellegrini, 1971; Meeker, 1979; Greyling et al., 2007). Horses' use of water can affect water sources that influence vegetation, soils, and other species, so amounts and effects of current use should also be considered in evaluating water as a habitat component (Greyling et al., 2007). Use of areas near streams can increase runoff (Dyring, 1990a; Rogers, 1994), break down streambanks (Dyring, 1990b), reduce water quality (Nimmo and Miller, 2007), cause vegetation trampling, alterations in stream flow, and downstream siltation (Rogers, 1991), and accelerate gully erosion (Berman et al., 1988). Boggy habitats also can be altered by free-ranging horses (Dyring, 1990a; Rogers, 1991; Clemann, 2002). Similarly, soils, vegetation, and small mammals in and adjacent to springs can be markedly affected by free-ranging equids even when livestock have been absent for extended periods (Beever and Brussard, 2000).

There is evidence of interaction between forage characteristics and riparian-area use; the characteristics of forage may be affected by concentrated animal use near water. In the Sheldon National Wildlife Refuge in Nevada, 3 years of exclusion of free-ranging horses from grazing in riparian zones led to a 40-percent increase in cover of plant litter compared to bare ground and a 30-percent decrease in extent of bare ground, whereas these metrics remained generally constant in the paired riparian plots that continued to be grazed by horses (Boyd et al., 2012). In the nonexclosed areas, estimates of use from September to October based on standing biomass varied from negligible to nearly 100 percent (Boyd et al. 2012). In contrast, Greyling et al. (2007), studying areas of heavy use around a waterhole in Namibia, reported that the "expected degradation gradient radiating out from the water troughs due to over-utilization by the horses was not found. Neither vegetation species composition, density, nor standing biomass measured at various distances from the troughs confirmed a degradation gradient."

Methods of measuring riparian condition are available. Proper functioning condition is a monitoring tool developed by BLM to assess the physical functioning of riparian and wetland areas (BLM, 1998). It provides a consistent approach that takes into consideration hydrology, vegetation, and soil-landform attributes and encourages a team approach which includes wildlife, hydrology, and plant-science expertise. This method is qualitative by design and thus lacks rigorous quantitative analysis and statistical inference. However, it can provide a framework for identifying sites where water impairments have occurred and where improved management of water resources is required. Measures of water quality (such as temperature, salinity, nutrients, dissolved oxygen, and sediment) or hydrogeomorphology (such as ground-water discharge, active floodplain, sinuosity, and width and depth ratio) do not appear to be actively used by BLM and might serve as indicators for modifying management decisions related to free-ranging horses and burros (BLM, 1998). Soil conditions—such as storing moisture, allowing infiltration, stabilizing vegetation, and balanced release of water—and preventing rill or sheet erosion by water-caused or wind-caused dust are also possible indicators. A new synthesis of literature pertaining to riparian management practices (George et al., 2011) may provide insights on how to manage free-ranging horses in riparian areas. Further, a standard range-improvement action for mitigating damage to riparian areas involves fencing sensitive areas and providing troughs at

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locations away from natural waters. Given the extensive diversion, piping, and regulation of springs already in place across the western Unites States, additional use of troughs should be balanced against consideration for native fauna dependent on natural flows.

Cover and Space

Vegetation provides cover for free-ranging equids. For example, trees provide shade that allows equids to avoid direct insolation during the hottest times of the day, a rubbing surface that they can use to scratch topical irritations, visual concealment from predators, and forage (Pellegrini, 1971; Hanley, 1982). In the second paragraph of Chapter 3 of the handbook, an emphasis is placed on evaluating habitat suitability on the basis of access to "forage, water, or thermal or hiding cover." The implication is that without access to those resources, horse removals may be necessary. Many models suggest that contemporary climate change may alter the distribution of trees and the balance of deciduous versus evergreen trees in parts of the domains of HMAs (Fuhlendorf et al., 1996, 2012; Tausch, 1999). The direct effects to horses of such changes are unknown. Before considering horse removals when cover and space are inadequate, where it does not cause conflict with other uses, managers may also consider increasing habitat availability by establishing greater connectivity between key habitats (through removing barriers and creating corridors for travel, habitat improvement, providing water at key points, land acquisition or other methods).

It is not clear from the handbook (BLM, 2010) what is meant by *space*, and there does not seem to be a good definition or way of measuring it in the scientific literature. The analysis of adequate "space" in the handbook apparently is derived largely from whether the horses and burros will stay in the habitat. For example, the handbook states that the animals "require sufficient space to allow the herd to move freely between water and forage within seasonal habitats" (BLM, 2010, p. 13). The need to adjust AMLs because of changes in the area available to equids was cited several times by surveyed managers—such changes as land closures, land trades, LUP efforts, boundary discrepancies, or a "checkerboard" jurisdictional pattern adjoining or within HMAs.

To be more specific, the discussion in the handbook should emphasize the spatial movements of free-ranging horses and burros relative to water, cover, and forage. Other aspects that might be considered include the influence of sunshine, shade, the viewshed, predator escape routes, and slope position (e.g., leeward for shelter from weather and windy gaps for insect avoidance). There is a direct relationship between space and access to spatially heterogeneous resources (such as those listed) in landscapes where horses and burros may be (Coughenour, 1991, 2008). Those resources are often dispersed patchily. As a result, the four key habitat components (forage, water, cover, and space) and other resources are naturally heterogeneous in distribution and availability and should be evaluated on the basis of their spatial and temporal variability.

Because horses and burros, like most ungulates (Hobbs, 1996), use landscapes heterogeneously, assessment ideally would occur at multiple spatial resolutions. In particular, free-ranging equids will use some portions of the landscape often (especially when equid densities are high) and use other parts rarely or never (e.g., areas more than 15 km from water sources, slopes of more than 50 percent [Ganskopp and Vavra, 1987], and areas dominated by large boulders or monoliths). Multiple-resolution assessment could be especially valuable in

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situations in which dynamics at one spatial resolution can influence dynamics at other spatial resolutions (cross-scale dynamics; Allen, 2007).

Forage Availability

In a case study in Appendix 3 of the handbook, the amount of forage available for sustainable use by herbivores, or the carrying capacity of an HMA, is the accessible, palatable biomass that grows on the site annually, modified by an allowable use factor (AU). An AU is the percentage of annual production that can be grazed without causing plants to decline in production and growth. Typical AUs are between 25 and 60 percent, meaning that 25 to 60 percent of the annual forage growth can safely be allocated to grazing; that is, it is available forage. However, AUs are often adjusted for local conditions, as it is in the case study, and for season of grazing; AUs are higher in dormant than in growing seasons. AUs are based on data about the effects of specific percentages of "use" on plant species and communities that are rarely available. Studies of the response of specific species and plant communities to herbivory and how the species and communities are influenced by season of grazing, the amount and frequency of herbivory, and varied growing conditions have been numerous but by no means comprehensive (e.g., Hanley, 1982; Paige and Whitham, 1987; Paige, 1992; Belsky et al., 1993; Hawkes and Sullivan, 2001). In fact, it is usually difficult to determine exactly how even widely used AUs were derived.

The handbook's case study details the use of at least 3 years of grazing utilization and use mapping data with annual population estimates of horses to determine weighted utilization data, potential carrying capacity, and a proposed carrying capacity. It is not clear where the AU for plant species is acquired. In the case study, it appears that all the available forage will be allocated to horses and that only horse data are used, although at the end it is shown that the results can be converted for other herbivores (BLM, 2010). The explanation of how to calculate the weighted average forage utilization is relatively clear, but it is not clear how annually adjusted population estimates of horses, expressed in animal unit months (AUMs), are acquired. An AUM is a standardized unit of forage consumed per "animal unit" each month. Knowledge of annual herd population sizes for at least 3 years is critical for the prescribed method in that they are the basis for establishing annual forage availability, the most common habitat factor used for establishing AMLs.

Use of utilization and use mapping data to infer forage production levels is a pragmatic approach that takes multiple factors into account, including "background" consumption by all users of forage, areas of concentration, and site-specific production limitations. Ideally, however, direct forage production data should also be used to determine forage availability. Measuring how much forage is consumed by what species (horses and burros versus livestock versus wildlife) would be helpful in determining how many animals can be supported relative to forage supply, although the committee acknowledges that this can be difficult. The methods for assessing utilization are not described in the manual; however, examination of various BLM reports indicated that utilization was simply visually estimated. This method is prone to inaccuracy and is generally not well validated. More direct measures of utilization could be made through the use of grazing exclosures, particularly movable exclosures. Issues related to determining horse population size are detailed in Chapter 2.

Another complication is that a substantial part of the diet of horses may not be herbaceous plants, such as grass, and the case study includes only herbaceous growth to calculate

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forage availability. A fair amount of research on diets of free-ranging horses of the western United States that occurred in the 1970s and 1980s confirmed that horses are typically grazers (that is, most of the food that they consume is grasses and graminoids) but that the proportions of individual food items and even of plant life forms consumed vary markedly annually, among seasons, by location, and among individuals, including variation by age, sex, and reproductive state and history (Hansen, 1976; Hubbard and Hansen, 1976; Hansen et al., 1977; Olsen and Hansen, 1977; Krysl et al., 1984; McInnis and Vavra, 1987). That is due in part to the fact that the nutritive value of plant species can vary markedly among seasons and years (Miraglia et al., 2008). Utilization of browse should be identified and incorporated into carrying-capacity calculations when it proves to be an important source of forage for horses.

The handbook guidelines recognize the high variability in forage production on arid rangelands, stipulating that forage-availability estimates should be based on 3-5 years of utilization and use-pattern mapping. In addition, that handbook states that to determine whether forage is sufficient for long-term sustainable equid grazing, production data, ecological site condition, trend, frequency, precipitation, and standards for land health may be used (BLM, 2010). It appears that each local office has a great deal of discretion in determining which methods to use. The handbook guidelines stipulate that years of above-average forage production are not to be used in calculations of forage availability—a conservative approach that aims to reduce the need for emergency gathers. Rangeland that is not commonly used is also not included. However, the committee considers 3 years of data to be inadequate typically for capturing variation in forage production on arid lands.

There are useful parallels between the setting of AMLs for free-ranging equids and the setting of sustainable stocking rates in managed livestock systems. Both endeavor to achieve ecological sustainability although management objectives and methods are quite different. Campbell et al. (2006) evaluated conditions that favor different ways of determining how to establish the number of livestock that can be supported on rangelands. They contrasted two types of strategies for setting a livestock stocking rate: conservative and tracking. A conservative strategy maintains a roughly constant stocking rate, which is set so that carrying capacity, the ability of the range to provide adequate forage, is unlikely to be exceeded even in dry years (Sandford, 1983, 2004; Tainton, 1999 in Campbell et al., 2006); this approach errs on the side of caution for dry years—in which overstocking can lead to livestock losses and vegetation deterioration—as does the handbook strategy. A strategy that tracks forage availability is less static and changes stocking rates to track variable forage supply; thus, more animals are on the range in years of high rainfall and fewer in dry years. Different conditions favor one strategy or the other (Table 7-1).

Campbell et al. (2006) summarized research that demonstrated that forage growth and distribution in semiarid rangelands are influenced by precipitation and are highly variable across time and space. Average annual rainfall is the key factor in temporal variation. Temporal variation increases as annual rainfall decreases (Ellis and Swift, 1988; Campbell et al., 2006; Briske et al., 2011). Because variability in rangelands also occurs on macro-scales (Campbell et al., 2006), even the largest HMA cannot buffer the variation in rainfall amount or distribution completely. As a result, variation in forage quality and quantity across space and time is high, and setting a static population level for herbivores runs counter to this complexity. The tracking strategy is argued to be more appropriate where environmental variability, such as in rainfall, is more predictable, allowing managers to anticipate need for adjustments in stocking, and a conservative strategy is more appropriate for locations with high variability and low

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predictability of environmental variability, such as in rainfall, because it reduces the number of years when drought would reduce forage production below levels adequate to support the animals (Campbell et al., 2006). As previously discussed, allowing free-ranging horses and burros to suffer from inadequate forage is precluded.

TABLE 7-1 Conditions That Influence the Number of Livestock That can be Supported by Forage Production in Pastoral Systems

Environmental Conditions	**Conservative Strategy—Setting numbers below average that can be supported over the long term is more likely to be optimal if:**	**Tracking Strategy—Managing animal numbers to follow changes in forage supply annually is more likely to be optimal if:**
Predictability of environmental variability	Environmental variability is high and unpredictable.	Environmental variability is highly predictable.
State changes and thresholds	The system is prone to state changes and thresholds that limit reversibility through management.	The system has high resilience and changes are likely to be reversible with management.

SOURCE: Adapted from Campbell et al. (2006).

Extreme droughts will inevitably occur at unpredictable times. The location-specific effects of climate change are as yet largely uncertain. Studies suggest that temperature stress on ecosystems will be markedly higher (especially in summer) in the western United States, and there will probably be an increased frequency of extreme climatic conditions (Christensen et al., 2007; Mote and Redmond, 2012). It is clear that AMLs will need to be adaptable and periodically reassessed over the long run and subject to rapid adjustment in the short run. Gathers are the major means of adjusting the number of animals in response to drought. BLM may consider other options, which might include temporary supplemental forage or temporary movement or expansion by animals into unused range (if there were not conflicts with other resources). That might be accomplished through provision of water where there is no natural supply. However, unused range areas are quite possibly rare, and those options will only delay the need for a gather unless population growth is reduced.

In the case study in Appendix 3 of the handbook, despite that fact that allowable use was originally established to consider "year-round grazing" by horses, AUMs for horses are converted to their equivalents for other species, including livestock that are not on the range year-round (BLM, 2010). That highlights the difficulty of evaluating forage availability independently of allocation to various grazing animals. BLM considers a horse to be a single animal unit, consuming 1.0 AUM of forage per month. Horses consume more forage per unit of body weight than do ruminants (Hanley and Hanley, 1982), and the standard measure of an animal unit is a 1,000-lb cow and nursing calf. Several references to animal units for horses

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report that they consume more than 1.0 animal unit per month (1.2,[3] 1.3,[4] or 1.0 for a 2-year-old horse and 1.5 for a horse 3 years old and older[5]). BLM should explain its choice of 1.0 animal unit for a horse.

Problematic Terms

As discussed in the section "Major Challenges in Defining Appropriate Management Levels in Prescribed Legislation," vague definitions in the Wild Free-Roaming Horses and Burros Act and related legislation have created difficulty in implementing and assessing management strategies for free-ranging equids. The handbook does not provide any greater clarity. The committee reviewed two terms in detail to illustrate the problem: *land health standards* and *thriving natural ecological balance*.

Land Health Standards

The handbook states that horses "should be managed in a manner that assures significant progress is made toward achieving the Land Health Standards for upland vegetation and riparian plant communities, watershed function, and habitat quality for animal populations, as well as other site-specific or landscape-level objectives, including those necessary to protect and manage threatened, endangered, and sensitive species" (BLM, 2010, p. 17). The basis for setting land health standards is not described in the handbook but is described elsewhere (BLM, 2001). However, land health standards are not specifically incorporated into the AML-setting process as outlined in the handbook, and this reflects a disconnect between AMLs and BLM land-health assessment procedures. If land health standards are to be at the crux of AMLs, a handbook should include procedures for their scientific determination or specific references to established procedures published elsewhere and recommendations for using such procedures to set AMLs.

The BLM land health standards policy has been in effect for over 15 years. BLM developed regulations for livestock grazing administration beginning in 1995-1997. One of the regulations was that each BLM state director would, in consultation with the Resource Advisory Council in that state, develop standards for public-land health. BLM posts a number of state-level land health guidelines developed accordingly.[6] The purpose of the standards is to provide a measure to determine land health and methods or guidelines to improve the health of public rangelands (BLM, 2001). Rangeland health is defined as "the degree to which the integrity of the soil and ecological processes of rangeland ecosystems are sustained. Rangeland health exists when ecological processes are functioning properly to maintain the structure, organization and activity of the system over time" (BLM, 2001, p. I-7). That is significant in that it calls for assessments not only of states but of ecosystem processes. Processes of interest pertain to hydrology, nutrient cycling, primary production, and vegetation dynamics. The 2001 document outlines a set of general procedures that should be followed to assess and achieve rangeland

[3]Available online: http://www.gov.mb.ca/agriculture/crops/forages/bjb00s17.html/. Accessed October 8, 2012.

[4]Available online: http://cals.arizona.edu/pubs/animal/az1352.pdf/. Accessed October 8, 2012.

[5]Available online: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/faq6722/. Accessed October 8, 2012.

[6]43 CFR §4180. Available online: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=5d253348ae12c9c0d76a8114b7eec027&rgn=div5&view=text&node=43:2.1.1.4.92&idno=43#43:2.1.1.4.92.9/. Accessed October 8, 2012.

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health. Notably, they include not only a call to assess current land health but a determination of the causal factors that have led to the current state on the basis of the best data and resource information available. That would require the development of conceptual or quantitative models of ecosystem functioning.

"Deterioration," like "health" or "condition," is determined by some measure of the difference between the current state of the system and some reference state. The question is, What is the appropriate reference state of a minimally managed free-ranging equid system? The difficulty of defining that state is similar to the difficulty of defining what constitutes overgrazing. Overgrazing is a level of herbivory that leads to some level of rangeland deterioration. However, overgrazing in a livestock production system may be defined differently from overgrazing in a system that is being managed for natural processes. Coughenour and Singer (1991) reported that definitions of overgrazing also depend on differences in theories of how ecosystems that have abundant large herbivores function without human intervention. Indicators of deterioration in rangeland health may or may not constitute evidence of overgrazing, depending on management objectives and the theory or conceptual model that the management is based on. Differences in definitions used by livestock producers and wildlife managers are particularly relevant here. It is problematic to define overgrazing where there is a call for minimal management and "wildness."

Thriving Natural Ecological Balance

The handbook does not provide guidance on how to assess a thriving natural ecological balance as called for in the legislation. It is also easily conflated with the allocation process, which is a policy-driven and sometimes court-adjudicated decision rather than something derived directly from currently available scientific information. The Wild Free-Roaming Horses and Burros Act is clear that habitat for wildlife and threatened, endangered, and sensitive species is not to be harmed by free-ranging horses and burros. Among the districts responding to the implementation survey, BLM consultation with state wildlife agencies (as instructed in the legislation) was fairly consistent. Wildlife considerations were mentioned in responses from several HMAs as reasons for adjusting AMLs, either explicitly in some HMAs or implicitly as reflected in allocation of forage. Concern for species listed as threatened, endangered, or sensitive under the U.S. Endangered Species Act was referred to by only one HMA complex in the survey sample to protect greater sage-grouse (*Centrocercus urophasianus*), an endangered species candidate, in Wyoming.

There are several possible interpretations of what constitutes a thriving natural ecological balance. It is not a scientific term.

Wildlife and Plant Diversity. BLM relies largely on state wildlife agencies to determine how to consider wildlife in the setting of AMLs. However, BLM has a responsibility to make sure that key indicators of free-ranging horse and burro effects are included in assessments of impacts to wildlife habitat.

Monitoring of wildlife and plant abundance and diversity is key to determining whether a thriving natural ecological balance is being preserved. Free-ranging horses and burros can affect species richness in a variety of habitats (Levin et al., 2002; Zalba and Cozzani, 2004). Manipulative experiments illustrate a dramatic array of indirect pathways by which free-ranging horses can affect components of marsh ecosystems (Levin et al., 2002). In addition to direct interference and other types of competition possibly experienced by large ungulates in areas that

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have free-ranging equids, wildlife sharing the range with free-ranging horses and burros can be subject to equids' effects on the structure, composition, and function of vegetation. Vegetation provides perching habitat for raptors, nesting habitat for breeding birds (including cavity-nesting and stick-nest–creating birds), concealment cover for greater sage-grouse and other ground-nesting birds (Beever and Aldridge, 2011), shade and thermal refuge, refuge from predators, and nutrients and energy for diverse animals. Numerous species are affected by equid impacts to soil. Recovery of some species has been attributed to removal of free-ranging horses (Nano et al., 2003). Wildlife and plant abundance has been reported to be influenced by free-ranging horses' presence (Coventry and Robertson, 1980; Mansergh, 1982; Gillespie et al., 1995; Beever and Brussard, 2000, 2004; Greyling, 2005). Reptile species richness was significantly lower at horse-used sites than at horse-removed sites studied in the western Great Basin (Beever and Brussard, 2004) and in the Austrian Alps (Coventry and Robertson, 1980; Mansergh, 1982), and reptiles are important as prey for numerous other species and as predators that influence biological integrity. Horse presence has been identified as potentially affecting ant mounds in the Great Basin (Beever and Herrick, 2006).

Interactions with Native Grazers. Native herbivores may have forage, space, water, and cover needs that overlap with those of free-ranging horses and burros. Therefore, monitoring of the status of native ungulates is crucial. In some cases, the presence of free-ranging horses has increased forage available to native species, as in the case of bitterbrush (*Purshia tridentata*) in Utah (Reiner and Urness, 1982). Horses and burros can dominate other herbivores and exclude them from water sources, forcing a change in the habitat use of native grazers (Meeker, 1979; Berger, 1985; Ganskopp and Vavra, 1987; Coates and Schemnitz, 1994). The degree of overlap in diets and habitats determines the potential for competition. Elk and bison diets overlap with those of horses, but there have been few cases of concern about their interactions with horses. Elk inhabit low-elevation sagebrush-steppe habitats (Hobbs et al., 1996; Manier and Hobbs, 2007) and are found in some areas that have horses (Hansen et al., 1977), but their preferred habitats tend to be more mesic (moderately moist) and at higher elevations. Bison are primarily residents of the Great Plains and portions of the Rocky Mountains (Mack and Thompson, 1982); there is little sharing of range with horses.

In some areas, there has been concern about potential competition for forage between free-ranging equids and bighorn sheep. In the Pryor Mountains, Coates and Schimnetz (1994) found partial dietary overlap year-round, and Kissel (1996) found little overlap except in summer. Dietary overlap was minimized by the fact that a substantial fraction of bighorn sheep diets was shrubs, particularly the evergreen shrub mountain mahogany (*Cercocarpus* spp.), but shrubs were insignificant in horse diets. Horses and bighorn sheep also used markedly different habitats and overlapped little spatially. Modeling studies including consideration of diets and the extent of overlap in spatial ranges of the bighorns and horses also supported the idea that there was only a small degree of competition (Coughenour, 1999). Kissel (1996) concluded that there was little if any competition between horses and mule deer, inasmuch as the latter are primarily browsers and horses primarily grazers. Those two species had little spatial overlap because their habitat preferences are different. In contrast, competitive interactions between burros and bighorn sheep are important inasmuch as burros are mixed feeders and have substantial quantities of browse in their diets (Walters and Hansen, 1978; Seegmiller and Ohmart, 1981).

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Interactions with Livestock. Free-ranging horses and livestock overlap in demands for forage and habitats. Cattle and horses are both primarily generalist grazers, consumers of palatable herbaceous vegetation. Horses and burros, however, are able to use lower-quality forage than cattle because of their cecal-digestive system (Hanley, 1982; Hanley and Hanley, 1982). Burros preferentially consume woody vegetation (shrubs, dwarf shrubs, stemmy forbs, and small trees). Horses and cattle use similar habitats, but they also diverge with respect to mobility and accessibility. Horses can travel great distances in a short time, they can travel further from water, and they can use rugged topography more readily than can cattle (Ganskopp and Vavra, 1987; Hampson et al., 2010).

Although it is often assumed that cattle, horses and burros, or wildlife always compete, recent research on zebras and cattle and on cattle and donkeys (donkeys served as surrogates for zebras in controlled experiments) showed that it is not always the case (Odadi et al., 2011a,b). When cattle were reared with donkeys, both grew faster than when each species was allowed to graze on its own. Facilitation occurred because the donkeys consumed tough, fibrous stems, allowing the cows to eat the more nutritious leaves, forbs, and regrowth; and the cattle helped to dilute the effects of ticks that plagued the donkeys. In semiarid habitat, the occurrence of light rains allowed grasses to continue growing after joint cropping by the two species changed the structure of the sward, thus improving forage quality. The extent to which horses and cattle can facilitate each other and improve rangeland in temperate grasslands requires further study and most certainly depends on the specifics of the ecosystem being considered. It is also critical to note that the Odadi et al. (2011a,b) research was carried out in African grasslands, which have a long, continuous coevolutionary history of herbivory by numerous ungulates and can have biomass and graminoid diversity one to two magnitudes higher than some areas encompassed by HMAs of the western United States. (Mack and Thompson, 1982). However, assuming that cattle and equids must compete because they share the same range is not necessarily warranted (du Toit, 2011).

Endangered Species. Of particular concern is the interaction of horses and greater sage-grouse. Possible interactions of free-ranging equids with greater sage-grouse were thoroughly outlined by Beever and Aldridge (2011). They described numerous mechanisms by which equids can influence their environment, and greater sage-grouse are known to be sensitive to those aspects of the environment (e.g., the height of herbaceous plants is important as concealment cover for nests), but no field research has directly addressed the relationships between equids and grouse. The authors outlined numerous research questions that might be addressed, given the continuing effort and concern related to greater sage-grouse and other sagebrush-associated species in western North America.

Possible alterations of the small-mammal community by free-ranging equids may be important because of the role of small mammals in aeration and bioturbation of soils, as prey for numerous terrestrial and aerial predators, in seed and nutrient redistribution, and as part of biotic integrity. Numerous other ecosystem processes and components are critically important for conserving the potential of BLM-administered landscapes to provide ecosystem services (e.g., clean water, noneroded soils, food, and fiber) and for allowing cost-effective maintenance of ecological function and biological diversity. All these are mandated by numerous laws, policies, and statutes related to rangeland health, water quality, endangered species, and other topics.

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Challenges to Managing for a Thriving Natural Ecological Balance. Although allowing an equid ecosystem to self-regulate could be one approach to establishing a balance, it is also evident that this may not be a realistic objective in many cases, owing to human effects that are beyond the purview of BLM. Thus, as a result of human disruptions, a self-regulated system is not necessarily natural. Land use is a foremost human effect that constrains natural horse movements, dispersals, or migrations. In natural wildlife systems, herbivores are free to seek forage and avoid situations of depleted forage. Fragmentation of habitats due to land use or ownership that does not permit such movements is problematic for herbivore and vegetation sustainability (Coughenour, 2008). Another human intervention that disrupts natural ecological processes is the development of water sources that make otherwise unavailable areas of the landscape available for equid use. Water-scarce areas would naturally be refugia from horse use for a variety of plant and animal species that are less tolerant of horses' presence. The recent incursion of invasive plant species, such as the *Bromus* species which includes cheatgrass (*Bromus tectorum*), is another example of human effects that alter the possibility of a natural balance, as is the extirpation of predators, such as wolves, in some environments where they would otherwise occur.

There are scientific approaches for assessing human effects on such ecosystems and the degree to which they impair free-ranging horse and burro numbers and management. They include scientifically based modeling studies of alternative scenarios of the presence or absence of human effects. Methods that meet the objective of minimal management could be identified, targeted, and justified to mitigate the adverse human effects. For example, if landscape fragmentation has altered the capacity of the habitat to support horses, model-based assessments would be able to quantify how this has occurred and therefore provide support for management interventions that mitigate it. Similar assessments could address lack of predation, invasive plants, and water development.

Managing horse and burro populations as free-ranging with the minimal management called for in the Wild Free-Roaming Horses and Burros Act thus entails conceptual challenges associated with defining what constitutes land deterioration or health. The handbook does not help in such definition. The handbook should address the challenge of defining terms used as management criteria, including *appropriate, thriving, natural, in balance, healthy*, and *deteriorated*. The approach would involve the development of a conceptual model for ecosystem functioning relative to management objectives and the development of indicators that can be used to measure the degree of departure from a scientifically informed conceptual model of an "appropriately" functioning free-ranging equid ecosystem.

Specificity of Methods and Their Consistency among Herd Management Areas

The handbook does not adequately respond to GAO's request for guidance; the level of detail that the handbook supports is too limited. The handbook does provide for some degree of consistency in goals, forage allocation, and general habitat considerations and should help to improve consistency in how AMLs are set. However, it does not provide detail on monitoring and assessment methods. That is intended to allow BLM managers to decide what specific approaches fit local environmental conditions and administrative capacity, but it makes it difficult to review the program's on-the-ground methods. A better approach would be to provide specific options. Similar issues were identified with respect to establishing AMLs, population

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inventory, use patterns, animal distribution, other site-specific and landscape-level management objectives, and forage allocation (BLM, 2010). For example, the handbook states that the amount of forage available to allocate to free-ranging horses and burros shall be determined through in-depth evaluation of resource-monitoring data after a site-specific environmental assessment and multiple-use decision process[7] that includes public involvement. There is no explanation of any of the data-collection methods. The handbook would be more informative if it provided guidelines on how various kinds of assessments are to be carried out even if a variety of appropriate methods available, or referenced appropriate sources, linking them to particular settings or situations. In general, the handbook lacks clear protocols for evaluating habitat components other than forage availability. That is critical because without clear protocols specific enough to ensure repeatability, the monitoring organization cannot determine whether observed change is due to changes in condition or to changes in methods. Protocols should also include establishment of controls when the goal is to distinguish treatment or management effects from other causes of change.

ESTABLISHING AND VALIDATING APPROPRIATE MANAGEMENT LEVELS: SCIENCE AND PERCEPTIONS

The committee was asked to recommend methods for establishing and validating AMLs. The establishment of AMLs should be linked to consistent, scientifically supported models of range and herbivore interactions. Validating AMLs requires methods that draw on information on rangeland, equid, and wildlife dynamics for adaptive decision-making. Improved and more consistent monitoring is also needed. Processes for establishing and validating AMLs should be open and understood by stakeholders, and ultimately AMLs should be amenable to adaptation in light of new information and environmental and social change.

[7]The multiple-use decision (MUD) is generally used to establish livestock grazing, AMLs for free-ranging horses and burros, and recommendations for wildlife habitat management.

> This process begins with an evaluation of range conditions; the evaluation assesses whether or not management and stocking levels for livestock, wild horses and/or burros, and wildlife are achieving rangeland objectives. If rangeland health objectives are not being met, changes in management or stocking levels are proposed. Proposed changes are analyzed in an environmental assessment and a proposed multiple-use decision is issued. Proposed decisions are subject to review and protest by parties affected by the proposal. BLM considers all protests filed and then issues a final multiple-use decision. BLM's final decisions are subject to administrative review (appeal). (Appropriate Management Level. http http://www.blm.gov/nv/st/en/prog/wh_b/appropriate_management.print.html. Accessed February 21, 2013)
>
> At the conclusion of the decision process the management actions are implemented and monitoring continues until the next evaluation. All decisions issued as a result of completion of an allotment evaluation are issued in the MUD format. The MUD format has four sections: Introduction; Livestock Grazing Management Decision; Wild Horse and Burro Management Decision; and Wildlife Decision. Each of these sections includes a rationale, citation of appropriate authority, and information about protests and appeal procedures. (Multiple Use Decision Process. http://www.blm.gov/nv/st/en/prog/grazing/multiple_use_decision.html. Accessed December 3, 2012)

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Understanding Ecosystem Dynamics

Numerous developments in ecological theory, in technologies and methods for assessing ecosystem status and trends at multiple resolutions, and in understanding arid rangelands dynamics and function have occurred since publication of the earlier National Research Council reports on free-ranging horses and burros (NRC, 1980, 1982). Developments in ecological research challenge the notion that a reliable minimum annual forage production that would allow the establishment of a static carrying capacity, or AML, over the long term can be determined. The research highlights the role of unpredictability on arid rangelands (Ellis and Swift, 1988; Westoby et al., 1989; Smith et al., 1995; Bestelmeyer et al., 2003; Briske et al., 2005; Vetter, 2005) and the importance of abiotic factors, such as weather events and fire, relative to biotic factors, such as competitive interactions among plants or grazing pressure, in determining vegetation expression. In short, the effects of a severe drought on forage availability often have more influence than herd population management.

It is important to distinguish between two foci for applying the concept of nonequilibrial rangeland dynamics. The first is a focus on plant-herbivore equilibria or nonequilibria. It was once theorized that plants and herbivores would come into a natural ecological balance or equilibrium if left undisturbed. Herbivore population growth would be slowed to zero at equilibrium because of density-dependent feedbacks arising from food limitation (see section "Density-Dependent Factors" in Chapter 3). However, it has been understood that population regulation also has density-independent terms, for example, weather variability (see section "Density-Independent Population Controls" in Chapter 3). Caughley (1987), who developed much of the theory of plant-herbivore dynamics, observed that, when abiotic variability is high, plant-herbivore systems exhibit nonequilibrial dynamics. That line of thought was further developed by others (DeAngelis and Waterhouse, 1987; Ellis and Swift, 1988; Behnke and Scoones, 1993; Illius and O'Connor, 1999). An important outcome of nonequilibrial plant-herbivore dynamics is that herbivore populations in such natural systems, where natural controls apply, cannot attain numbers high enough to degrade vegetation. Vegetation dynamics are driven largely by climate rather than herbivory. Vetter (2005) cited evidence from arid environments with annual rainfall coefficients of variation[8] (CV) over 33 percent that suggests that these systems better fit the nonequilibrium plant-herbivore model (Ellis and Swift, 1988; Ward et al., 1998, 2000; Sullivan, 1998 cited in Sullivan and Rohde, 2002; Fernandez-Gimenez and Allen-Diaz, 1999 cited in Vetter, 2005). In such areas, vegetation cover, composition, and productivity are influenced largely by rainfall and other abiotic factors, and grazing intensity has been reported to have much less influence on these three aspects of the vegetation (Vetter, 2005). In more mesic sites with lower annual rainfall variation or reliable soil moisture, grazing has been reported to cause such changes as brush encroachment (Desta and Coppock, 2002) and alteration of grassland species composition (Fernandez-Gimenez and Allen-Diaz, 1999). Those sites may occur in or be intermixed with arid rangelands. Caughley (1987) first observed that plant-herbivore equilibria diminish markedly in strength above an annual rainfall CV of 33 percent. Ellis and Swift (1988) extended the theoretical 33-percent CV threshold. On a regional scale, HMAs are most commonly in areas that have an annual rainfall CV exceeding 33 percent (Figure 7-1).

[8]The coefficient of variation is the ratio of the standard deviation to the mean.

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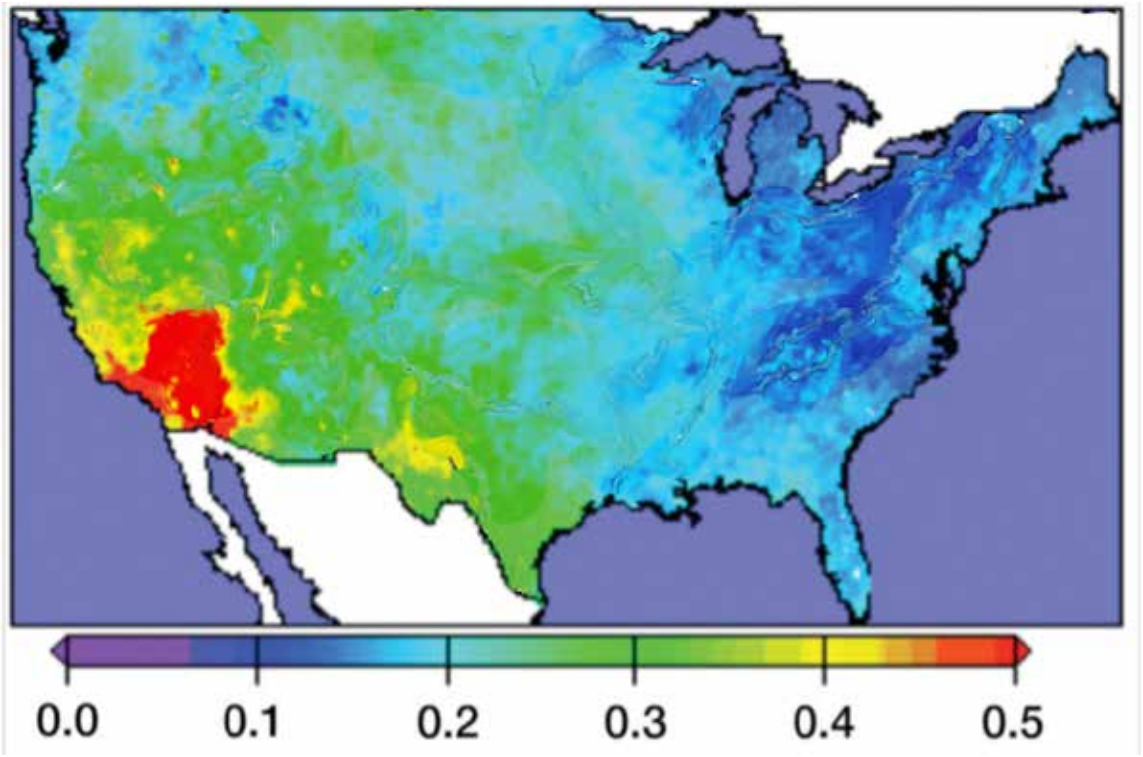


FIGURE 7-1 Coefficient of variation of annual rainfall in the contiguous United States. SOURCE: Adapted from Lettenmaier et al. (2008) and Maurer et al. (2002).

The second focus for the application of nonequilibrial rangeland dynamics has been more broadly on vegetation dynamics and the multiplicity of factors that drive them, including climate and disturbance. A wealth of evidence and observation, perhaps beginning with Westoby et al. (1989) and Laycock (1991) if not Gleason (1917, 1926, 1927), supports the idea that vegetation dynamics in arid climates do not necessarily follow the theory of linear successional dynamics first proposed by Clements (1916), which provided the basis for assessing rangeland condition in the United States for several decades (Dyksterhuis, 1949; Briske et al., 2003). The ecological dynamics of vegetation on arid rangelands are now commonly characterized by using state-and-transition models that posit that relatively stable configurations of vegetation, or "states," exist and that they may "transition" to other such states as a result of the influence of biotic or abiotic factors, such as grazing, precipitation, species invasions, fire, and seed sources (Westoby et al. 1989, Bestelmeyer et al., 2003, Stringham et al. 2003; Briske et al., 2005, 2006). An inherent aspect of this concept is the acknowledgment that there may be thresholds between states and nonlinear dynamics: instead of a predictable, directional pattern of change, a state may transition to one of several alternative states, may not do so in any predictable timeframe, and may not transition back after a change (Belovsky, 1986; van de Koppel et al., 1997; Rietkerk et al., 2002; Peters et al., 2006; Bisigato et al., 2008). The state-and-transition framework does not exclude the occurrence of changes that follow linear successional trajectories (Bestelmeyer et al., 2003; Briske et al. 2005, 2006).

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When an ecological threshold is crossed and an HMA or part of an HMA has entered an alternative state, the simple removal of horses or burros may not result in a return to the conditions of the previous state and AMLs may need adjustment. If recovery of biological structure and ecological processes that promote self-repair and facilitate long-term sustainability can be expected at all, such areas require additional resources and time. Areas that were suitable for horses or burros may become unsuitable, and areas that were unsuitable may become suitable.

In addition to the unpredictability and irregularity of rangeland dynamics, climate and social change add another level of uncertainty about future conditions. Setting of AMLs takes place in a context of ecological and social change (Bestelmeyer and Briske, 2012). Vegetation change, soil degradation, invasive species, and changing climate have already altered many rangelands, and such state changes are expected to occur more frequently (Williams and Jackson, 2007; Stafford Smith et al., 2007; Dai, 2011). Social values, economic conditions, and land use in HMAs as well as stakeholders, markets, and policies influencing ecosystem management are all undergoing change (Holmes, 2002; Sheridan, 2007; Brunson and Huntsinger, 2008). Ultimately, the challenges of these numerous sources of unpredictability demand that AMLs be adaptable.

State-and-transition models are synthetic, conceptual models that describe soil and vegetation dynamics (Bestelmeyer et al., 2003; Briske et al., 2005, 2006; Herrick et al., 2012). Models are refined as data become available, and they become increasingly data-driven rather than conceptual over time. Monitoring and site selection can be improved through identification of ecological sites with state-and-transition models (Herrick et al., 2012). The inventorying of ecological sites and linking of them to state-and-transition models are important efforts that BLM is already participating in with the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS). Such models offer the opportunity to capture information about the influence of management and both linear and nonlinear dynamics of ecosystem change, and they are useful in modeling efforts. Good conceptual models implicitly or explicitly identify influences and short-term response indicators in the description of transitions and pathways (Herrick et al., 2012). Information about free-ranging horse and burro management should be linked to ecological sites whenever possible. Over time, the outcomes of adaptive management can be used to improve the state-and-transition models.

The NRCS effort to develop state-and-transition models to guide rangeland management throughout the West is a valuable opportunity to create a standardized basis for managing for desirable ecosystem states that will go a long way to maintaining a thriving natural ecological balance as mandated by the Wild Free-Roaming Horses and Burros Act as amended (see Box 7-2). The committee recognizes that the development of state-and-transition models is in its infancy, is difficult, and may be beyond the purview of BLM and instead be in the domain of NRCS or other natural-resources management agencies and the scientific community. Increased and better defined collaboration between such agencies, the scientific community, and BLM is needed.

An encouraging initiative in this direction is the collection of rangeland data on BLM lands by NRCS staff familiar with the National Resource Inventory data collection methods for rangelands that have been used since 2003 (L. Jolley, NRCS [retired], personal communication, February 2013). Those data are linked to development of state-and-transition models for specific ecological sites. Eventually, this will allow BLM to the use of the nationwide National Resource

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Inventory Resource Assessment database.[9] This would be a valuable contribution to standardizing BLM methods and data nationwide.

BOX 7-2

The Pryor Mountain Wild Horse Range Example of the Natural Resources Conservation Service Approach

The Pryor Mountain Wild Horse Range is probably the most well-studied HMA in the nation (e.g., Garrott and Taylor, 1990; Singer and Schoenecker, 2000; Fahnestock and Detling, 1999a,b; Coughenour, 1999; Ricketts et al., 2004; Roelle et al., 2010). Widespread concern about the ability of the range to support wild ungulate populations prompted BLM to ask NRCS to perform a comprehensive inventory and assessment of the health of range in 2002-2003 (Ricketts et al., 2004). According to NRCS, its report was the most detailed assessment of any wild horse range to date (this presumably referred to all the HMAs under BLM purview). Although the Pryor Mountain Wild Horse Range supported 161 horses in 2003, the NRCS assessment determined carrying capacity should be 45-142 horses on the basis of the percent of rangeland in poor condition, the low similarities of vegetation to potential climax vegetation, a perceived downward trend in range condition, and evidence of severe erosion.

The approach taken by NRCS was different than that described in the BLM handbook. A more exhaustive methodology was used by NRCS, and this approach serves as an example of potential improvements to the BLM handbook approach. Nevertheless, it too has had notable limitations.

The approach used a systematic sampling of the entire landscape. The landscape was stratified into ecological sites on the basis of an earlier Soil Conservation Service soil survey. Transects were distributed among ecological sites within broader-scale inventory units by using stratified random sampling. Along each transect, 10 circular plots were sampled at 10- or 20-foot intervals. Vegetation biomass was determined by harvesting and weighing all plants, by double sampling with some being visually estimated, or by visual estimation only. Total forage availability was used to determine stocking rates. A “harvest efficiency” was applied in the same way as a proper use factor would be applied in the BLM approach. It was assumed, on the basis of an earlier literature review (Holecheck, 1999), that 35- to 45-percent use is moderate for desert and semidesert environments. A value of 30 percent was used for preferred and desirable species and 10 percent for undesirables. Estimates were subjectively adjusted on the basis of judgments of whether plants had reached peak biomass and to account for grazing removals. Forage availability was further modified by distance from water and slope class. This approach is a more direct way of assessing forage biomass than the BLM handbook approach, but it is still subject to uncertainty in that visual estimates of biomass are used without clear evidence of calibration against actual measured weights; samples were taken in open, grazed vegetation, and a subjective and unsubstantiated method of adjusting for grazing removal was used; sampling occurred only once in the growing season, but biomass is dynamic through the season; sampling occurred in only 1 year, but precipitation is highly variable among years (the BLM approach is superior in accounting for such variability); and a source based on pre-1976 range literature was cited for setting proper use levels. Proper use levels are based on available site-specific research, local experience, and trend data and should be adjusted through adaptive management (Swanson et al., 2006). Updates were not mentioned.

Rangeland condition was based on similarity in composition to that inside reference long-term exclosures. The underlying assumption was the traditional one: climax, ungrazed plant communities are in the best condition, as in the BLM method. However, plant communities grazed by herbivores cannot be expected to be like communities exclosed from grazing. They may be different, but they may be stable and productive. An attempt was made to assess trends in conditions relative to the presumed climax community, as evidenced by conditions in long-term exclosures. However, the assessment was based on judgments of condition at one time as determined by comparison to the presumed ungrazed climax condition rather than observations of changes over time. That underscores the need for long-term

[9]Available online: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/?&cid=stelprdb1041620. Accessed February 21, 2013.

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monitoring. It was not established that the vegetation community was changing, only that it was different from that in the ungrazed area. It is noteworthy that the grazed and ungrazed plots have not become more similar despite the fact that management removals have, for the most part, kept the horse population near the AMLs for many years. There is little evidence that all but elimination of the horses would result in such a convergence and no evidence that one "condition" is generally superior to the other.

Rangeland health was assessed by using a number of indicators "relative to soil and site stability, watershed and hydrologic function, and soil and plant community integrity" (Ricketts et al., 2004, p. 104). They included hydrological indicators—such as pedestaled plants, rills, gullies, and soil loss—and observations of plant mortality, bare ground, and litter (detritus). Although there was evidence of erosion due to overland flow and wind, it was not established how long it had been occurring, that it was not going on in the absence of grazing, or that changes in herbivore density would reduce erosion rates.

Finally, the assessment did not make substantial references to or comparisons with more detailed studies of vegetation and ecosystem functioning that used a greater number of grazing exclosures, measures of live and dead biomass dynamics over time, experimental design, statistics, and spatially explicit ecosystem modelling (Coughenour, 1999; Fahnestock and Detling, 1999a,b; Singer and Schoenecker, 2000).

Assessing Rangeland Deterioration

The handbook assumption appears to be that if forage and habitat components are adequate, range deterioration will not occur. Habitat structural characteristics and amount of forage available can be measured in a straightforward way, but what defines "range condition"—the "health" of the range—has been a subject of debate in scientific and management communities for decades, and the handbook provides no additional clarity. As noted above, concepts underlying range-condition assessments in the 1970s, when the Wild Free-Roaming Horses and Burros Act was written, are now viewed as simplistic and not in line with current thinking regarding vegetation dynamics in arid lands. Although the handbook focuses primarily on the level of forage utilization as a determinant of AML, forage consumption is only one process associated with grazers' use of the landscape. Horses and burros have mechanical effects on plants and soils through trampling and on shrubs through rubbing (Beever et al., 2008). Therefore, other factors sensitive to equid presence may indicate ecosystem change due to equid grazing, including insect activity, soil compaction, species richness, condition of woody vegetation, and cover of plants (Beever et al., 2003). Areas used by free-ranging horses have been reported to exhibit soil loss, compaction, and erosion (Dale and Weaver, 1974; Dyring, 1990a; Whinam et al., 1994; Nimmo and Miller, 2007); soil was the ecosystem component that differed most between horse-occupied and horse-removed sites in the western Great Basin study (Beever and Herrick, 2006).

Although invasive species are receiving increased management and conservation attention (both in and outside BLM), the committee observed that there was relatively little guidance in the handbook on the effects of invasive species on AMLs. Invasive species may be brought in by free-ranging equids (Campbell and Gibson, 2001) and spread by them (Dyring, 1990a; Rogers, 1991; Weaver and Adams, 1996; Campbell and Gibson, 2001; Loydi and Zalba, 2009). Most seeds pass through the equine digestive tract in less than 2 days, but some can be carried and remain viable for much longer periods (Janzen, 1981) and so can be transferred long distances. Seeds are also carried on the animal body. It can be difficult in practice to ascribe

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causation of invasive-plant presence and density to free-ranging equids, especially without controlled experiments. It is likewise unclear whether alterations (either decreases or increases) in grazing intensity can be expected to reverse or halt the spread of invasive species. Although invasive-plant ecology is still an emerging field, the handbook should offer some guidance based on what is known. Given the importance of invasive plants in altered fire regimes in the domain of BLM HMAs, the topic of how free-ranging equids relate to distribution and abundance of invasive plants may deserve increased research attention.

Livestock grazing has been reported to alter soil properties via compaction, hoof action and consequent erosion, and redistribution of nutrients such as nitrogen (Archer and Smeins, 1991; van de Koppel et al., 1997). However, hoof action may break physical surface crusts that impede infiltration and seed germination. Soil surface horizons are involved in numerous biotic and abiotic pathways in communities (Thurow, 1991; Belsky and Blumenthal, 1997; Beever and Herrick, 2006). Given the importance of soil chemistry and physical attributes (e.g., related to compaction) for ecological function, the tight connection of soil measures to so many BLM mandates and arid-lands monitoring frameworks, and the relative dearth of information on equid-soil relationships, Beever and Aldridge (2011) reported that further research on these relationships would increase ecological understanding and identify the implications of the relationships for the management of equid influence on soil resources. For example, they asked provocative questions, including the following: To what depth below the soil surface does compaction extend? Under what conditions will treading by equids lead to favorable or adverse hydrological outcomes? What factors (such as soil texture or percentage of clays, concentration of calcium carbonate, and depth to water or an impervious layer) most strongly modify soil responses to horse and burro densities? Consideration of such factors and interactions would strengthen assessments used to set AMLs.

Beever et al. (2003) reported that 19 horse-grazed and horse-removed sites could not be clearly discriminated on the basis of the cover of key plant species consumed by horses (species measured by BLM specialists in horse-effects monitoring) or by using cover or frequency of all plant species. However, horse-occupied and horse-removed sites were clearly discriminated by using a diverse suite of variables that research had suggested were sensitive to grazing disturbance. The variables included density of ant mounds, soil-surface hardness, species richness, grass cover, forb cover, and shrub cover (Beever et al., 2003).

Monitoring and Assessing Forage Availability

Once AMLs are established it is essential to determine whether forage consumption is at the predicted level. To account for factors other than grazing (such as weather) that can affect rangeland condition, determining effects of equid foraging ultimately requires comparisons of vegetation in areas where foraging occurs and where it is prevented. Consumption levels can then be compared with rangeland productivity. Grazing and browsing effects are typically measured by comparing vegetation production and composition in areas where grazing occurs with those in areas where it is excluded.

One of the easiest and most effective ways to compare vegetation features in grazed and ungrazed areas is to establish pairs of exclosed and grazed plots. Plots are chosen at random with one plot at each site as a control and the other enclosed by an exclosure device such as a 1-m^3 cage covered in wire mesh. With grazing excluded, changes in vegetation height, biomass, and percentage cover in cages provide estimates of productivity. In the paired plots outside cages,

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grazing will reduce vegetation biomass. Thus, differences between vegetation biomass inside and outside cages provide estimates of consumption. Clipping-based estimates are more accurate than visual estimates. Cages are moved regularly (one to three times per year) to prevent the cages themselves from altering productivity. The temporary exclosures can be used to determine whether current herbivore densities, as set through management removals, are achieving anticipated or target levels of offtake. Larger, permanent exclosures can also be established to determine the extent to which grazing changes vegetation cover and composition over time. Such exclosures can also be used to test the hypothesis that removal of grazing results in vegetation recovery.

Temporary exclosures are easy to deploy and relatively inexpensive to implement, but many replicates in habitats are required because each cage and the control paired with it provides estimates of productivity and consumption over only a small area. Moreover, small cages generally exclude trees and shrubs that provide browse for burros. Care must be taken to avoid statistical pseudoreplication because samples in each permanent exclosure are likely to be spatially correlated to a greater extent than samples among exclosures, for example, in different vegetation types or patches of vegetation and soils in the larger-scale matrix of landscape heterogeneity.

Although small-scale and large-scale exclosures are similar in many respects, they differ in important ways. Fenced areas allow detection of long-term changes in vegetation where grazing is excluded, whereas 1-m^3 cages enable frequent and easy movement for measurement of annual production. Long-term exclosures may foster the development of vegetation and soil conditions different from those in areas routinely grazed by large herbivores, whereas small, movable exclosures maintain conditions more similar to the conditions of grazed vegetation. The different approaches have two implications. First, the conditions inside long-term exclosures may enhance or suppress plant growth compared with grazed vegetation. Reduced growth could arise from self-shading, rainfall interception, and lower rates of nutrient cycling in the ungrazed than in the grazed vegetation. As a result, growth (primary production) of the vegetation that is grazed cannot be estimated from data collected in long-term exclosures. Comparisons of vegetation in and outside large permanent exclosures provide different estimates of production and consumption from those of temporary exclosures because vegetation that develops within long-term exclosures often becomes quite different from that outside the exclosure. The vegetation that develops in long-term exclosures should not be considered “natural” or “desirable” if the objective is to conserve free-ranging populations of large herbivores.

Beever and Brussard (2000) concluded that exclosures are nonetheless an excellent monitoring and experimental design tool that had been underused to quantify influences of free-ranging horses on vegetation and wildlife. That is particularly relevant for BLM managers of free-ranging equids because numerous exclosures have been in place for some time, and a strategically placed network of large exclosures could provide BLM with robust data for quantifying the effects of free-ranging equids among HMAs, seasons, and years of different weather.

Sampling vegetation in and outside either type of exclosure is labor-intensive. As a result, techniques that relay easily acquired, remotely sensed data have become popular (see Box 7-3), even though the data are relatively coarse and generally cannot be used to monitor exclosures. Images from satellites routinely measure many spectral bands of reflected light from vegetation and provide long-term time series for examining changes in vegetation. The Normalized Difference Vegetation Index (NDVI) is widely used and compares infrared and near infrared

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reflectance to measure vegetation abundance and quality. However, interpretation of those values in relation to actual rangeland quality requires “ground-truthing” based on actual measurements of vegetation. Moreover, sample ground-truthing in and outside large-scale exclosures remains essential for estimating consumption levels from remotely sensed spectral indexes and thus foraging effects on large areas. Care must also be taken in interpreting the meaning of reflectance values because they are affected by the abundance of bare ground and the abundance of grasses and forbs relative to trees and shrubs. Once predictive statistical models are developed, remotely gathered data on large spatiotemporal scales can be used to measure changes in rangeland quality repeatedly. In that way, the effects of AMLs can be monitored from remote sensing and adjusted on a regular and timely basis.

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BOX 7-3

Use of Remote Sensing

Remote sensing is an effective and universal tool adapted to a wide array of applications in natural-resources science and management (Gross et al., 2006, Kennedy et al., 2009). It has utility for landscape assessment ranging from site-specific habitat management to broad landscape-scale predictions. Remote sensing can be used effectively to characterize heterogeneous landscapes on the basis of detection of abrupt changes or gradual trends and patterns. It can provide consistent and reliable information on ecological effects and can be used to monitor landscape change and to extract unique or important features from complex ecosystems (Kennedy et al., 2009). It is an excellent tool for landscape-level applications, such as range assessment, ecological monitoring, weed-invasion detection, and woodland-encroachment assessment.

The spatial resolution of an image refers to the size of the smallest object that can be detected (resolved) on the ground. In raster-based information, the resolution of an image is limited by the smallest pixel size. High-resolution information is characterized by small pixel sizes and low resolution by large pixel sizes. When comparing images or datasets from different HMAs, it is critical that the resolution of the images be known and preferable that they be comparable. The accuracy and reliability of an analyzed (classified) remotely sensed image may depend on its resolution.

Diverse sensor types and remote-sensing platforms are available, each with specific-resolution and spatial-extent parameters. Which sensor is chosen depends on management objectives and expected outcomes. Several of the sensors provide specific advantages for management of free-ranging horses and burros (Table 7-2).

TABLE 7-2 Description of Remote-Sensing Types and Their Advantages in Management of Free-Ranging Equids

Attribute	Image Type	Advantages and Opportunities
Patch-size detection	Fine grain: IKONOS,[a] Quickbird,[b] Aerial photography[c]	High spatial resolution. Delineation of habitat heterogeneity. Characterization of primary horse grazing and drinking areas.
Gradual landscape change	Fine grain: IKONOS, Quickbird, Aerial photography	Fine scale habitat structure and change in HMAs. Monitoring of effects and resource availability.
	Moderate grain: Landsat, ASTER[d]	Regional disturbance assessment, forage detection availability, and landscape change detection.
	Coarse grain (MODIS,[e] AVHRR[f])	Atmospheric influences and surface detection across broad spatial areas. Monitor regional shifts in vegetation structure.
Abrupt landscape change	Fine grain: IKONOS, Quickbird, Aerial photography	Inference of land use and land-use change by image analysis and interpretation. Annual or seasonal effect detection in HMAs.
	Moderate grain: Landsat, ASTER, SPOT, hyperspectral, AVRIS	Detection of disturbance events in large areas.
	Coarse grain (MODIS,[e] AVHRR[f])	Large-scale disturbance and regional vegetation change such as drought. Cloud screening. NDVI of large areas for vegetation cover and predicted annual forage production.

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[a]The IKONOS sensor is a high-resolution satellite that captures 3.2-m multispectral images and 1-m panchromatic data. It has wide application in natural-resources assessment and mapping, agriculture, forestry, natural disasters, change detection and so on. It collects reflected wavelength bands that include panchromatic, blue, green, red, and near-infrared wavelengths; it can also be used to develop digital elevation models that represent the earth's topographic surface (http://www.satimagingcorp.com/satellite-sensors).

[b]Quickbird is a high-resolution satellite sensor that collects 0.61-m resolution imagery. It is an excellent sensor for land use and change detection, environmental analysis, and resource management. It has a short revisit time (93.5 minutes), making it effective in abrupt to gradual time-change analysis. Data come in panchromatic, red, blue, green, and near-infrared bands. It can be used to map and analyze fine-scale HMA features.

[c]Several types of aerial photography are available or can be produced, depending on the type of information needed. Since 2006, the National Agricultural Imaging Program (NAIP) has provided color, and for some states and dates, color-infrared imagery. The images have a 1-m resolution and can be used to identify and map landscape features. In contrast with most high-resolution satellite sensors, which can be expensive, NAIP imagery is free to the consumer.

[d]ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is used to obtain information on surface temperatures, reflectance patterns, and elevation changes. It is used to predict variability and trends in climate, weather, and surface structure (http://asterweb.jpl.nasa.gov/index.asp).

[e]MODIS (Moderate Resolution Imaging Spectroradiometer) views the earth every 1-2 days, collecting data in 36 spectral bands. It is used to measure global dynamics and processes, including prediction of global climate change, to assist policy-makers in land protection. With a 250-m pixel size, the resolution can be considered relatively coarse-grained.

[f]AVHRR (Advanced Very High Resolution Radiometer) is a satellite sensor that collects earth reflectance in five wide spectral bands (red, two near-infrared, and two thermal).

Analytical and Modeling Approaches

Scientifically defensible approaches have been developed over the last 2 decades for assessing vegetation, herbivore, and ecosystem dynamics in spatially heterogeneous environments from landscape through regional and even to global scales. A wide variety of models have been developed that are capable of simulating vegetation, biogeochemistry, and hydrology dynamics in response to soils, changing climate, and, to a lesser extent, herbivory. A body of science in this field does exist focusing on vegetation and ecosystem responses to herbivory. Some models are capable of simulating interactive responses to herbivory, climate, and soils. Although computer modeling has been adopted by BLM to predict horse population responses to management and to assist in the setting of the lower bounds of AMLs (see Chapter 6), modeling has not been used to set the upper bounds of AMLs or to inform AML decisions. That would necessitate models of vegetation and ecosystem dynamics and the ability of such models to represent ecosystem dynamics in spatially heterogeneous environments and mobile herbivore populations. Assessments of AMLs could be made more robust and more informative by using the powerful analytical and modeling approaches.

A first step would be to use geographic information systems (GIS) and remote sensing to a greater extent in setting and evaluating AMLs. BLM uses GIS to some extent to quantify vegetation and forage production potentials in different range sites, as delineated by NRCS or older Soil Conservation Service soil surveys. Forage production estimates for each range site have been combined or scaled up by using GIS to derive forage production. However, there is a potential to do more with spatial data and to derive additional data from remote sensing, for example,

- Overlay spatial data on equid distributions, which are temporally variable, on to forage-production estimates to predict percentage utilization across the landscape. Even if the equid distributions are coarse or estimated, they represent what is known.
- Use spatial modeling of equid habitat selection on a seasonal basis to provide estimates of equid distributions. Equid habitat-selection patterns will be influenced by distance to water, topography, forage quantity and quality, shrub and tree cover,

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barriers to movement, conflicting land uses, forage offtake by livestock, and other factors. All those can be represented as GIS data layers.

- Use remote-sensing data to cross-check and augment estimates of forage production.
- Use spatially explicit precipitation maps that account for patchy rainfall and topographic gradients to refine estimates of forage production.
- Estimate snowpack distributions by using remote-sensing products, SNOTEL data, snowpack modeling, and spatial interpolation to estimate areas that are available to horses in winter. The snowpack in turn affects the forage supply for the horses in winter.

As just noted, various vegetation and biophysical-ecosystem models have been developed over the last 3 decades. All have capabilities of simulating realistic scenarios of plant production and vegetation dynamics in response to soils and climate. However, few have focused on simulating vegetation or ecosystem responses to herbivory. Few have explicitly represented herbivores or their dynamic distributions on the landscape. However, one example that does is the application of the SAVANNA ecosystem model to the Pryor Mountain Wild Horse Range (Coughenour, 1999) and to a variety of other large herbivore ecosystems in the western United States, East Africa, and elsewhere.

To be useful in informing and assessing AMLs, key capabilities of such an ecosystem model would include

- Prediction of plant-biomass dynamics and production responses to climatic variations and soils. Dynamics must be represented at least seasonally and ideally on a weekly or even daily basis. Dry, wet, and average years should be realistically simulated. Seasonal dynamics are important because forage biomass varies greatly owing to intraseasonal and interseasonal precipitation patterns and herbivore offtake on different parts of the landscape at different times throughout the year.
- Realistic simulation of plant-production responses to herbivory, including undercompensatory and overcompensatory responses.
- Simulation of changes in vegetation cover over multiyear periods.
- Differentiation of simulated plants into functional groups, including preferred and nonpreferred species for herbivores.
- Representation of spatially variable patterns of precipitation and temperature and their effects on vegetation. Spatial patterns of precipitation can be thought of as dynamic precipitation maps in the model.
- Simulation of dynamic snowpack distributions across the landscape because these affect forage availability and herbivore distributions.
- Simulation of dynamic herbivore habitat selection and resulting spatial distributions in response to water, forage, topography, cover, and barriers.
- Simulation of herbivore forage intake and resulting effects on herbivore body condition.
- Representation of key nutrient cycles, particularly nitrogen and soil-carbon dynamics.
- Representation of key hydrological responses, particularly runoff and infiltration responses to changes in vegetation cover, which may result from herbivory.

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- Simulation of interactions with other species via competition for forage, water, and habitat and effects on other species resulting from equid-induced habitat alterations. Ecosystem modeling can represent forage competition, and effects on habitats could be represented by linkages to habitat models for other species.

With those modeling capabilities, it would be possible to predict the effects of different horse or burro densities and distributions on ecosystem dynamics and to assess whether horse or burro densities are sustainable in the long term. It would also be possible to infer or directly represent interactions with other species, including wildlife and livestock. Competition between livestock, wildlife, and horses or burros is affected by the degree of overlap in species forage preferences and spatial distributions. Modeling could also be used to assess the effects of restrictions on horse or burro movements that arise from fencing and other land uses. Such habitat fragmentation results in reduced opportunities for herbivores to access key grazing areas in times of food shortages on primary ranges. Restrictions of movement can also result in higher herbivore densities and grazing pressures than would occur if the animals could disperse or migrate. Vegetation or ecosystem models must be verified through comparisons with monitoring data described above. It is recognized that no single model is completely accurate; however, iterative adjustment of a model on the basis of data will improve it and make it more useful.

Adaptive Management

Environmental variability and change, changes in social values, and the discovery of new information require that AMLs be adaptable. Perhaps the most fundamental approach in this regard is adaptive management (Holling, 1978; Williams et al., 2009). Adaptive management can be used in a variety of social decision-making settings (see Chapter 8). Herrick et al. (2012) defined adaptive management as an iterative decision-making process that incorporates development of management objectives, actions to address the objectives, monitoring of results, and repeated adaptation of management until desired results are achieved. A key tenet of adaptive management that is relevant to managing free-ranging horses and burros is the treatment of management actions as testable hypotheses. In turn, maximizing long-term knowledge of the system and thereby improving management (balanced with achieving optimal short-term outcomes, given current knowledge; Stankey and Allan, 2009) hinges on several fundamental tenets of research and monitoring design. Those tenets include use of control plots (against which to evaluate the effects of a given management "treatment," such as erecting exclosures, administering immunocontraception broadly in a population, or removing or transferring animals from a population); use of replication to increase confidence that results are generalizable rather than anomalous; and controlling for variability (such as that due to annual differences in precipitation and thus productivity), for example, through Before-After Control-Impact designs (Underwood, 1992, 1994). Also essential for adaptive management specifically and for applied ecology generally is the explicit incorporation of uncertainty (such as the use of 95-percent confidence intervals, standard errors or standard deviations, and probability density functions) into estimated measures (such as herd size, utilization rate in a site or HMA, and average penetration resistance in a landscape).

Several other approaches to analysis and interpretation of management actions and monitoring data can improve confidence in the results. First, if there is interest in understanding whether or how a particular factor (e.g., average site growing-season precipitation) affects the

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degree of ecosystem alteration caused by a given density of free-ranging horses and burros, ecosystem attributes mentioned above should be measured at numerous sites with comparable horse and burro density across a broad range of that factor (gradient analyses; Austin, 1985; Gosz, 1992). Such approaches provide quantitative information on the major driving variables, permit the generation of information for extrapolating between sites and across scales, and begin to address mechanistic explanations of phenomena relevant to management (Gosz, 1992). Although ideally other important factors would remain constant in all sites along the gradient, that is rarely the case; for example, soils may differ markedly along the gradient. In those situations, explicitly accounting for this key factor (e.g., soils) can be approached in a manner comparable with complete factorial or blocked designs (e.g., Underwood, 1994, 1997; Sokal and Rohlff, 2012). A related example might be the use of landscape-scale analyses to identify portions of the landscape most likely to be early-warning indicators of deterioration of landscape condition, such as areas of heavy use.

Numerous relatively recent advances in ecological monitoring that can further increase confidence in results are relevant and noteworthy for the Wild Horse and Burro Program. For example, if a particular question is being addressed in terms of testing of the null hypothesis and the null hypothesis fails to be rejected (that is, no effect of a management action or "treatment" was found), a post hoc power analysis can be performed to assess how likely the effort was to detect an existing effect (what power the effort had) given the sample sizes used for and the variability among replicates in the various groups. Over time, however, a priori power analyses have generally come to be regarded more favorably than post hoc analyses. A priori analyses can tell managers and researchers what level of effect size (i.e., only if a 50-percent difference exists) can be detected for given levels of power, sample size, and variability within groups. BLM managers should note that the error structure (e.g., partitioning of degrees of freedom) in these analyses reflects the design of their monitoring. In more complex designs, simulation analyses can be a more realistic alternative. Concepts related to power can improve setting and adjusting of AMLs by providing quantification of sensitivity of a monitoring system, that is, the ability to be an early-warning system of environmental change as opposed to confirming that a system has already been dramatically altered and perhaps crossed an ecological threshold.

The committee believes that the above principles could be more thoroughly integrated into the Wild Horse and Burro Program to increase the defensibility and scientific validity of management actions. Generally speaking, when the domain is as spatially vast and biotically heterogeneous as the area managed by BLM for free-ranging equids, a compromise approach can be taken. The compromise seeks to balance the incorporation of as much repeatability as possible (to permit analyses at numerous hierarchical spatial and temporal scales) with the ability to tailor management and monitoring efforts to local biota, interests, and priorities (to allow stakeholder involvement and investment and have relevance on both local and broader scales). That may mean, for example, that a core suite of field methods and monitoring indicators are used and that databases and analysis templates exist for all HMAs (Box 7-4). In contrast, individual HMAs or district offices may add to the core suite by creating standard monitoring approaches for monitoring locally important rare plants or animals or may add additional metrics for a given field method that are important to local interest groups.

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Validity for Stakeholders

Because AMLs are a focal point for controversy, it is important to develop and maintain standards for transparency, quality, and equity in the establishment, adjustment, and monitoring of AMLs. Research suggests that transparency is an important contributor to the development of trust between agencies and stakeholders (Rowe and Frewer, 2000; Webler and Tuler, 2000). The public should be able to understand the methods used and how they are implemented and should be able to access the data used to make decisions. Transparency will also encourage adherence to a high level of quality in data acquisition and use. The data and methods used to inform decisions must be scientifically defensible. Allocation of resources to management of free-ranging horses and burros takes place in a context of contending uses for BLM lands, all of which have some standing in the agency's charge for multiple-use management. The law makes clear that rangeland resources are to be protected from deterioration, but there is no known formula for creating a balance among such uses as cattle grazing, wildlife, hunting, mining, recreation, and free-ranging horses.

From submitted public comments and statements made by members of the public at information-gathering meetings, it is clear that stakeholders vary in their opinions about AMLs. Some believe that herd numbers should be higher and should take precedence over other rangeland uses administered and managed by BLM. Some believe that equid population size needs to be increased to protect genetic diversity or to ensure survival of the herds in an unpredictable environment. Some believe that herd levels are too high or that AMLs are not adequately adhered to and that free-ranging horses and burros are damaging habitat and taking resources away from other uses. Some argue that HMAs should be managed exclusively or primarily for horses and that other uses should be considered secondarily or excluded from allocation of forage and habitat resources. Different ideas about what constitutes rangeland health and a thriving natural ecological balance pervade such debates. The multiple, and often conflicting, views regarding AMLs emphasize the need for robust data and transparent processes in the setting of AMLs. Data and transparency will of course not fully resolve differing public viewpoints about allocation. Chapter 8 discusses approaches to working with stakeholders.

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BOX 7-4

Development of a Comprehensive Monitoring Strategy

BLM's 2011 report *Assessment, Inventory, and Monitoring Strategy for Integrated Renewable Resources Management* (BLM, 2011), also known as the AIM strategy, is part of a laudable effort to standardize and improve monitoring and assessment agency-wide. The strategy will help considerably with the transparency of how AMLs are set and adjusted, and the committee strongly supports the effort. As the document states, "the AIM Strategy is intended to reach across programs, jurisdictions, stakeholders, and agencies to provide data and information valuable to decisionmakers." The type of date to be acquired is described as follows

> To effectively manage renewable resources, the BLM needs information at multiple scales about resource extent, condition and trend, stressors, and the location and nature of authorized uses, disturbances, and projects, Acquiring and assessing this information will be accomplished through the integration of several fundamental processes, including the: (1) development and application of a consistent set of ecosystem indicators and methods for measuring them (i.e., core quantitative indicators and consistent methods for monitoring); (2) development and implementation of a statistically valid sampling framework; (3) application and integration of remote sensing technologies; and (4) implementation of related data acquisition and management plans (e.g., Geospatial Services Strategic Plan, Enterprise Geographic Information System architecture, and rapid eco-regional assessments). (BLM, 2011, p. 1)

The AIM strategy is based on the premise that a few carefully evaluated integrative indicators can be used to monitor complex ecological processes. Herrick et al. (2012) evaluated how to integrate such monitoring into a "holistic strategy for adaptive land management." The report points out that monitoring cannot be separated from its objectives and that processes to be monitored include driving processes, short-term responses, and long-term responses. In the context of free-ranging horses and burros, short-term indicators of management effectiveness would include vegetation measurements to learn whether offtake levels are as predicted and to see whether the horse and burro populations are within the bounds of AMLs. Long-term indicators would include measures of vegetation composition and cover, soil fertility and hydrological properties, and riparian ecosystem functioning. Monitoring must always include climate; it is the foremost driving variable because it occurs outside the realm of management but affects system dynamics. The set of indicators used in the AIM strategy should be reviewed for their applicability to the objectives of the Wild Horse and Burro Program.

The committee recognizes and the AIM strategy report observes that BLM has limited staff and resources and that it is therefore difficult to make complete, distributed, and recurring assessments and evaluations. The report makes suggestions for setting priorities for assessment, data collection, and increased use of remote-sensing technologies (BLM, 2011). The AIM strategy argues that "remote-sensing indicators can complement and even replace ground-based indicators where spatially and temporally consistent relationships can be established" (Herrick et al., 2012).

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CONCLUSIONS

Establishing and validating AMLs could involve six steps.

- Inventorying the landscape to assess the current states of the system quantitatively and qualitatively.
- Developing conceptual models and hypotheses for the processes that have led to the current states, particularly differentiating the relative roles of climate, horses and burros, livestock, wildlife, and other factors.
- Developing predictions of future changes based on conceptual and quantitative models, particularly of changes in response to alternative management practices that are hypothesized to lead to alternative desired states.
- Developing monitoring approaches to assess the success of the adopted management approach in bringing about a hypothesized, predicted change.
- Refining the models to improve accuracy and predictive power in setting AMLs.
- Providing transparent information about the data and decision-making process to stakeholders and obtaining their responses.

Essentially, this is an adaptive-management approach in that it calls for the development of a model or set of hypotheses, predictions of responses to management and environmental variables, learning from observed responses to management, and refinement of the model. It can fit a state-and-transition format.

To carry out this adaptive management process, BLM needs to solve five major challenges, which its handbook does not adequately address. Specifically, BLM should

- Increase the specificity and consistency of its protocols for establishing and adjusting AMLs.
- Develop a scientific approach to identifying objectively the constraints on equid populations and their explicit effects on the expression of natural processes under minimal management.
- Improve transparency of forage allocation.
- Manage for change and unpredictability in ecosystems and in social contexts.
- Improve the scientific validity of the concept of a thriving natural ecological balance.

Increased Specificity and Consistency

BLM should continue moving toward consistency in its protocols for setting and adjusting AMLs; repeatability is a hallmark of ecological monitoring. The BLM handbook should define terms explicitly and precisely, use them consistently, and include citations of research or methodological references in the text. An intermediate approach that achieves continuity and comparability among spatial resolutions for numerous ecological components and attributes (by using standardized methods) but allows for “stepping-down” or options in monitoring approaches to address issues or resources of local or regional concern may be an ideal compromise approach.

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Direct forage-production measures should augment the inference of production from visual estimates of percentage utilization; back-calculations involving total offtake based on equid counts, which may not be accurate; and assumed per-animal intake requirements. The use of small, temporary exclosures implemented in a spatially representative and statistically robust sampling design would provide more transparent and scientifically supported data. BLM should also develop approaches for quantitatively distinguishing horse or burro use from livestock and wildlife uses of forage, riparian areas, and other resources to verify utilization partitioning between livestock, horses, burros, and other herbivores. Table 7-2 describes various remote-sensing methods. BLM should use the ones that are applicable in monitoring and assessment for particular locations. GIS and spatial modeling could be used to map and overlay total and percentage utilization by the different species in the landscape. The committee believes that BLM should continue to develop the AIM strategy and to participate in development of state-and-transition models for western rangelands with NRCS.

As is the case with all large herbivores, free-ranging horses and burros not only use the environment but change it, and these effects need to be considered in assessment of AMLs. Effects of trampling and concentrated use on soils, insects, small mammals, and plants should be monitored in addition to forage consumption. Given BLM's multiple-use mandate, it may want to consider wider monitoring of one or more aspects of ecological condition and function that are not tied solely to equid health. Metrics related to such aspects should reflect the effects of processes that large-bodied herbivores impose on ecosystems—namely, patch creation, redistribution of nutrients via selective herbivory and later urination and defecation, compaction of upper soil horizons, and rubbing and trampling of vegetation. Although it can be challenging to measure ecological function directly, there are numerous methods and techniques for indexing ecological services, such as loss of soil by wind or water erosion; riparian-channel function; clean water; and physical structure of vegetation for perching, resting, or escape cover. Explicit attention to a reasonable subset of ecological services and ecosystem components is a good idea fiscally because conserving the potential of landscapes to remain resilient and to resist degradation may make expensive remediation, rehabilitation, or emergency recovery efforts unnecessary. Native threatened, endangered, and sensitive species require focused conservation attention. Such attention provides BLM with a mosaic of conservation elements that reflect diverse disturbance regimes, including parts of the landscape with no nonnative herbivores. Many disturbance-sensitive species seem likely to become increasingly rare, especially in the arid and semiarid landscapes of western North America that are being affected by invasive plants, climate change, and uncharacteristic fire regimes.

Water quality needs to be considered in addition to water supply in looking at availability for multiple species. Numerous methods have been developed to perform such monitoring, including ones that involve robust statistical designs, have been used specifically for grazing systems, and have been used by many local, state, and federal agencies that have diverse stakeholders (Beever and Pyke, 2004; Herrick et al., 2005a,b; Thoma et al., 2009). Consultation and collaboration with state and federal agencies charged with water quality responsibilities are necessary.

BLM should use a strategically placed network of large, long-term exclosures to quantify the long-term effects of free-ranging equids, livestock, and wildlife among HMAs, seasons, and years of different weather.

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The Challenge of Minimal Management

The way that AMLs are established and adjusted ensures that population growth rate is maximized (see Chapters 2 and 3). The density-dependent and environmental constraints that would reduce population growth rate and keep a natural population in check are precluded by management removals to avoid range deterioration. In a self-regulating, food-limited system, a lack of adequate food eventually suppresses the population if predation does not (see Chapter 3), and this sometimes results in effects on vegetation, soils, and other species. Removals to prevent those effects also prevent self-regulation of the horse population and in fact may allow it to reach its maximum potential growth rate. Therefore, there is a need to predict and state explicitly the population-level outcomes of managing for vegetation conditions that may be expected in a sustainable but differently functioning ecosystem that includes large herbivores.

A program of continuing, ad infinitum removals may not be economically sustainable or socially acceptable. However, letting horses become food-limited, having many horses in poor condition, and having horses die of starvation on the range are not acceptable to a sizable proportion of the public. The use of more benign methods to control population growth rate (such as contraception) may reduce (but perhaps not minimize) the level of management intervention while avoiding the unacceptable outcome of food limitation. Various fertility-control mechanisms are described in Chapter 4 with their consequences for population processes (see Chapters 3, 4, and 6) and genetic processes (see Chapter 5).

A scientific approach is needed to identify objectively the constraints on horse and burro populations and their effects on the expression of natural processes under minimal management. The ecosystem might look different and function differently in the presence of more minimally managed equid populations from how it does with no or markedly reduced populations, but it may nevertheless be sustainable over time. Such a scientific approach would provide a more solid justification of management interventions. For example, the anticipated effects of different equid densities on vegetation and rangeland ecosystem functioning should have a scientific basis. Likewise there should be a basis for assertions that barriers to dispersal or barriers to access to critical habitats preclude natural processes; and the assertions should be explicitly described and justified for a specific HMA on the basis of an understanding of how ecosystems would function with large herbivores and minimal management. Ideally, from a research standpoint, such questions would be addressed in a replicated spatial mosaic in which some herds or areas would be allowed to self-regulate and others would be managed as they are currently being managed.

Allocation versus Assessment

Transparent processes for allocation should be developed, such as participatory adaptive approaches. Participatory approaches are discussed in Chapter 8.

Managing for Unpredictability

The committee examined traditional pastoral systems adapted to arid ecosystems. BLM is charged with using “minimal” management for free-ranging horses and burros, so extensive pastoral systems adapted to arid rangelands that use little or no supplemental feeding, energy, and physical infrastructure might offer some insight into how to manage free-ranging equids.

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Traditional pastoral systems emphasize mobility, flexibility, and reserves (Oba et al., 2000). Mobility is the movement of animals from one area to another on scales from the local to across biomes; flexibility is being able to adjust boundaries, herd sizes and components, and timing and patterns of mobility. Reserves are areas that are grazed only during extreme events. The origins of those practices owe much to the natural movements and behaviors of free-ranging herds. Can BLM use this information in developing strategies for coping with the unpredictability of arid rangeland environments?

How much and within what kinds of bounds in nonequilibrium environments grazing influences vegetation trajectories is debatable; however, it is indisputable that there is great unpredictability in forage production and that grazing management cannot reduce it (Vetter, 2005). BLM's system of calculating forage availability without including years of high production attempts to adjust for this unpredictability by removing high-productivity years from the calculation; however, there will always be extreme events in nonequilibrium conditions. Even with a conservative approach, an important lesson from traditional pastoral systems is that the extreme events need to be planned for and that flexibility in numbers, timing, and boundaries is important. From the theoretical developments in rangeland ecological dynamics, it is also known that some sites will be permanently altered by unpredictable events. There will be a constant need for adaptation, so an adaptive-management process for setting and adjusting AMLs should be explored.

In addition to intensive monitoring of grazing utilization, rangeland ecological condition and trend, actual use and climate data, using NRCS ecological site descriptions and associated state-and-transition models for horse-occupied habitat would not only help to standardize ecological information agency-wide, but it would build on substantial previous work and facilitate use of the already existing National Resource Inventory database. That would provide value to the consistent investment by BLM that is needed at this time.

Ecological site descriptions are land-classification systems that identify and stratify lands on the basis of soil-, climate-, and herbivory-influenced ecological potential and ecosystem dynamics. State-and-transition models are included in individual ecological site descriptions that characterize thresholds, community phases within states, and irreversible transitions that degrade ecological processes and lead to alternative states (Stringham et al., 2003). In fact, BLM has already recognized the need to develop such models for BLM lands in its 2011 AIM monitoring strategy. Conceptual ecological models based on science and other expert input are being developed to provide a common language that addresses ecosystem sustainability, a means of identifying indicators of key ecosystem attributes, and a basis for resource decisions predicated on maintaining or restoring ecosystem capacities.

Managing for a Thriving Natural Ecological Balance and to Prevent Rangeland Deterioration

If maintaining a thriving natural ecological balance and preventing rangeland deterioration are to be used as scientific justifications for setting AMLs, these goals need a more scientific basis and clear definition. Recently developed concepts that might be of use in helping to set and adjust AMLs include those of ecological sustainability (Smith et al., 1995; Turner et al., 2003; Weltz and Dunn, 2003; Mitchell, 2010) and ecosystem resilience (Briske et al., 2008; Carpenter et al., 2001; Walker et al., 2006). As those concepts are developed and tested

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scientifically, adopting a sustainability or resilience framework would be a marked advancement, and it would be more likely that such a framework would have a credible scientific basis.

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8

Social Considerations in Managing Free-Ranging Horses and Burros

This chapter focuses on the Bureau of Land Management (BLM) request for guidance on addressing divergent and conflicting perspectives about free-ranging horse and burro management and on considering stakeholder concerns while protecting land and animal health.

BLM is obliged to manage free-ranging horse and burro populations in a way that satisfies the requirements of the Wild Free-Roaming Horses and Burros Act (92 P.L. 195). In making decisions about how to do so, it must also address the public's concerns and expectations under the National Environmental Planning Act (91 P.L. 190). As was pointed out in Chapter 7, the Wild Free-Roaming Horses and Burros Act leaves considerable room for interpretation of its mandates. In 1982, the National Research Council noted that public opinion was the "major motivation behind the wild horse and burro protection program and a primary criterion of management success," suggesting that control strategies must be responsive to public attitudes and preferences and could not be based only on biological or cost considerations (NRC, 1982, p. 54).

A variety of stakeholders want to participate in shaping policy and management decisions before proposed actions are taken, and there are ways for BLM to make use of their input. This chapter discusses several approaches for improving communication with the public and leveraging public participation to increase confidence in decisions about the free-ranging horses and burros under BLM management. While not repeating information easily available elsewhere, the report highlights important elements of various techniques and approaches to working with the public.

The possible approaches include conducting research to understand stakeholder values and the economics of different management regimes better; using *appreciative inquiry* to reduce the tension between polarized views; and creating opportunities for greater public participation through *structured decision-making, adaptive management,* and *citizen science*. The likelihood of success in improving communication, earning the support of different segments of the public, and improving management decisions, will be substantially increased if the activities to engage the public are themselves planned, evaluated, and monitored with public collaboration under the guidance of practitioners of social science with a process called *analytic deliberation*. Using

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those tools successfully will require BLM to make a commitment to public engagement and provide the staff and resources to enhance the potential for success.

DISPARATE VALUES RELATED TO FREE-RANGING HORSES AND BURROS

In a comprehensive study of attitudes toward animals, Kellert and Berry (1980) found that of 50 species of animals, the horse was the second-most liked animal by U.S. respondents, behind only the dog. Horses maintain immense cultural value as symbols of grace, beauty, companionship, and courage (Nimmo and Miller, 2007; UHC, 2009).

Given the complexity of issues surrounding free-ranging horses and burros, it is not surprising that Nimmo and Miller (2007) refer to them as having a pluralistic status: their bodies and behavior are sites of conflict. Various members of the public (including all those interested in or affected by a decision [Dewey, 1923]) differ in the values that they attach to free-ranging horses and burros, and some parties have strongly held perspectives on the issue (Symanski, 1994; White and Ward, 2010). In some citizen groups, horses are highly valued and beloved animals that should receive a greater share of BLM resources. In other organizations, free-ranging horses are competition for agriculture and wildlife and an interloper and stressor of fragile ecosystems.[1]

Differing values and beliefs regarding the "tameness" of animals may cause some stakeholders to value them differently. The dispute regarding whether the free-ranging horse is a re-established native species was reviewed by the National Research Council (1980, 1982), but there is more recent science on the issue (see Weinstock et al., 2005). The viewpoint that the free-ranging horses are an invasive species may factor into the decision-making of those who consider them an unnatural addition to the landscape of the United States (Coates, 2006; Rikoon, 2006; Nimmo and Miller, 2007). The view of the horse as an invasive species contrasts sharply with the iconography of the horse as central to the "traditional" West and native to the North American landscape.

Scientists note that the morphology of horses—including their flexible lips, elongated head, and digestive system—make them unique consumers on the American West landscape, using resources differently from other grazers, such as cattle (NRC, 1980; Beever, 2003). Horses consume more rangeland forage per unit of body weight than their ruminant counterparts (see review in NRC, 1980). That disparity in forage consumption is argued by many stakeholder groups to cause inequitable resource allocation because calculations used by BLM to set stocking rates consider a horse to be the equivalent of a cow-calf pair in terms of forage consumption (see Chapter 7).

These conflicts illustrate why policy to manage the free-ranging population should be carefully attentive to divergent public values. It is important to have a management plan that

[1]During the public comment sessions of the committee's meetings and in written comments submitted to the committee, it heard from representatives of such groups as the American Farm Bureau Federation, the American Society for the Prevention of Cruelty to Animals, the American Wild Horse Preservation Campaign, the Animal Welfare Institute, the Cloud Foundation, the Equine Welfare Association, the National Association of Conservation Districts, the National Cattlemen's Beef Association, the Nevada Cattlemen's Association, the Public Lands Council, the Western Watersheds Project, the White River and Douglas Creek Conservation Districts, and the Wildlife Foundation and from many members of the public expressing a wide variety of opinions on the management of horses and burros on public lands.

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accounts for the opinions and concerns of a variety of stakeholders—not only scientists and advocates but a variety of community members and parties that may have strongly held perspectives on the issue (Symanski, 1994; White and Ward, 2010). Decisions will have to take these values into account.

It is unlikely that all the values involved can be monetized in a way that is satisfactory to all parties, so use of economic policy tools such as benefit-cost analysis and contingent valuation, although potentially informative, is not able to resolve value differences fully and is not adequate to support decisions. In particular, a vocal, mobilized segment of the public argues that the free-ranging horse and burro population has the right to exist because the animals have intrinsic value. It considers free-ranging equids a "cultural service," and such services are notoriously hard to monetize (NRC, 2005; Reid et al., 2005; Chan et al., 2012). Beever and Brussard (2000) note that managers often cannot satisfy all interest groups, but they can help to shape public attitudes if they communicate research findings transparently.

However, the flow of ideas should not be unidirectional, from scientists to the public. It is important to recognize that values are the lens through which the public views scientific issues related to free-ranging horses and burros. Values come into play in creating conflict, for example, where the economic and regulatory environment determines in large part whether a species is considered a "pest" or a "resource" (Zivin et al., 2000) or "feral" or "native," with all the attendant implications for management (see Box 8-1). Conflict can also emerge with uncertain information or poor management performance. For the public, the priority that BLM gives to free-ranging horses and burros on federal lands, relative to other uses, reflects the values of BLM.

BOX 8-1

Management of Animals Perceived as both Wild and Feral

Polarization of opinion on the value of particular species has been demonstrated in community debates concerning the management of deer (Wright, 2009), feral pigs (Zivin et al., 2000), buffalo (Albrecht et al., 2009), feral cats (Lloyd and Miller, 2010) and free-ranging horses (Rikoon, 2006). The differing public opinions regarding the management of particular species, especially those considered to be feral, have inspired resource managers to adopt innovative approaches to managing wildlife populations. *Feral* describes animals that are wild but descended from domesticated stock. Recreational hunting has been proposed to manage feral pigs (Zivin et al., 2000), and initiatives to trap, neuter, and return feral cats are common across the United States (Lloyd and Miller, 2010). In each of those examples, the cultural role of a species in a given society is a factor in how individual animals are treated and managed, and different cultures have different views on management. Taking careful account of those views acknowledges that policy should inevitably be based on both scientific evidence and human values. As Bhattacharyya et al. (2011) noted, the debate over whether free-ranging horses are wild or feral is highly complex and involves a wide variety of issues, including the behavioral and physiological traits of different horse populations, their effects in different ecosystems, and disparate human values and perceptions of nature.

For example, some members of the public, arguing that horses should be treated as a native species, point to recent molecular genetic evidence showing that today's free-ranging horses are similar to the native horses that roamed North America before their extinction more than 7,000 years ago (Weinstock et al., 2005). Others say that they are domestic in that U.S. free-ranging horses descend from European stock and cannot be considered "native" because the

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complex of animals and vegetation has changed since horses were extirpated from North America. Whether the split between the ancient and modern lineages is sufficiently old for them to be considered two species still needs to be clarified (B. Shapiro, Pennsylvania State University, email communication, August 23, 2012). However, a more pertinent set of questions is related to whether the distinctions should matter and, if so, how in the management of free-ranging horse and burro populations.

Acquiring a better understanding of such perspectives and their implications for management policy was recommended by previous National Research Council reports (1980, 1982) that addressed BLM's Wild Horse and Burro Program. The reports highlighted the need for research into the social context for free-ranging horse and burro management, including a recommendation to fund studies that would evaluate what aspects of free-ranging horses and burros were most important to the public.

The 1980 report addressed social considerations. That report noted the lack of empirical data on public attitudes about free-ranging horses and burros or on the relative values associated with free-ranging horses. That committee noted one study by Rey (1975), who surveyed recreationists and other resource groups in the Pryor Mountains area regarding wildlife and the benefits associated with free-ranging horses. It also noted that other sociopolitical analyses had been written (see Appendix C of the 1980 report). That committee recommended research projects (a sentiment echoed in the 1982 report) to provide a base of socioeconomic and political data to facilitate decision-making in connection with equid management. Suggestions for research, listed by priority, were the following

- Taxonomy of values and benefits of free-ranging horses and burros.
- Costs of free-ranging horse and burro management alternatives.
- Economics of management alternatives drawn from proposed research programs.
- Public preferences for alternative management and control strategies.
- Analysis and evaluation of demands for excess free-ranging horses and burros.
- Nonmarket values of free-ranging horses and burros.
- Public attitudes, behaviors, and knowledge regarding free-ranging horses and burros.
- Conceptual development of public-rangeland management models. (NRC, 1980)

It is unfortunate that BLM did not conduct this suggested research because a better understanding of the knowledge and values that frame public opinion about free-ranging horses and burros would give BLM managers insight and possibly help them to find more ways to bring polarized groups into a deliberative process. Such research is needed to help BLM design constructive opportunities for public participation in BLM's decision-making process—a key to gaining public support for free-ranging horse and burro management.

When ecological science is combined with social science, an ecologically and sociopolitically sound management program is possible (Nimmo and Miller, 2007). The preceding chapters in this report and earlier reports by the National Research Council make it clear that decisions regarding the management of free-ranging horses and burros should draw on the best available scientific information. It is equally clear that scientists and managers will continue to make decisions despite unanswered questions and a high degree of uncertainty. For example, the effects of climate change on horse and burro habitats cannot be projected with certainty. Even as substantial effort is being allocated to "downscaled" climate models that will

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improve projections at scales useful for ecosystem management, uncertainty in projections of key parameters will persist (White and Ward, 2010). Fertility control also presents uncertainty. What is the timeline for a longer-term fertility-suppression drug to be developed and made available to BLM? Additional information is needed about how the various fertility-control treatments affect horse social behaviors and interactions, in addition to information about how the drugs are administered, in order to improve understanding of how fertility-treatment outcomes might compare to those from gathers.

One possible method to gather the latest information from experts and to focus it on a particular problem is to use a Delphi process. This process involves iterative engagement with experts via anonymous surveys or group meetings (Webler et al., 1991). The eventual outcome is a summary of agreement among the experts that has been steadily developed over the course of the process (Dietz, 1987a; Rowe and Wright, 2001).

As more is learned and uncertainty is reduced, will it reduce controversy about management strategies? Without understanding the reasons for differing values and coming to grips with why different publics see things in different ways, it will be difficult to build broader support for management decisions. The remainder of this chapter discusses ways of engaging the public in decision-making so that polarization can be reduced and BLM can formulate plans that draw on the research, experience, and values that are essential to informing decision-making. In order to create more socially and ecologically sustainable approaches to free-ranging horse and burro management, it is necessary to increase levels of public acceptance of and confidence in BLM management decisions by engaging the public in a clearly articulated and transparent process of public participation and decision-making.

THE CASE FOR PUBLIC PARTICIPATION

During the committee's information-gathering sessions, some individuals and groups provided comments to the committee that expressed a lack of confidence in BLM management, some using the phrase "managing to extinction" to characterize the agency's attitude, and some taking issue with the agency's transparency, whether in reporting accurate numbers of horses on the range, projecting reproduction and population growth, describing the underlying rationale for the development of appropriate management levels (AMLs), reporting the effects of roundups on animal welfare, managing the health of horses in captivity, or assessing the physiological and behavioral effects of different contraceptive approaches. Some of those issues involve scientific information examined in the preceding chapters of this report, in which the committee found varied completeness, consistency, uncertainty, and transparency (Box 8-2). Left unaddressed, or at least unacknowledged, such shortcomings in the scientific information used for management undermine confidence in agency decisions, especially when it seems that efforts are made to reduce the visibility of the knowledge and information gaps.

BOX 8-2

Transparency

Transparency involves openness, communication, and accountability and is important in building trust and relationships with the public. Considered essential to effective public participation, a transparent process ensures continuing communication and public access to information and is critical from the earliest through the final stages of the process (NRC, 2008).

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Attempts to resolve conflicts in which values and opinions about land management are polarized often turn to principles of community-based public participation and engagement in decision-making. Slocum and Thomas-Slatyer (1995) argued that communities need to be empowered to participate in decisions that affect them because they have knowledge relevant to the solutions needed. Free-ranging horse populations are situated in specific geographic locations, and it is necessary that local communities that interact with the animals or are affected by management decisions be represented in some way in the decision-making process, along with nonlocals, including national lobbying groups. A community-based approach can incorporate science, the mass media, and public opinion into the decision-making process, and this facilitates a deeper understanding of the issue at hand. However, although public participation and engagement are popular phrases in policy discussions, they have not always been implemented in ways that enhance knowledge and public support. Effective public participation can be identified by the degree to which consensus is able to emerge from the gathering, sharing, and processing of pertinent information by and with all the relevant parties (Rowe and Frewer, 2005).

The literature provides numerous examples of effective engagement of public values in making natural-resources policy decisions. The next section begins with a review of public engagement in framing plans for managing free-ranging horses in the United States, Australia, and New Zealand, and then discusses the use of specific processes to engage the public in wildlife management.

Studies of Public Participation in Management of Free-Ranging Equids

In a study of public engagement in management of free-ranging horses in Australia, Chapple (2005) discovered that when top-down management systems and aerial culling were imposed on free-ranging horses, there was a lack of community support. The author found that the role of expert scientific advice was insignificant in the decision process (a policy ban on aerial culling was instituted contrary to scientific recommendations) and that there was a low level of commitment to community involvement that alienated community members. In addition, community forums did not adequately respond to community concerns.

Nimmo and Miller (2007) conducted a comprehensive review of the human dimensions of management of free-ranging horses in Australia, New Zealand, and the United States. They noted that no studies of the human dimensions of managing free-ranging horses appeared in the peer-reviewed literature at the time of their writing, although horses had been the focus of some “gray literature” social research. That literature included the results of opinion surveys in a number of locations, including Kellert and Berry’s 1980 survey. In 1997, free-ranging horses were considered pests by 13.6 percent of survey respondents in Victoria, Australia (Johnston and Marks, 1997); by 2005, that number had risen to 21 percent (Nimmo, 2005). In the same study, 50 percent of respondents indicated that aerial culling was “never acceptable” and that alternative (nonfatal) methods were preferred. Most of those surveyed by Fraser (2001) responded that they would like to see free-ranging horses in the New Zealand countryside. Finch and Baxter (2007) found that most Queensland respondents thought that free-ranging horses were not pests (25 percent) or were only slight pests (26.1 percent). In New South Wales, 40 percent of respondents indicated a desire for free-ranging horses in national parks (Ballard, 2005).

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Nimmo and Miller (2007) discussed case studies in each country. They found, not surprisingly, that in the United States there has been great contention over the management of free-ranging horses. The 1971 Wild Free-Roaming Horses and Burros Act states that the horses are a "national treasure" and a symbol of the "historic and pioneering spirit of the West." When BLM took action in 1978 (Public Rangelands Improvement Act, 95 P.L. 514) to reduce the increasing numbers of free-ranging horses, the American public objected (Symanski, 1996).

In Australia, the Australian Conservation Commission of the Northern Territory (now the Parks and Wildlife Commission of the Northern Territory) offered to assist pastoralists who wanted free-ranging horses gone from their land when it discovered that free-ranging horse populations had reached over 200,000 in the mid-1980s. However, animal-rights organizations around the world objected, and the International Court of Justice for Animal Rights tried and convicted members of the Australian government for the massacre of horses (International Court of Justice for Animal Rights, 1987; Symanski, 1994). Eventually, a government report concluded that reducing horse populations was most effectively accomplished by aerial culling, but that this course of action, and any management plan for horses, needed to involve all interested parties (Dobbie et al., 1993). The targeted shooting of animals was supported by the Australian Veterinary Association (AVA) at the time, which deemed shooting acceptable as a last resort option. AVA stated that only trained, licensed marksmen familiar with horse anatomy should take part in well-regulated culls (AVA, 2002). The culling of 600 horses in New South Wales in 2000 resulted in an outcry from citizens and social groups, as there were reports of inhumane practices (Reuters, 2000) and interested parties were not adequately consulted in advance (Berman, 2011). The cull occurred in an area of habitat that AVA said was not suitable for aerial culling and was one of the largest removals that had ever been conducted. Since then, additional methods of managing the horses have been explored, including passive trapping and rehoming (adoption). The Australian management agency formed a working group to involve local communities in management decisions about free-ranging horses.

In New Zealand, the southern Kaimanawa Mountains hosted a small population of free-ranging horses in the early 1980s. Because of their low numbers (under 200), the horses were given protected status, and over the next decade the population grew to an estimated 1,100. Concerns about deteriorating range health caused by the growing horse population led to the formation of a working group that amended a management plan. Aerial culling was one of the management methods included in the plan, but it engendered public opposition. The New Zealand government compromised and, in place of aerial culling, implemented a gather and adoption plan. The first year saw over 1,000 animals removed; some were adopted, and others were slaughtered. Since then, the program has removed about 100 animals each year, most of which have been adopted out successfully.

Bureau of Land Management Processes for Engaging the Public

There is a continuum of potential levels of participation in decision-making processes, ranging from simply informing stakeholders to sharing decision-making authority with them (Figure 8-1). BLM tends to operate in a consultative manner, mid-way along the continuum. Although public participation in federal land management is mandated by the National Environmental Policy Act of 1969 (NEPA), the law has been interpreted to mean that the agency must inform the public and listen to comment (Moote et al., 1997).

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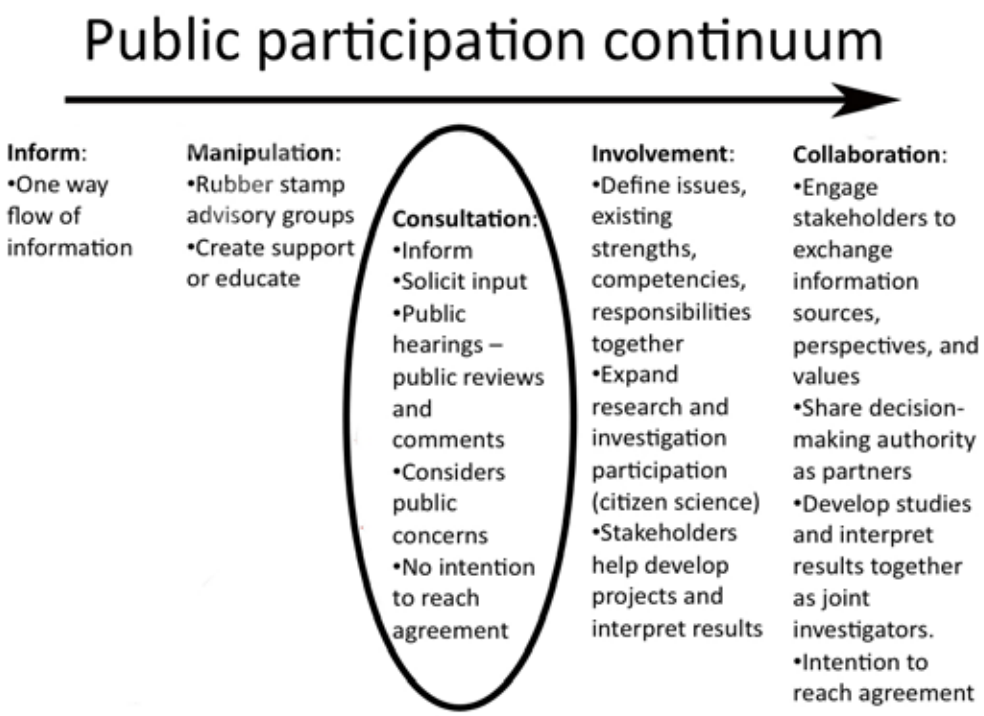


FIGURE 8-1 Types of public involvement in agency decision-making.
SOURCE: Adapted by A. Sulak from CEQ (2007) and Germain et al. (2001).

NEPA requires that "all federal agencies involve interested publics in their decision-making, consider reasonable alternatives to proposed actions, develop measures to mitigate environmental impacts, and prepare environmental documents which disclose the impacts of proposed actions and alternatives."[2] The agency publishes an environmental impact statement or an environmental assessment showing what the environmental effects of a proposed action will be or showing "no significant impact" and requests public comments and information.

BLM can consult with the public in many different ways within the confines of the Federal Advisory Committee Act (FACA) of 1972 (92 P.L. 463) and the Administrative Procedures Act (APA) of 1946 (79 P.L. 404). Under FACA, a process for establishing, operating, overseeing, and terminating advisory bodies is formalized with the goal of ensuring that advice by the various advisory committees formed over the years is accessible to the public. APA requires that agency rules line up with the U.S. Constitution and with an agency's statutory commands from Congress. Legal scholars have argued that final decision-making authority must remain with the agency and cannot be devolved or abdicated outside Congress's reach (Coggins, 1995, 1999; Moote et al., 1997). One study concluded that the "concept of shared decision-making is in direct conflict with federal officers' responsibilities to Congress" (Moote et al., 1997). These restrictions have been interpreted as limiting BLM to a "consultation" model for public interaction. Whatever the participatory or collaborative model, agency personnel should be absolutely clear about the laws, regulations, and policies at play so the collaborative solution falls within acceptable legal parameters (BLM, 2007).

[2]National Environmental Policy Act. http://www.blm.gov/wy/st/en/info/NEPA.html, accessed February 19, 2013.

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BLM has worked to bring stakeholders into the decision-making process through advisory boards and committees, such as the Wild Horse and Burro Advisory Board, a national BLM advisory body that holds public meetings, and the Resource Advisory Councils (RACs), 29 regional and state groups that advise BLM on resource-management issues. Such entities do not make decisions but have input into them.

The Wild Horse and Burro Advisory Board meets regularly to discuss issues and to advise BLM. Board members are selected to represent various interests: free-ranging horse and burro advocacy groups, free-ranging horse and burro research institutions, veterinarians, natural-resources organizations, humane advocacy groups, wildlife associations, livestock organizations, and the general public. Board members are appointed by the secretary of the Department of the Interior and the secretary of the Department of Agriculture. Board meetings and calls for board nominees are published in the *Federal Register*.

The RACs in the western states have direct effects on horse and burro management because of their role in the development of Land Health Standards and Guidelines. These guidelines are generally used to assess whether the "rangeland deterioration" prohibited by the Wild Free-Roaming Horses and Burros Act of 1971 (as amended) is taking place. The RACs also advise BLM on other aspects of managing free-ranging horses and burros. In fact, RAC recommendations address all public-land issues, including land-use planning and recreation. According to the website for the RACs,

> Each RAC consists of 12 to 15 members from diverse interests in local communities. . . . Each Council must include representatives of three broad categories: commercial/commodity interests; environmental and historical groups (including wild horse and burro and dispersed recreation); state and local government, Indian tribes, and the public at large.[3]

BLM has attempted to go beyond consultation to more collaborative "land use planning processes," as described and recommended in its *Land Use Planning Handbook* (BLM, 2005). AMLs for free-ranging horses are established and maintained through a land-use planning (LUP) process, the multiple-use decision-making process[4] that is associated with an allotment evaluation, or both processes. Appendix A of the *Land Use Planning Handbook* provides a guide to collaborative planning that states that "collaboration implies that Tribal, state, and local governments, other Federal agencies, and the public will be involved well before the planning process is officially initiated, rather than only at specific points stipulated by regulation and policy" (BLM, 2005, p. A-1). That document makes a number of recommendations and highlights the legal and political responsibilities of BLM, including consultation with tribes. It recommends inclusiveness, accountability, full disclosure of agency responsibilities and roles of the participants, and recognition of the limitations of the process.

Although the objectives of the LUP process include better decisions, improved relationships, and leveraged resources, many of the frustrations experienced by stakeholders (as described to the committee in information-gathering sessions) are related to the opacity of the

[3]Resource Advisory Councils. http://www.blm.gov/wo/st/en/info/resource_advisory.html, accessed November 20, 2012.

[4]Available online at http://www.blm.gov/nv/st/en/prog/grazing/multiple_use_decision.html/. Accessed October 11, 2012.

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sources of information that feed into the process of establishing AMLs, which undermines the transparency of the LUP process.

Finally, although volunteer and observation programs are not decision-making efforts, they do facilitate direct interaction with the public and may help to build trust and relationships with stakeholders. BLM has a volunteer program that engages the public in the adoption program in particular. Volunteers mentor those who are adopting horses, help with compliance checks on adopted horses, and help with rangeland improvement. When it is feasible for horse and human safety, the public may be invited to observe gathers.

Methods for Successful Public Participation

Moving into more collaborative processes would be helpful in creating long-term constructive relationships with the concerned public. Although it is true that not all decisions are appropriate for collaborative processes, the committee believes that in the case of planning for the management of free-ranging horses and burros, substantive public participation is warranted because of the depth and breadth of public concern and the need for a long-term, sustainable program. In all these processes, however, the limitations on what BLM can and cannot do collaboratively should be clear to all participants from the outset.

There are a number of well-developed methods for encouraging public participation in public-lands decision-making and management. The goal is not only to reduce conflict but to improve the quality of decisions. Here, the committee reviews four methods of participatory decision-making that focus on helping the public, scientists, and managers to work together: appreciative inquiry, structured decision-making, participatory adaptive management, and analytic deliberation. The four frameworks are not mutually exclusive; many of their criteria overlap. For example, the adaptive-management model in which management is designed as an experiment could be part of any of the other three decision-making processes. After discussing the four approaches, citizen science is reviewed. There is considerable interest emerging in citizen science; it is one way for the public to participate in science as part of participatory adaptive management or any other decision-making framework.

At the heart of all the participatory processes is the fostering of the development of a shared understanding of the ecosystem, of an appreciation of the viewpoints of others, and of working relationships, which some characterize as based on trust but which the committee might argue may be based on transparency and balance of power. Some researchers have described the development of a “hybrid culture” of shared norms and values as a key to creating an effective management and decision-making process with participants of diverse backgrounds and viewpoints (Earley and Mosakowski, 2000; Sulak and Huntsinger, 2012).

Appreciative Inquiry

The contentions that often divide the public from experts can lead to resentment on the part of all involved, whether because of the perception that public participation is a hindrance to an investigation or the notion that experts consult with the public only to push an agenda (NRC, 2008). As part of a well-planned initiative, the Cooperrider et al. (2008) tenets of appreciative inquiry (AI) can be used to ameliorate some of the tensions that may arise when people who have differing opinions are asked to weigh in on a highly contested subject. AI advocates for the reframing of problem statements to focus foremost on a community’s strengths. Every project,

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this approach argues, should begin with appreciation of what is working well in the social system. Central goals of AI are to identify and describe the characteristics of the system that are positive and to reinforce the capability of society members as agents of change and transformation (Cooperrider et al., 2008).

Rather than initially "problematizing" the issue of free-ranging horses and burros with negative language, AI encourages members of the public and investigators to look at what is functioning well in the system and to build on existing strengths. For example, rather than focusing exclusively on the fact that there are more horses in need of adoption than there are adopters, a task force using AI may reframe the problem statement to acknowledge that thousands of horse owners in the United States have taken an active role in horse management by choosing to adopt free-ranging horses and that these adopters could potentially be used as a resource in other aspects of the management plan. The tone and frame of community engagement can set the stage for cooperation, trust, and collaboration. AI is intended to inspire members to work within a framework of positivity and common experience and could be useful in engaging people who might have to capitulate on their views. In an AI process, Wright (2009) used "deliberative dialogue" to resolve citizen conflict around the contested issue of the management of free-ranging deer in a local community. A series of key steps were initiated to achieve deliberation: awareness and education, task-force planning and proposal development, submission of task-force proposal to public for input, presentation of task-force proposal to the city council, implementation of the plan, and monitoring of actions and plan modification. The public forums were held on three occasions, which gave residents a chance to voice their views. During the forums, citizens were urged to consider the long-term and short-term effects of each tactic in their deliberations. Wright concluded that dialogue and deliberation as problem-solving tools must be grounded in the historical and material realities of individuals as well as the situated character of local knowledge. The participants found that they could elucidate their opinions and values more effectively after the dialogue and deliberation of the forums and in turn were more able to comprehend the ideals and concerns of their peers. In short, having an improved understanding of others' experiences can reduce conflict among stakeholders.

Structured Decision-Making

Structured decision-making is a process by which a problem is methodically analyzed and decisions are reached to facilitate the achievement of clearly defined objectives. The process is made up of simple steps that allow flexibility in problem-solving and deals directly with the issues of transparency and legal compliance. It incorporates public opinion, while maintaining a firm foundation in scientific evidence. Each component of the decision-making process—objectives, available actions, and potential outcomes—can be analyzed separately for more effective execution. This method of decision-making lends itself particularly well to complex issues that involve government agencies, public stakeholders, and the scientific community.

Berkes (2010) exemplifies structured decision-making by outlining the stages of incorporation of community participation and adaptive comanagement into environmental conservation: deliberation; visioning; building social capital, trust, and institutions; capacity-building through networks and partnerships; and action-reflection-action loops for social learning. For example, Blumenthal and Jannink (2000) documented ways to incorporate change and growth into existing program models by continuous monitoring, re-evaluation, and information collection.

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In the case of management of free-ranging horses, Chapple (2005), like Blumenthal and Jannink (2000) and Berkes (2010), recommended implementing policy that can adapt and adjust to new information, feedback, and knowledge. Analysis of a management program's effectiveness is a part of the cycle, and new data gleaned through careful monitoring can be incorporated into practice to make an initiative more effective (Kelsey, 2003; Garmendia and Stagl, 2010). Stringer et al. (2006) documented that different types of stakeholders can play key participatory roles at different stages in the management process and that multiple participatory mechanisms can be used at different stages. Although there is a demonstrated need for adaptability in participatory research, strong planning and structure ensure that adaptive measures fall within sound program designs (Von Korff et al., 2010).

Planning might include research on how to approach the next step of a discussion with the public. For example, to analyze which approaches to communication about risk would improve decision-making, Arvai et al. (2001) had six to eight groups of seven to 10 people participate in one of two types of risk-communication workshops: alternative-focused (risk-focused) and value-focused. By comparing groups that focused on potential adverse outcomes with groups that reframed the issue with favorable outcomes, the authors determined that focusing on values led to more thoughtful discussions and better-informed decisions. Thus, the exploration, a priori, of the terms in which a problem is framed for the public discussion is a possible step in the use of structured decision-making. That is an example of how background research like that recommended by previous National Research Council reports (NRC, 1980, 1982) could help in preparation for public participation.

Because of its somewhat formulaic and hierarchical nature, structured decision-making lacks the flexibility of some other participation processes, such as adaptive management and analytic deliberation.

Adaptive Management

Holling (1978) and Walters (1986) first developed adaptive management for the stewardship of natural resources, and it has since been used for agricultural and sociopolitical issues (Lee, 1994; Stankey et al., 2005). A process that emphasizes flexibility and continual learning (Holling and Meffe, 1996; Walters, 1997), the adaptive-management framework, as originally proposed, calls for designing management actions as experiments, learning from the experiments, and adjusting management as more is learned about the system (Herrick et al., 2012). Gradually, a model or body of knowledge about a system that enables improvements in management capacity is developed. Adaptive management has been identified as particularly appropriate in the context of climate-change uncertainty (Nichols et al., 2011) and could be adapted for such situations as management of free-ranging horses and burros, in which knowledge of the complex interactions between free-ranging equids and their environment and other species is insufficient, the climatic trajectories of arid rangelands are in flux, and the annual variation in weather, forage production, and horse populations is high and difficult to predict. Chapter 7 discusses the potential use of adaptive management for examining the basis of setting AMLs. Involving the public, scientists, and managers in adaptive management is suggested as a means of creating an enhanced learning-based and research-based setting for management (McLain and Lee, 1996).

In a participatory process, stakeholders may participate in the setting of goals, design of experiments, monitoring and interpretation of results, and adjustment of management practices to

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various degrees that depend on the situation. Indigenous knowledge can be incorporated in an adaptive-management approach but, like scientific perspectives, needs to be tested (Toledo et al., 2003). Rather than a process of trial and error, adaptive management is ideally a hypothesis-driven exercise carried out by managers and stakeholders (Walters, 1997) who use controls and replication.

A participatory adaptive-management process for the setting and adjustment of AMLs, for example, might involve testing the effects of different herd levels on wildlife habitat. With the objective of meeting the stipulation of the Wild Free-Roaming Horses and Burros Act of 1971(as amended) to protect wildlife, stakeholders—including scientists, the public, and managers—could decide on an AML to be tested, examine together the outcomes of monitoring (or even participate together in monitoring), and, on the basis of the results, propose adjustments of the AML. For adaptive management to be effective, objectives and hypotheses must be clearly defined. Agreed-on goals or objectives will serve as the baseline against which changes or progress can be measured (Stankey et al., 2005). As noted in Chapter 7, the explicit incorporation of measures of uncertainty into studies is essential.

Adaptive management could provide much-needed transparency for BLM's management of free-ranging horses and burros. Because it is a flexible system (Holling and Meffe, 1996; Huntsinger, 1997), it allows managers to experiment with a variety of policies and actions to determine which provide the desired management outcomes (Walters, 1997). That could be particularly useful for BLM, given the number and variety of stakeholders involved in this issue. BLM could implement "experimental" policies to determine whether they produce desired outcomes. Later, management actions could be adapted on the basis of the previous outcomes, and BLM could provide a clear view of its practices to stakeholders.

However, even complete transparency in practices and information sources will not resolve the issues faced by BLM because of fundamental differences in values unless stakeholders engage with and buy into the process. Hence, public participation is crucial in any adaptive-management process that involves free-ranging horses and burros. Recognizing that different groups bring different values and agendas to public participation, adaptive management can foster both a common understanding and acknowledgement of others' views (Fernandez-Gimenez et al., 2008) and increase confidence in the information generated.

An example of the importance of participation in adaptive management was provided by Kelsey (2003), who argued that it must be used in conservation measures to incorporate lay and traditional ecological knowledge that may not be available to scientific authorities. In a study of Canadian biodiversity, traditional knowledge was found to be underrepresented and undervalued despite its important implications for conservation. To remedy that knowledge gap, public participation and the inclusion of other stakeholders were used.

Williams (2011a) provided a precautionary note, pointing out that Gunderson (1999) reported that for some institutions engaged in natural-resources management, history and tradition may pose barriers to implementing adaptive-management approaches that require greater flexibility and tolerance of uncertainty. Yet Williams (2011a) concluded that "utilizing management itself in an experimental context may in many instances be the only feasible way to gain the understanding needed to improve management."

Adaptive management in its original form—management as "experiments"—has also been criticized for its expense and for the length of time it takes to adjust management on the basis of field experiments (Herrick et al., 2012). Various alterations of the original model have been promoted, including "passive" adaptive management that does not require experiments

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(Walters, 1986; Williams, 2011b) and incorporation into a "holistic" framework (Herrick et al., 2012). The recently published Department of the Interior Applications Guide for adaptive management provides guidelines for federal agencies, including BLM, on using adaptive management (Williams and Brown, 2012).

Analytic Deliberation

For more than a decade, the National Research Council has urged an approach to environmental and resource-management problems that has come to be called analytic deliberation (AD) (NRC, 1996, 1999, 2007, 2008, 2011). AD takes its name from a hybrid of scientific analysis and public deliberation, two activities that have often been pursued as separate endeavors by resource-management or regulatory agencies but that can be mutually informing and supportive when conducted in coordination with one another. In a sense, the AD approach acknowledges that the public has a form of expert knowledge that complements and informs scientific analysis (Dietz, 1987b). The AD approach emphasizes the importance of sound science but also recognizes that there will be multiple views on the part of the public and that the public can be skeptical of scientific analysis applied to policy and management decisions.

A substantial body of research, summarized in *Public Participation in Environmental Assessment and Decision Making* (NRC, 2008), shows that carefully designed AD processes that engage the public can substantially reduce conflict over natural-resources decision-making. In particular, that report concluded that in the case of local to regional issues, where face-to-face engagement over time is feasible, it is possible to develop highly effective processes for public participation that not only improve the quality of agency decisions but make the decisions more transparent from the perspective of the citizens involved, increasing the chances that the decisions will be supported and implemented. Many of the issues involved in horse and burro management are local to regional in scope—for instance, management techniques that are suitable for one ecosystem may not be applicable to another, and different Herd Management Areas (HMAs) will be managed for different needs and uses (U.S. Congress, 1997). Those are the types of cases in which AD has been used most effectively.

There are four principles for the design of a participatory process: inclusiveness of participation, collaborative problem formulation and process design, transparency of the process, and good-faith communication (NRC, 2008). The AD approach calls for iterative interactions between agency representatives, the public, and social-science practitioners in a shared stewardship of the participatory process itself, beginning when a problem or question to be addressed is defined (Dietz and Stern, 1998; Tuler and Webler, 1999; Webler and Tuler, 2005; NRC, 2008). In a "best-process regime," the participants collectively identify important difficulties in or challenges to the effectiveness of the process on which they are about to embark. Challenges might include, for example, a high level of uncertainty related to the available scientific data, legal constraints on the agency, and disparate views of the participants. Box 8-3 contains a list of questions suggested for the diagnostic phase of the process to prepare a solid footing for effective participation (NRC, 2008). After diagnosis, participants collaboratively design tools and techniques for addressing or mitigating the challenges identified, whether joint fact-finding about the uncertainty of information, ensuring the airing of all views, or, in light of disparate values, seeking commonality in outcomes. Deliberative or social mapping could provide a way to assess the areas in which stakeholders hold similar or divergent opinions (Fiorino, 1990; Burgess et al., 2007) and what key issues are most important to them. With this

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information, outcomes can be used to inform further actions (Burgess et al., 2007). As the participatory process (in whatever format it may take) unfolds, the practitioners, participants, and agency representatives continue to evaluate the process, formally or informally, to understand whether and how well the previously identified hurdles are being overcome and to adapt or implement changes when they are needed. Using AD to shape and monitor the participatory process helps to build public confidence in the scientific analysis for those who might otherwise be skeptical or simply reject the science underpinning management decisions (Chilvers, 2007), reducing the extent to which value differences are confused with differences about facts (NRC, 2008).

BOX 8-3

Diagnostic Questions to Assess the Challenges to Public Participation in a Particular Context

Questions about scientific context

1. What information is currently available on the issues? How adequate is available information for giving a clear understanding of the problem? Do the various parties agree about the adequacy of the information?
2. Is the uncertainty associated with the information well characterized, interpretable, and capable of being incorporated into the assessment or decision?
3. Is the information accessible to and interpretable by interested and affected parties?
4. Is the information trustworthy?

Questions about convening and implementing agencies

1. Where is the decision-making authority? Who would implement any agreements reached? Are there multiple forums in which the issues are being or could be debated and decided?
2. Are there legal or regulatory mandates or constraints on the convening agency? What laws or policies need to be considered?

Questions about the abilities of and constraints on the participants

1. Are there interested and affected parties who may have difficulty being adequately represented?
    a. What does the scale of the problem, especially its geographic scale, imply for the range of affected parties?
    b. Are there disparities in the attributes of individual potential participants that may affect the likelihood of participation?
    c. Are there interests that are diffused, unorganized, or difficult to reach?
    d. Are there disparities across groups of participants in terms of their financial, technical, or other resources that may influence participation?
2. What are the differences in values, interests, cultural views, and perspectives among the parties? Are the participants polarized on the issue?
3. Are there substantial disparities across participant groups in their power to influence the process?
4. To what degree can the individuals at the table act for the parties they are assumed to represent?
5. Are there significant problems of trust among the agency, the scientists, and the interested and affected parties?
    a. Are there indications that some participants are likely to proceed insincerely or to breach the rules of the process?
    b. Are some participants concerned that the convening agency will proceed in bad faith?
    c. Do some participants view the scientists as partisan advocates and so mistrust them?

SOURCE: NRC, 2008, Table 9-1.

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The 2008 National Research Council report on public participation in decision-making developed key principles for carrying out public involvement that are particularly relevant to the social considerations aspect of the Wild Horse and Burro Program (see Box 8-4).

BOX 8-4

Basic Principles for Carrying Out Public Involvement

1. *Clear purpose:* The convening organization and the participants should agree on the goals and objectives, the scope of legally possible actions, and the constraints on the process.

2. *Agency commitment:* The agency responsible for the relevant decision should be committed to the process and take seriously the results.

3. *Adequate capacity and resources:* The process should be scaled to the level of resources available, but also the convening organization should make sure the resources are sufficient to run an acceptable process. Resources include more than just money; having continuity of staff is also known to be important.

4. *Timeliness in relation to decisions:* The process should be designed so that it can come to closure in time for the results to have an influence on the decision-making.

5. *Focus on implementation:* Processes should be designed to relate in clear ways to the decision. Agencies need to be clear about what they can and cannot do.

6. *Commitment to learning:* The process should be adaptable and should use mid-course formative evaluation to enable the convening organization to learn how to run a better process.

7. *Inclusiveness:* Better processes involve the full spectrum of interested and affected parties.

8. *Collaborative problem formation and process design:* People should be meaningfully involved early on to substantively shape the focus and structure of the process.

9. *Intense deliberation:* Processes are more successful when people spend more time in face-to-face interaction.

10. *Transparency:* It is better for processes to have clear objectives and purposes and for the conveners to give clear information about the way the process will unfold, opportunities to participate, and information and other inputs that are available.

11. *Have a competent discussion:* This requires having transparent decision-relevant information and analysis, attending to facts and values, being explicit about assumptions, acknowledging uncertainties, having independent reviews, and iterating between technical analysis and stakeholder deliberation.

SOURCE: NRC, 2008.

There is a substantial literature describing the design of the analytic-deliberative process (Dietz and Pfund, 1988; Dietz and Stern, 1998; Renn, 1999; Tuler and Webler, 1999; Kinney and Leschine, 2002; Jasanoff, 2003; Webler and Tuler, 2005; Burgess et al., 2007; Chilvers, 2007). Box 8-5 describes two analytic-deliberative design recommendations that might serve as a

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starting point for BLM, but the committee emphasizes that the details of the design should be tailored to the specific context (NRC, 2008).

BOX 8-5

Examples of Specific Principles Suggested for Deliberative Policy Decisions

Dietz and Stern (1998, p. 442) provided four main principles to be considered in conflict over biodiversity policy.

- The deliberation should involve all perspectives that can offer insights into the policies under consideration.
- The deliberation should begin early, when the policy and scientific questions are first being formulated, and continue in iteration with other forms of analysis until a decision is made.
- The deliberative process must be carefully structured so that it promotes discussion, not posturing.
- Deliberation does not need to produce a consensus or resolve all of the conflicts.

Renn (1999, p. 4) advocated three consecutive steps in a "cooperative discourse model" on energy policy and waste disposal issues.

- Identification and selection of concerns and evaluative criteria. All relevant stakeholder groups are asked to reveal their values and criteria for judging different options. All relevant value groups must be represented.
- Identification and measurement of impacts and consequences related to different policy options. Evaluative criteria are operationalized and transformed into indicators by the research team or an external expert group and then reviewed by the participating stakeholder groups. Once approved by all parties, the indicators are used to evaluate the performance of each policy option on all value dimensions.
- Conducting a discourse with randomly selected citizens as jurors and representation of interest groups as witnesses. These panels evaluate and design policy options based on the knowledge of the likely consequences and their own values and preferences. Random selection ensures that all potentially affected persons have an equal chance to be included in the sample, including people with nonpolarized views which facilitates mutual understanding and consensus seeking.

Finally, three of the recommendations of the 2008 National Research Council report on public participation in decision-making are particularly relevant to the social considerations aspect of the Wild Horse and Burro Program: clarity of purpose and commitment to the process of participation, provision of adequate funding and staff for implementation, and a commitment to self-assessment and learning from experience. It is important to note that one of the most strongly argued points of that report is that the only way to develop effective public-participation processes is for the agency, practitioners, and public participants to work together to address the diagnostic questions developed in the report to assess the situation and then follow the best process regime described in it. Thus, the committee cannot provide recommendations about the practice of public participation save to reiterate what that report says. The 1996 and 2008

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National Research Council reports are explicit that the development of a specific set of operations can only be done in context because each is situation-specific.

However, given the high level of public concern regarding the management of free-ranging horses and burros, the diverse values that come to bear on the issue, and the substantial scientific uncertainty that is inevitable in dealing with such complex issues, effective public-participation practices are essential. Therefore, BLM should engage with the public in ways that allow public input to influence agency decisions, develop an iterative process between public deliberation and scientific discovery, and codesign the participatory process with representatives of the public. In addition, because there are also concerns about horses and burros among the national, not just the local and regional, public, it would be appropriate for BLM to support research by using survey methods that go beyond opinion polls to capture tradeoffs in public concerns and thus improve understanding of public perceptions, values, and preferences regarding horse and burro management.

The mixture of AD and AM can be cost-effective. It is true that sound AD and AM require a commitment of resources, but minimizing public controversy with effective AD and finding successful policies and practices through AM reduce costs in the long run, especially if they reduce the number and scope of lawsuits. For example, BLM could link AD and AM to figure out how to sterilize the right number of animals each year and in each location to achieve an unknown ideal free-ranging population while minimizing the number of animals gathered and put into holding facilities. The AD process could help to clarify issues of public concern while informing the public about the issues that BLM faces. Thus, AD forms the basis for designing AM experiments. After the experiments have run for a reasonable time, another AD process could be used to extract management lessons learned from the AM experiments.

Citizen Science

In recent years, public participation has moved toward more active interaction and collaboration between stakeholders and managers in research and monitoring processes (Fortmann, 2008). Joint monitoring, in which stakeholders participate in or observe monitoring efforts associated with management, has been shown to build trust and improve relationships among participants (Fernandez-Gimenez et al., 2008).

Miller-Rushing et al. (2012, p. 285) noted that members of the public have been actively engaged in scientific research for centuries (usually observing the world around them), producing "important datasets, specimen collections, and scientific insights of all types."[5] Citizen science expands the role of the public in scientific research, and this leads to a more informed public and enhanced scientific education and insights (Miller-Rushing et al., 2012). Henderson (2012) argued that citizen scientists need to be more fully engaged in the scientific process beyond data collection; they should be involved in the development of research projects and in the interpretation and reporting of results.

A review of citizen-science collaborative monitoring efforts concluded that they provided a focal point for resolving conflicting interests, encouraged collective learning, and raised awareness about the interdependence between human systems and natural ecology (Fernandez-Gimenez et al., 2008). Adaptive-management processes can incorporate stakeholders into decisions about research topics, monitoring regimes, and interpretation of results. Although there

[5]The past, present and future of citizen engagement in science were reviewed in a special issue of *Frontiers in Ecology and the Environment* (Vol. 10, August 2012).

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is no doubt that satisfying the demands of scientific rigor is challenging (Fernandez-Gimenez et al., 2008), for an issue that has been so contentious it may be worth time and effort to develop such programs for free-ranging horses and burros.

Interactive websites that allow participants to discuss issues and report observations can broaden opportunities for participation to the global level (Kelly et al., 2012). In a study of the role of the Internet in collaborative adaptive-management processes, the authors found that the Internet played an important role throughout the adaptive-management cycle by supporting communication through the dissemination of information to the public and increasing the transparency of the scientific process. The Internet also played a small but important role in public consultation by providing a forum for targeted questions and feedback from the public. In the BLM context, the Internet could be an important complement of more face-to-face local interactions. Meetings and local activities privilege some stakeholders, but the Internet can allow a more widely scattered group or those who have heavy family and work obligations to participate.

Austin et al. (2009) offered a good example of the use of citizen science to engage the public in decision-making. They used participatory GIS to give stakeholders opportunities to document deer abundance on landscape-scale maps. The method was useful in contributing to incomplete scientific knowledge about abundance data, and this informed wildlife research and management. Investigating further, Austin et al. (2010) found that the management priorities of private-sector managers of deer differed from those of private landowners. Deer caused ecological and economic damage to private property, making landowners bear a disproportionate share of the costs of deer management.

FeralScan[6] is an online tool that allows users in Australia to map the presence of "pest" species, document movements and damages caused, and share that information with other users. At the time this report was prepared, horses were not included in the species in the program.

The use of "scout" programs has been found to enhance public engagement in free-ranging zebra conservation and management in Africa. A scout program that paid local pastoralists 2 days each week to record the number of Grevy's zebras seen during the course of a day brought valuable income to the community, but it was observed that "just as important is the empowerment that comes from gathering the data and owning the results, whether good or bad" (Rubenstein, 2010). Similarly, scouts recruited from communities in the Samburu District of Kenya kept records on the location, group structure, and habitat of Grevy's zebra herds. Those records were valuable for conservation planning. Scout participation also served to develop greater understanding of and a more favorable attitude toward wildlife conservation in the community. When citizens are involved in management, both agencies and citizens ideally learn to appreciate the needs and concerns of other participants.

OPPORTUNITIES FOR THE BUREAU OF LAND MANAGEMENT TO ENGAGE THE PUBLIC

BLM has involved the public in a consultative way in the past, but to move to the right in Figure 8-1 toward a collaborative process, BLM and the public must come together to work in new ways and with a new spirit. To accomplish that goal, the committee offers some specific

[6]Available online at http://www.feral.org.au/feralscan/. Accessed March 14, 2013.

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suggestions for getting the public engaged in the decision-making processes surrounding the management of free-ranging horses and burros.

As the 1980 and 1982 National Research Council reports noted, research on a number of topics related to social and economic valuation of free-ranging horses and burros would provide a foundation for analytic deliberation and other means of public participation. BLM may have already laid some of the groundwork for the exploration of possible fronts on which to engage the public in participatory decision-making. In 2010, the BLM Office of the Inspector General noted that

> In June 2010, BLM invited interested stakeholders to offer their opinions and suggestions about its "Working Toward Sustainable Management of America's Wild Horses and Burros – Draft Goals, Objectives and Possible Management Actions – June 2010" document. BLM planned to develop its strategy to find solutions that are best for wild horses and burros, wildlife, and the many other uses of the public lands by working closely with partners, stakeholders, the public, and employees to develop a strategy. In October 2010, BLM announced key findings based on the public response to the strategy development document, which included the following: many Americans continue to be passionate about wild horses and burros and their management; there continue to be very different views about how America's wild horses and burros should be managed. These include 1) focusing management on a smaller number of "Treasured Herds" on "preserves" or sanctuaries in the West; 2) reducing the AML of wild horses and burros or implementing aggressive population suppression; and 3) returning wild horses and burros to their original 1971 Herd Areas or expanding the use areas to other places on public lands, while allowing natural processes to adjust population size. (OIG, 2010, p. 12)

The differing views about appropriate management strategies offer potential platforms for the use of the approaches described in this chapter.

The 1982 National Research Council report concluded that on the basis of the available data on public attitudes toward equid management, three factors needed to be considered in designing equid-removal programs: the humaneness of the control procedure, the specificity of its effects, and its cost-effectiveness. That report emphasized that the public was especially concerned about the possibility of pain and cruelty during equid removals. The public is also concerned about the treatment of animals after removal from public lands (in adoption or under the care of BLM) (GAO, 2008). Those may be important topics around which the public could be engaged in analysis and the development of solutions. The committee suggests that BLM continue its volunteer programs in horse and burro adoption and the public observation of gathers; these actions would facilitate the agency's direct interaction with the public and may help build trust and relationship with stakeholders.

BLM could do more with how people want to feel close to the animals, such as making it possible for people to see them easily in at least one or two places. That was also suggested in the 1982 National Research Council report. It would be useful to consider a webcam set up in a few places where the animals come often. That would build on the affection that people have for the animals and give them a chance to see for themselves that the animals are there. The public might participate in some kinds of monitoring with the webcams. When it is feasible, BLM should develop ways for stakeholders to participate in research and monitoring. Interactive web

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technology can facilitate stakeholder participation in gathering and reporting information about free-ranging horses and burros.

Also of potential use in involving the public in the management of the free-ranging horses and burros would be reporting all equid sightings and their numbers and distinguishing markings if possible as part of the official counts of free-ranging equids. The public could provide high-quality photographs of horses to be used in mark-resight population counts as part of the official counts of free-ranging equids. It would be important that photographs are taken of both the marked (distinguishable) and unmarked (undistinguishable) horses to provide accurate count estimates, and care should be taken to avoid resighting animals that are more commensal with humans and animals that are less "camera-shy." The image data would be most credible and valuable for BLM if photographs were automatically date-stamped and time-stamped and linked to GPS locations.

In addition, the creation of a large citizen-science network would be helpful. Cornell University sponsors the Christmas Bird Count in which people go out 1 day a year and in a systematic way count all birds that they see and send in the data. Such data are being used to see whether range changes are resulting from climate change. As the committee learned from the invited public presentations, mark-resight studies are the best way to estimate population-size changes, habitat use, and movements that potentially can connect HMAs and thus help to mitigate loss of genetic heterozygoisty. They would constitute a powerful strategy for engaging the public and improving the available information. Volunteer groups have engaged with BLM and have been trained by Dr. Jay Kirkpatrick to dart horses with the porcine zona pellucida vaccine. As of January 2013, these volunteer groups treated five herds of less than 150 animals in four states (Philipps, 2012). In addition, BLM has partnered with the Nevada Department of Corrections and the Nevada Department of Agriculture to gentle and train free-ranging horses and burros for adoption.[7]

Many citizens and some scientists (see Kirkpatrick, 2010) view free-ranging horses as native to North America, and addressing this question would increase the validity of this report of BLM's management strategy for some stakeholders (and indeed some people may decide to shelve the report for not addressing the issue). The committee suggests that convening a forum of experts on the biology and ecology behind the horse's status as native or feral might be one way to address these issues. The forum should be open to the public so that all can listen and learn.

The management of free-ranging horse and burro populations is an issue of concern in many countries of the world and in the eastern part of the United States. BLM could provide links on its website to national horse management associations in other countries and to the National Park Service management of horses on Assateague Island, Shackleford Banks, and Cumberland Island. Access to that information would provide the American public with a broader view of international and national equid management issues, strategies, and solutions and an improved understanding of BLM management objectives and operations.

In addition, developing and updating a public website on BLM's management of horses and burros would be valuable. The committee recommends that BLM develop and maintain such a site. Timely updating and the inclusion of public comments (and BLM's responses) would be essential to maintain good faith in the process.

[7]Bureau of Land Management Saddle Horse Training Program. Northern Nevada Correctional Center/Stewart Conservation Camp. Available online at http://www.blm.gov/nv/st/en/prog/wh_b/warm_springs_correctional.html. Accessed February 13, 2013.

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Ultimately, BLM itself will have to determine which types of questions are amenable to participatory processes and can best serve the purposes of informing management decisions and increasing public confidence, although public input into the initial determination could also be useful. As noted earlier, such efforts will require a commitment to public engagement and the resources to carry out the process, which are necessary if the agency is to achieve its mission.

CONCLUSIONS

Horse and burro management and control strategies cannot be based on biological or cost considerations alone; management should engage interested and affected parties and also be responsive to public attitudes and preferences. Three decades ago, the National Research Council reported that public opinion was the major reason that the Wild Horse and Burro Program existed and public opinion was a primary indicator of management success (NRC, 1982). The same holds true today. To complicate matters, the public holds disparate values related to free-ranging horses and burros. Some groups perceive free-ranging horses as highly valued animals native to North America, icons of the Western landscape, and deserving of more BLM resources; others see free-ranging horses and burros as invasive "feral" species in competition for rangelands and stressors of fragile ecosystems. Values are the lens through which the public understanding of scientific issues related to free-ranging horses and burros is focused, and management decisions should navigate these divergent public values.

Regardless of the diversity of public opinion on free-ranging horses and burros, there is broad consensus that the current management conditions for these animals are not sustainable (GAO, 2008) and that the ever-increasing number of horses kept in long-term holding facilities should be mitigated. BLM is faced with the problem of finding and implementing a cost-effective management strategy that is based not only on the best scientific evidence but on reducing polarization and increasing public confidence in its decision-making.

The committee believes that attempts to resolve polarized public values and opinions should draw on the principle of community-based public participation and engagement in decision-making, an analytic-deliberative process that engages lay people and experts in a constructive consideration of management options. Local communities that interact with the animals or are affected by management decisions should be represented in the decision-making process in a collaborative process that engages the public, scientists, and managers and that fosters the development of a shared understanding of the ecosystem, appreciation of the viewpoints of others, and the development of good working relationships based on transparency and the balance of power. A forum of experts could be convened to address one of the most contentious issues among the public: the biology and ecology related to the horse's status as native or feral. The forum should be open to the public so that all can listen and learn.

The committee encourages BLM to develop new ways to engage the public in the management of free-ranging horses and burros. For example, citizen-science networks may be used more extensively to collect data on herd population-size changes and habitat use. Other efforts tailored to local needs should be explored.

With respect to formal, long-standing participatory processes that BLM could use, the committee reviewed four—appreciative inquiry, structured decision-making, adaptive management, and analytic deliberation—and concludes that the analytic-deliberative approach is

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the most appropriate for use in the Wild Horse and Burro Program. Carefully designed analytic-deliberative processes that engage the public have been found to substantially reduce conflict over natural-resources decision-making, improve the quality of agency decisions, make the decisions more transparent from the perspective of the citizens involved, and increase the chances that the decisions will be supported and implemented (NRC, 2008).

The analytic-deliberative approach is particularly relevant to resolving the conflicts surrounding the Wild Horse and Burro Program because it is founded on the principles of inclusiveness of participation, collaborative problem formulation and process design, transparency, and good-faith communication (NRC, 2008). When public participation is shaped and monitored by the analytic-deliberative process, public understanding and confidence in the scientific analysis can be improved and conflict over values can be mitigated. To ensure the effectiveness of the analytic-deliberative process, BLM should have clarity of purpose and commitment to the participatory process, should provide adequate funding and staff for implementation, and should commit to self-assessment and learning from experience.

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9

A Way Forward

On the basis of its assessment of the issues contained in the statement of task, the committee concluded that tools available to the Bureau of Land Management (BLM) could help the agency to address formidable challenges facing the Wild Horse and Burro Program successfully. Using those tools would require changes in common practices, and new approaches would probably be more expensive than standard procedures in the short term. Over the long term, however, improvements may be cost-effective and help to improve the public's confidence in BLM with respect to the management of free-ranging horses and burros in the context of the agency's multiple-use mandate for public lands.

THE PROBLEM WITH "BUSINESS AS USUAL"

In its presentation to the committee (Bolstad, 2011), BLM highlighted two goals developed in response to the U.S. Senate Committee on Appropriations' 2009 demand for a comprehensive, long-term plan for the Wild Horse and Burro Program: to balance removals with adoptions and to achieve appropriate management levels (AMLs). The committee found that it may be possible to meet those program goals but not with the system in place at the time of the committee's study.

Chapters 1 and 6 stated that the program reportedly spent almost 60 percent of its fiscal year 2012 budget, or over $40 million, caring for more than 45,000 animals that had been removed from the range (BLM, 2012). Over 30,000 of those animals, almost all horses, were in long-term holding. From 2002 to 2011, the number of horses removed from the range each year averaged over 8,000; roughly half those removed were ultimately placed in long-term holding. The continued removal of horses perpetuates a supply of animals that outstrips adoptions each year. The Government Accountability Office (GAO, 2008) concluded that holding-facility costs would "continue to overwhelm the program" if adjustments were not made; the committee concurs with this assessment. "Business as usual" practices will probably also continue to alienate interested parties concerned about the free-ranging nature of the animals and the program's fiscal sustainability.

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Furthermore, as discussed in Chapters 2 and 3, the management strategy of removing free-ranging horses and burros from the range leaves the animals that remain on the range unaffected by density-dependent population processes. Thus, population growth is not regulated by self-limiting pressures, such as lack of water or forage, and this allows horse, and possibly burro, populations to grow at an annual rate of 15-20 percent. Such successful herd productivity hampers BLM's ability to keep population sizes within AMLs and affects the agency's ability to maintain rangeland health.

THE TOOLBOX

Fortunately, tools that could help BLM to tackle many of those challenges already exist. Available improvements of common management practices on the range have been reviewed in this report and, if broadly and completely implemented, could address concerns about animal welfare and program expense. More immediately, they could help BLM to respond to two chief criticisms of the Wild Horse and Burro Program: unsubstantiated estimates for Herd Management Areas (HMAs) populations and of the population as a whole and lack of evidence that management decisions are informed by science. Addressing those issues could help increase public confidence in the agency.

Improving Population Estimates and Informing Management Actions with Science

Consistently conducted surveys of horse and burro populations that use scientifically sound methods of population estimation would substantially increase the credibility of the numbers reported by the Wild Horse and Burro Program. Improving the methods of horse and burro surveys was also called for by the National Research Council Committee on Wild and Free-Roaming Horses and Burros in its 1980 and 1982 reports. BLM has already taken a step in that direction through its collaboration with the U.S. Geological Survey (USGS). This cooperative work has demonstrated that survey methods available to BLM can increase the accuracy and quantify the uncertainty of population estimates.

Statistically rigorous and scientifically defensible estimates of demographic parameters and population sizes of horses and burros constitute essential data for any model that could project the outcome of different management decisions. As reviewed in Chapters 3 and 6, the absence of such data limits the applicability of modeled outcomes projected by WinEquus because the input parameters used in the model are most likely based on default datasets available within WinEquus rather than on the specific population being modeled. It is unknown whether the default datasets are representative of other horse herds or even of the populations studied, given that the default parameters were estimated from data collected more than 2 decades ago. There are no representative population data on burros. Inaccurate data on demographic and management parameters and population size and structure undermine the relevance of modeling effects of management decisions. Similarly, it undercuts efforts to develop forage production estimates made using forage utilization data as recommended in the *Wild Horses and Burros Management Handbook*.

In addition to more accurate demographic and population-size data, the Wild Horse and Burro Program would benefit from a more comprehensive model or suite of models. WinEquus can capture effects of contracepting mares, changing the sex ratio, or removing animals from the

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range, but it cannot model the implications of contracepting males, forecast the effects of management decisions on genetic diversity, or link the effect of climatic variability on forage availability with survival and reproductive success. It also lacks sensitivity-analysis and economic-optimization capabilities, both of which could help managers of equid populations to set priorities for management actions.

A model that captures the population-level effects of contracepting males and females could help in designing efficacious, herd-specific contraceptive treatment plans to meet management goals. According to BLM's presentation to the committee, the agency treated an average of 500 mares a year with the porcine zona pellucida (PZP) vaccine from 2004 to 2010; just over 1,000 were treated in 2011 (Bolstad, 2011). Contracepting 500-1,000 mares a year with a 2-year vaccine will not substantially lower the rate of growth of a population of over 30,000 horses. To reduce the population growth rate with contraception, a much higher proportion of the population would need to be treated in a comprehensive, strategic fashion, making use of PZP (in the PZP-22 or SpayVac® formulation) and GonaCon™ for females and chemical vasectomy for males. Recording information on the date and type of treatment applied would allow BLM to measure the success of its contraception management actions and adapt its strategy accordingly. It would also contribute to knowledge about the effects of contraception on individual reproductive success if the contraceptive is administered multiple times, on the longevity of treated mares, and on behavior in individuals, harems, or the larger population. Tracking responses to a large-scale fertility-control strategy would be particularly important for BLM to be able to respond quickly and appropriately to known and unknown side effects that may affect population or genetic health. Any information learned from analysis of management actions could be used to modify the model or models to continually improve their predictive ability and hence their utility going forward.

Another way to reduce the growth rate is to allow horses and burros to self-limit. As reviewed in Chapter 3, few scientific studies have been conducted on equid self-limitation. However, there is substantial evidence in wild ungulate populations that self-limitation will involve shortages of forage and water for the population, which will increase the number of animals that are in poor body condition and dying, either directly from lack of food and water or indirectly from increased vulnerability to disease. Although increased mortality would reduce population growth rates, it is unclear how much the growth rate would be lowered and what affect this strategy would have on the health of the rangeland and on the welfare of other animals on the range. Without further research, experimentation, and modeling exercises, it is difficult to predict mortality, body conditions of all animals, and rangeland ecological conditions at the point of horse and burro self-limitation.

An issue that is vitally important for improving the operation and the image of the Wild Horse and Burro Program is the connection of the establishment of AMLs to results of scientific research. AMLs involve policies that allocate rangeland resources among many uses of the land, but information regarding the interaction of horses and burros with the environment and other species, which informs these policies, should be robust and of the best quality possible. The committee suggests that a science-based assessment of the range and the interaction of animals with the range, consistently applied over time and among districts, could inform the establishment of AMLs more accurately. The committee could not identify a science-based rationale used by BLM to allocate forage and habitat resources to various uses within the constraints of protecting rangeland health and listed species and given the multiple-use mandate.

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The committee also finds that, if AMLs remain set at their 2012 levels (Appendix E, Table E-1), contraception or self-limitation strategies may not reduce horse and burro populations to target levels. To manage horses at 2012 AMLs, horses may first have to be removed. Large-scale removal would require the public to accept gathers on a number of HMAs over a short period, probably within less than 5 years, which would be expensive. Once horses were removed, this approach would also require the culling of thousands of animals or the warehousing of many more thousands of horses in long-term holding. If contraception or self-limitation strategies could curtail population growth rates after a large-scale removal, the costs of long-term holding would eventually decline as fewer horses were placed into these facilities and the horses in holding would eventually leave through sale or death.

In most HMAs managed for populations of burros, 2012 AMLs were exceeded. However, the total population of burros is much smaller than that of horses; in 2012, BLM reported 5,841 burros in HMAs. That number needs to be verified with appropriate survey methods, but if it is accurate, removing burros permanently from the range could jeopardize the genetic health of the total population. The burro population is more fragmented than the horse population. Burro HMAs exist in five states; no state-aggregated AML exceeds 1,500 burros; and the cumulative, program-wide AML for burros is 2,923. Translocation of burros between HMAs would need to occur more often than it would for horses to compensate for the geographic fragmentation and small size of the population. BLM may also need to assess whether the AMLs set for burros can sustain a genetically healthy total population. It is possible that a more accurate population estimate could reveal that there are already enough previously unaccounted-for animals on the range to support genetic health at the total population level. However, if more animals were needed to sustain a healthy population, burros from HMAs that are above their AMLs could be relocated to HMAs that have AMLs set for burros but few or no animals on them.

Cultivating Public Confidence

A statement that the committee heard often in public comment sessions was that the public has no confidence in the information that BLM provides about the Wild Horse and Burro Program. Skepticism of BLM's credibility applied to all aspects of the program, including population estimates and population growth rates, genetic health of the animals, consequences of population-control strategies, AML establishment, and public-land allocation to free-ranging horses and burros.

The committee acknowledges that science cannot transform how BLM is perceived by all members of the public. However, having a scientific underpinning for its decisions would help BLM to explain and defend its management actions. For example, improving the accuracy and quantifying the uncertainty of population estimates would allow BLM to respond with data to criticism about the numbers of equids that it reports on public lands. Recording information on genetics and on animals treated with contraception would strengthen input data for models and thereby increase their predictive power with respect to the effects of management actions, such as translocation and contraceptive treatment. Even in decisions that are largely policy-driven management decisions, such as the proportion of rangeland resources that should be allocated to horses or burros, science-based information about forage availability can help BLM to explain one of the constraints underlying forage-allocation decisions.

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Making the data that it collects available to the public would also be an opportunity to increase public confidence that BLM could explore. For example, improving population estimates through statistically rigorous survey methods probably will not enhance public confidence in the agency unless the methods and the numbers produced by the surveys are made available to the public. The committee is aware that BLM has already taken steps towards creating such a database. Fully populating the database on a timely and routine basis and making it accessible to the public is an example of an action that BLM could take to increase the transparency of its decisions. Another opportunity would be to include in gathering plans and environmental assessments a clear explanation of how models are used to inform management decisions. Finally, BLM districts need resources and training to develop consistently applied monitoring and allocation methods. Investment in BLM's own human capital through training, interaction with professional and research organizations, and interaction throughout the agency is needed as a foundation for improved and consistently applied methods.

Greater public participation in BLM decision-making and data-gathering could increase public confidence in agency actions, and the committee recommends the analytic-deliberative approach to engaging the public in management decisions and increasing trust through transparency. Social-science research may help to identify opportunities and improved processes for cooperation between BLM and the public. Finally, citizen-scientist reports could be used to bolster BLM-collected data on sentinel populations and rangeland conditions.

A NEW APPROACH

The committee believes that the tools suggested above would entail more intensive management of horses and burros than it observed during its review of the Wild Horse and Burro Program. The horses at Assateague Island in Maryland and at Shackleford Banks in North Carolina are not subject to the Wild Free-Roaming Horses and Burros Act (92 P.L. 195), but intensive management has proved successful on these islands. Those locations have advantages over many BLM HMAs from a management perspective in that the animals are confined to discrete spaces and the herds are small enough for each animal to be uniquely identified. Nevertheless, they stand as scientifically studied examples of how intensive management can work and what effects BLM could expect from reducing population size and implementing contraception more consistently and widely. As has been seen on Assateague Island and Shackleford Banks, fertility control can help to stabilize population size (Kirkpatrick and Turner, 2008; S. Stuska, National Park Service, email communication, November 1, 2012). Such an outcome on BLM HMAs could be achieved with intensive management if contraceptives were applied every year, as is the case on eastern barrier islands. Although more frequent gathers would be required to achieve similar results on large HMAs in the western United States, any application of contraceptives or chemical vasectomies to a large percentage of horses in a gather would reduce growth rate and thus the number of horses that BLM would have to remove to meet management goals.

The committee recognizes that the multipronged approach of science-based tools that it is proposing would require substantial financial resources from BLM in the short term. It therefore recommends the identification of sentinel populations and HMAs. As suggested in Chapter 2, select HMAs representative of diverse ecological settings could be studied more intensively to improve assessment of population dynamics and ecosystem responses to changes in animal

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density, management interventions, and variation in seasonal weather and trends in climate. The results of such studies could be used to inform population and ecosystem modeling efforts for HMAs that have similar characteristics. Selecting sentinel HMAs would be more cost-effective than studying every herd, and it is a scientifically sound strategy. The committee views the population and ecosystem research conducted by USGS on the HMAs of Little Book Cliffs, McCullough Peaks, and Pryor Mountains as a step in that direction and encourages BLM to continue working with USGS and perhaps ecologists in academic institutions on the identification of and research on representative HMAs for both horses and burros.

That complex, intensive approach would substantially benefit from a commitment by BLM to support an integrated team of competent, dedicated scientists. Cooperation among reproductive experts, animal behavior specialists, rangeland and ecosystem scientists, wildlife population modelers and demographers, and geneticists would help to achieve the program's goals. By supporting such a team, BLM would be able to generate the scientific data needed to inform, explain, and defend management decisions.

Furthermore, as recommended strongly by the National Research Council Committee on Wild and Free-Roaming Horses and Burros in its 1980 and 1982 reports and by the authoring committee of this report, using social science to proactively identify issues that may cause tension with parties interested in horses, burros, and the multiple uses of public lands could help BLM to address some of the criticisms expressed to the committee by members of the public. Increasing the transparency of data used to inform management decisions would probably also improve how the agency is perceived by the public.

In the short term, more intensive management of free-ranging horses and burros would be expensive. However, addressing the problem immediately with a long-term view is probably a more affordable option than continuing to remove horses to long-term holding facilities. The committee recognizes that for over 40 years BLM has managed horses and burros in an environment in which there are often incongruent mandates and mandates not accompanied by the required financial resources, attempting to manage the land for multiple uses (including but not limited to free-ranging horses and burros), to preserve a thriving natural ecological balance, to prevent rangeland deterioration, and to respond to concerns voiced by a variety of stakeholders. Meeting those myriad, and often conflicting, demands may not be possible. At the time the committee was preparing its report, BLM districts seemed to be struggling with many of these demands independently. However, there are steps that BLM can take and, in cases has already taken (such as its work with USGS), that could help the agency to address its mandates more successfully. Further investment in science-based management approaches and in helping districts to apply them consistently cannot solve the problem instantly, but it could lead the Wild Horse and Burro Program to a more financially sustainable path that manages healthy horses and burros with greater public confidence.

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Appendix A

Biographical Sketches

Guy H. Palmer *(Chair)* is director, Creighton chair, and Regents Professor in the Paul G. Allen School for Global Animal Health of Washington State University. Dr. Palmer's goal is to improve control of animal diseases that have direct effects on human health and well-being. With that focus, he leads global health-research programs in sub-Saharan Africa and Latin America. For his research at the interface of animal disease and human public health, Dr. Palmer was elected to membership in the Institute of Medicine and serves on its Board on Global Health. He is also a member of and serves on the Board of Directors of the Washington State Academy of Sciences, which provides expert scientific and engineering analysis to inform public policy. Dr. Palmer has been recognized with the Merck Award for Creativity, the Schalm Lectureship at the University of California, the National Institutes of Health (NIH) Distinguished Scientist Lecture, and the Sahlin Award for Research, Scholarship, and the Arts; he is a fellow of the American Association for the Advancement of Science. Dr. Palmer serves as an adviser to NIH, the International Science Foundation, the Northwest Regional Center for Excellence in Infectious Diseases, and the Bill and Melinda Gates Foundation and is on the external boards of several universities in the United States and Latin America. He received his BS summa cum laude and DVM from Kansas State University and his PhD from Washington State University. Dr. Palmer he is board-certified in anatomic pathology.

Cheryl S. Asa is director of research at the St. Louis Zoo and director of the Association of Zoos and Aquariums (AZA) Wildlife Contraception Center. She is adjunct professor in the Biology Department of St. Louis University and in the Department of Forest, Range and Wildlife Sciences of Utah State University and teaches at Washington University in St. Louis. She previously worked on a Bureau of Land Management project on control of fertility in feral horses in Nevada and Oregon. Dr. Asa is a member of many professional organizations, including AZA, the AZA Contraception Advisory Group, and the Society for the Study of Reproduction. In 2005, she was coauthor of a book titled *Wildlife Contraception: Issues, Methods, and Applications* in addition to her many publications in scientific journals. Dr. Asa received her MS and PhD from the University of Wisconsin--Madison in endocrinology and reproductive physiology.

Erik A. Beever is a research ecologist with the U.S. Geological Survey, Northern Rocky Mountain Science Center. His specializations are disturbance ecology, mechanisms of biotic responses to climate change, and monitoring in conservation reserves—all at community to landscape scales. His greatest research experience is with mammals, but he has also studied plants, soils, reptiles, amphibians, ants, birds, and fishes. Dr. Beever worked with the U.S. National Park Service as a quantitative ecologist. He is currently a member of the American Society of Mammalogists, the Society for Conservation Biology, and the Wildlife Society in which he is a past chair of the Biological Diversity Working Group. Dr. Beever received his PhD from the Department of Ecology, Evolution, and Conservation Biology at University of Nevada, Reno, specializing in grazing ecology of free-ranging horses and in patterns of persistence of mountain-dwelling mammals. In his postdoctoral research, he studied grazing ecology of free-ranging burros, horses, and livestock in various contexts across the western United States.

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Michael B. Coughenour is senior research scientist at the Natural Resource Ecology Laboratory at Colorado State University. He was a joint principal investigator on the South Turkana Ecosystem Project, investigating a native pastoral ecosystem in northern Kenya. He has carried out several major modeling and field studies of grazing ecosystems and assessments of ungulate carrying capacities in Yellowstone National Park, Rocky Mountain National Park, and the Pryor Mountain Wild Horse Range. He has developed three ecosystem models that have enjoyed wide success: GRASS-CSOM, GEMTM, and SAVANNA. He has been involved in research on pastoral and grazing ecosystems in Tanzania, Kenya, South Africa, Australia, Inner Mongolia, Kazakhstan, Venezuela, and Canada and has consulted on grazing ecosystem ecology in many other locations around the world. He has carried out ecosystem modeling studies of grassland responses to atmospheric change and has worked with atmospheric scientists to develop one of the first linked ecosystem-atmosphere models (RAMS-GEMTM). Dr. Coughenour received his PhD from Colorado State University, specializing in systems ecology and nutrient cycling in southern Montana grasslands. He later studied the Serengeti grazing ecosystem of Tanzania, using simulation modeling and experimental studies to determine how the ecosystem supports the world's largest ungulate herds.

Lori S. Eggert is an associate professor in the Division of Biological Sciences of the University of Missouri–Columbia. Research in her laboratory uses the tools of molecular genetics to study wildlife species that are difficult or dangerous to study with traditional methods. By combining intensive field studies with individual-based genetic analyses, she asks questions about the ecology and evolution of species that would be almost impossible to study in any other way. Current projects include field and laboratory studies aimed at refining the methods that Dr. Eggert uses for "genetic censusing" of elusive species in the forests of Africa and Asia. Using DNA extracted from elephant dung samples, she has applied multilocus genotypes as genetic tags for estimating population sizes and sex-specific markers to estimate sex ratios. Previously, Dr. Eggert had been a research and postdoctoral associate at the Smithsonian Institution National Museum of Natural History in Washington, DC. She received her MS in ecology from San Diego State University and her PhD in biology from the University of California, San Diego.

Robert Garrott is a faculty member in the Department of Ecology of Montana State University and director of the Fish and Wildlife Ecology and Management Program. The focus of his research is understanding the abiotic and biotic ecological processes that influence mammalian populations and communities. He works in both terrestrial and marine ecosystems and contributes to basic science and applied wildlife management and conservation through collaborations with state and federal natural-resources agencies. Dr. Garrott teaches undergraduate courses in wildlife management techniques and principles of fish and wildlife management. He received his MS in wildlife management from Pennsylvania State University and his PhD in wildlife conservation from the University of Minnesota.

Lynn Huntsinger is professor in the Department of Environmental Science, Policy, and Management of the University of California, Berkeley. She is a rangeland ecologist whose work focuses on the conservation and management of rangelands and ranching. Current studies include research on oak woodland landowners and management in California and Spain, land fragmentation and conservation in oak woodlands, and participatory management strategies. She is a team leader in the Sierra Nevada Adaptive Management Project, working with the U.S. Forest Service and state agencies to restore forest health. She continues to pursue lines of inquiry and theory that she has found useful in her work: ecological models for disequilibrium systems as tools to understand the linkages between human relationships and ecological change, work in political ecology founded on basic notions of who wins and who loses in struggles over access to natural resources, and adaptive management as arbitrator in landscape and resource management. Dr. Huntsinger is a California-certified rangeland manager. She received her PhD in rangeland ecology and management from the University of California, Berkeley.

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Linda E. Kalof is a professor of sociology, animal studies, and environmental science and policy at Michigan State University and founding director of the university's interdisciplinary graduate specialization in animal studies: humanities and social-science perspectives. Her research interests include cultural representations of animals, public perceptions of wildlife, and conservation and conflict management of urban carnivores. She has published widely in animal studies, including *Making Animal Meaning* (MSU Press, 2011), *Looking at Animals in Human History* (University of Chicago/Reaktion, 2007), *The Animals Reader* (Berg, 2007), and *The Earthscan Reader in Environmental Values* (Earthscan, 2005). She edited the multivolume *A Cultural History of Animals* (which received the 2008 Choice Award for Outstanding Academic Title) and currently edits *The Oxford Handbook of Animal Studies* (Oxford University Press) and *The Animal Turn* book series (MSU Press).

Paul R. Krausman is the Boone and Crockett Professor of Wildlife Conservation in the University of Montana Wildlife Biology Program. He received his PhD from the University of Idaho in wildlife science. His professional interests lie in the study of large mammals, especially as influenced by anthropogenic factors. Projects he is conducting include those on ecology of desert mule deer in southeastern California, winter ecology of mule deer in Montana and Idaho, predator-prey relationships between wolves and ungulates in Arizona, bison use of water in Montana, caribou calving shifts in Newfoundland, use of clearcuts by caribou in Newfoundland, and diet quality of bighorn sheep during dry and wet periods. He belongs to many professional organizations, including The Wildlife Society (TWS), the Society for Range Management, and the American Society of Mammalogists. He is a fellow and honorary member of TWS and received its Aldo Leopold Award in 2006. Other awards include the Desert Ram Award from the Desert Bighorn Council and the O. C. "Charlie" Wallmo Award from the Western States and Provinces. He has also received awards for his editing and for books and monographs from TWS. He was the editor of *Transactions of the Desert Bighorn Council*, *The Journal of Wildlife Management*, and *Wildlife Monographs* and is the editor of the TWS-Johns Hopkins University Press Wildlife Book Series.

Madan K. Oli is a professor in the Department of Wildlife Ecology of the University of Florida. He seeks to understand factors and processes that influence dynamics, regulation, and persistence of populations and to contribute to science-based management of wildlife populations. His research addresses both basic theoretical questions and practical solutions to ecological problems and uses a combination of ecological theory, mathematical and statistical models, and field data. He was granted the University of Florida Foundation Research Professor Award in 2010 to fund his projects. Dr. Oli is the author or coauthor of over 100 publications. He received his PhD from Auburn University.

Steven Petersen is an associate professor at Brigham Young University (BYU), where he teaches landscape ecology, natural-resources planning, GIS, remote sensing, and forest ecology and management. He conducts research on the spatiotemporal effects of juniper invasion on natural resources, sage-grouse habitat assessment on broad spatial scales, and the effects of free-ranging–horse distribution patterns on plant community structure. He advises graduate and undergraduate students, is the coach for the BYU plant team, and is an adviser for the range and wildlife club. He was employed by the department to teach a suite of rangeland classes including arid-land plant identification, ecophysiology, landscape ecology, and rangeland ecology and management. Dr. Petersen received his PhD from the Oregon State University Department of Rangeland Ecology and Management.

David M. Powell is a research associate at the Smithsonian Institution's National Zoological Park and associate curator of mammals at the Bronx Zoo, overseeing hoofed animals and carnivores. His research interests lie in studies of the role of dominance and subordinance in animal societies. As a zoo biologist, Dr. Powell is interested in application of behavioral knowledge to management of animals in captivity with the goal of promoting captive breeding, preparing animals for reintroduction, and ensuring optimal animal welfare. He has also studied the application of captive population genetic-management techniques to wild populations. He has studied a variety of species both in captivity and in the field including feral

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horses, gorillas, flamingos, lions, golden lion tamarins, kori bustards, octopuses, small carnivores, and giant pandas. He is a member of the Association of Zoos and Aquariums (AZA) Animal Welfare Committee, Equid Taxon Advisory Group, Caprine Taxon Advisory Group, and Contraceptive Advisory Board. Dr. Powell also participated in the International Union for Conservation of Nature Conservation Breeding Group's Horses of Assateague Island Population and Habitat Viability assessment workshop. He received his BS in Biology from the University of Miami, and his PhD in zoology from the University of Maryland.

Daniel I. Rubenstein is chair of the Department of Ecology and Evolutionary Biology of Princeton University. His research focuses on decision-making in animals. Dr. Rubenstein develops simple mathematical models to generate predictions that can be tested with data gathered from structured field observations or experimental manipulations. Much of his recent research on the adaptive value of behavior has centered on understanding the social dynamics of equids—horses, zebras and asses. How risks are assessed, how decisions are made, and how conflicts of interest among individuals of differing phenotypes with differing needs are avoided is the focus of his research on the control of behavior. His latest research focuses on one such problem—the rules governing animal movements and migration—and involves the interaction of "self-organizing" behavioral movement rules, ecological information, and habitat structure on multiple spatial scales to understand how migratory animal movements respond to human-induced land-use change and how the changes in movement in turn affect population stability. Dr. Rubenstein has received his BA from the University of Michigan, MS degrees from Cambridge and Oxford Universities and his PhD from Duke University.

David S. Thain is a consulting veterinarian. Previously he was an assistant professor and state extension veterinarian at the University of Nevada, Reno (UNR). Prior to his work at UNR, Dr. Thain was the state veterinarian at the Nevada Department of Agriculture where he managed the state's Virginia Range Estray Horse Program. While in this position he developed his expertise in techniques to manage feral horse populations. Dr. Thain's research was some of the first to assess new contraceptive products in the field setting to evaluate efficacy and safety as well as cost-effective practical methods for maintaining viable herds without the need for routine gathers to reduce excess numbers of horses. Early in his career he was a private practitioner in Wyoming and Nevada. He received his DVM from Colorado State University.

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Appendix B

Previous National Research Council Reports on Free-Ranging Horses and Burros

Unlike the Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program, the committee for the 1980 and 1982 reports (Committee on Wild and Free-Roaming Horses and Burros) and the committee for the 1991 report (Committee on Wild Horse and Burro Research) were asked to develop and evaluate specific research programs and activities related to free-ranging horses and burros. In 1979, the Committee on Wild and Free-Roaming Horses and Burros was charged to develop a research program that would

- Develop data on the biology of wild horses and burros, including the population dynamics of wild horse and burro herds;
- Identify principles and procedures for managing populations of wild horses and burros in accordance with the policies and objectives of this Act;
- Develop information concerning the availability and use of forage and water resources, dietary and habitat overlaps, and other factors relevant to the determination of the number of wild freeroaming [sic] horses and burros that a herd area can sustain; and
- Provide the Secretaries of Interior and Agriculture with scientific information upon which to make the determination as to excess animals required by this Act. (NRC, 1980, p. 13-14)

That committee fulfilled its statement of task in a three-phase study. The first phase reviewed the existing knowledge of free-ranging horses and burros and from that developed 18 research projects that it recommended that the Bureau of Land Management (BLM) pursue to fill gaps in knowledge that would contribute to the sound management of free-ranging horses and burros. In Phase II, the committee reviewed requests for proposals that were issued by BLM for research on census methods, habitat selection, range effects, comparative nutrition of range horses and cattle, pregnancy rates in horses and burros, and horse survival rates. The report published in 1982 summarized the results on the six research topics and reiterated the necessity of a more thorough research program, as laid out in the Phase I report, to inform management decisions related to free-ranging horses and burros. The 1982 report completed the third phase of the study.

In 1985, the Committee on Wild Horse and Burro Research was asked to

- Review research on wild horses and burros completed since 1982;
- Assess the research recommendations of an earlier committee of the National Research Council in light of current issues, and update these recommendations if necessary;
- Develop guidelines to assist the BLM in contracting for additional studies;
- Monitor the progress of contracted research projects; and

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- Evaluate the final reports of the research projects and prepare a final committee report. (NRC, 1991, p. 1)

That committee recommended research topics and guidelines that were based on BLM's identification of high-priority research. BLM funded research on two subjects: wild horse population genetics and control of fertility in wild horses. The National Research Council committee reviewed the research proposals that were submitted on those topics after a BLM request for proposals. BLM ultimately funded one project in each. The committee's report, published in 1991, reviewed the design and results of the two projects.

The study committee formed in 2011, the Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program, was not asked to evaluate specific current research projects funded by BLM or to design research activities and then review the results. Instead, it was charged to use the previous reports and later relevant research to inform an independent evaluation of the science, methods, and technical decision-making approaches of BLM's management program.

COMMONALITY IN NATIONAL RESEARCH COUNCIL STUDIES ON FREE-RANGING HORSES AND BURROS

Although the Committee to Review the Bureau of Land Management Wild Horse and Burro Management Program was not tasked with designing a research program or reviewing specific research projects, its statement of task echoed many of the issues addressed in the earlier reports. Like the committee that prepared the present report, the Committee on Wild and Free-Roaming Horses and Burros examined issues related to genetic diversity, fertility control, population estimates, population growth rates, forage use, and societal opinions; it looked specifically at the results of a free-ranging horse genetics study and a project on fertility control.

Genetic Diversity

The 1980 report flagged two management issues related to the genetic diversity of free-ranging horses and burros. First, it noted that a population that can sustain itself must have enough genetic variability to survive a multitude of environmental contingencies. Genetic information could be used to determine the size of a sustaining population for a given area that had particular environmental characteristics, and populations could be managed with that size as an objective. Second, the committee recognized that there was considerable disagreement about the origins of the free-ranging herds. One position held that the horses were the descendants of Spanish mustangs. Another took the view that the horse herds were the result of released or escaped cavalry mounts and work animals. At the time that the 1980 report was written, no data existed to answer questions about the amount of genetic variation within and between populations and the relatedness of free-ranging equid populations to domestic horses and donkeys. Therefore, the report recommended that studies be carried out to determine the genetic variation between populations of free-ranging horses and burros and the genetic similarity between free-ranging equids and domestic breeds.

The research was not carried out in Phase II of the study by the Committee on Wild and Free-Roaming Horses and Burros, but it was one of the research projects overseen by the

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Committee on Wild Horse and Burro Research. Blood samples were collected from nearly 1,000 horses at seven trap sites in Nevada and Oregon from December 1985 and October 1986. The objectives of the research project were to

- Assess the average and individual heterozygosity in the populations to determine if there has been loss of heterozygosity or inbreeding through genetic drift, selection, removals, or management restrictions;
- Estimate the contributions of the original wild mustangs (descendants of animals released by the Spanish) and the current domestic lineages (13 breeds) to the present feral horse populations;
- Evaluate the several populations for possible divergence in gene frequencies and for the development of population substructure; and
- Determine parentage and particularly paternity within bands to evaluate the proportion of foals sired by the dominant band stallion. (NRC, 1991, p. 3-4)

The data showed that there was less difference between populations of horses in the Nevada and Oregon herds than there was between domestic horse breeds. It also supported the hypothesis that the free-ranging horses in that region descended from escaped or released domestic draft, saddle, and cavalry animals. Dominant stallions did not sire about one-third of the foals born in intact harem bands. There was no evidence of loss of herterozygosity in the populations studied.

Census Techniques, Population Estimates, and Population Growth Rate

The committee that prepared 1980 report identified many problems with counting free-ranging herd populations that raised questions about the accuracy of the population estimates and about the rate of growth of free-ranging horse and burro populations.

Herds on BLM land were not counted at a consistent frequency. The frequency of counts of each herd varied between 1 and 11 years, and the number of counts conducted ranged from 1 to 18 for each herd. The herds were not counted at the same time each year, and this negated the ability to compare counts of a single herd in different years. Horse herd population size varied with the time of the year, increasing in spring because of foaling and declining in the rest of the year because of deaths (NRC, 1980). Foaling in burros can occur throughout the year, although it is largely in spring. Counts made before or after foaling in different years are not comparable. In addition the counting method used was not standardized among herds and was not tested for robustness. Most BLM surveys sought a complete count of the animals from the air, but the ability to count animals was strongly affected by terrain, vegetation cover, and the skill of the census counter and the pilot. To address the variation and inconsistencies, the committee recommended a research project to compare the accuracy and precision of three methods: complete counts, mark-resight estimates, and strip–transect estimates. It suggested that the agency develop a set of criteria to determine the appropriate approach for a given habitat.

Research conducted during Phase II of the study confirmed that free-ranging horses and burros were usually undercounted, particularly in areas of tree cover and dissected topography. Burros are particularly difficult to see because they tend to stand still in response to an airplane or helicopter, and their coloring does not stand out from the terrain. The 1982 report concluded that mark-resight, capture-recapture, or counting animals immediately before and after a gather would be needed to improve accuracy. It also concluded that contemporary BLM counts of free-

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ranging horses and burros were conservative. The committee suggested that conducting a count of a herd every 2 or 3 years would be adequate for managing populations at a specified level.

Because herd populations are affected by the rate of reproduction, the Committee on Wild and Free-Roaming Horses and Burros extensively reviewed the available literature on free-ranging horse and burro reproduction. The 1980 report examined the information available about the age at which free-ranging females first successfully foal and compared these observations with those of domestic female horses and burros. It also looked at the fecundity of domestic and free-ranging females over their lifespan and at how the age distribution of a free-ranging herd affects its growth rate.

The committee found that data on reproductive rates and on survival rates of free-ranging horses were insufficient and resulted in a wide range of population growth rates of herds (NRC, 1980). Burro reproductive and survival rates were also uncertain because of deficiencies in data on foaling rates, foal survival, adult survival, and the response of reproductive activity to environmental conditions (NRC, 1980).

The research funded during Phase II of the Committee on Wild and Free-Roaming Horses and Burros was not sufficient to ascertain the population growth rate of free-ranging horse and burro herds. The committee concluded that growth rates probably vary because of a number of conditions: annual variations in forage conditions due to year-to-year weather changes or longer-term changes in climate, variations in forage conditions related to equid population densities, and variations in forage conditions related to the population density of other herbivores. The committee posited that because of those factors, population growth rates vary spatially and temporally. The 1982 report noted that more research would be needed to ascertain the relationships between variations in forage conditions and population growth rates.

The committee also investigated whether free-ranging horse and burro populations will self-limit. It noted that there was little information to demonstrate whether populations limit themselves at densities below those which would affect ecosystems or to support the theory that populations will not limit themselves until severe ecosystem damage has occurred. The committee cited a few examples in which members of a population had starved over the winter but added this caveat

> We do not cite these examples to imply in any way that these kinds of severe impact are widespread or common in the wild horse and burro ranges of western United States. In fact, we have seen very few areas with heavy vegetation impacts, although we have asked the BLM to show them to us.
>
> Our purpose here is simply to convey our impression that, while there may be some density-dependent tendencies in the demography of these equids, they do not appear effective enough to prevent populations from increasing to the point of significant impact on other ecosystem components. What population control policy this dictates depends on the management goal for any given piece of land. If the goal is solely equid management that is experimental and "natural" as possible, a laissez-faire approach may be appropriate. The equids and other ecosystem components could be allowed to seek their own balance. But where the goal is a multiple-use one, as set forth in PRIA [Public Rangelands Improvement Act of 1978], and there is concern for the values of other ecosystem components, it seems likely to us that horse and burro populations will need to be limited artificially by human action to avoid undesirable effects on other ecosystem components. (NRC, 1982, p. 17-18)

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Fertility Control

The 1980 report did not advocate the use of contraception in free-ranging horses and burros, because such a decision was related to policy rather than to science. However, that committee did review the research conducted on equine contraception up to that time and recommended research that could advance the use of contraception in free-ranging horses and burros. Research on a population of burros that included vasectomized dominant male burros had reported that female burros were later bred by younger males. The committee found that reversible endocrine contraception was feasible for both mares and stallions. The report noted that tests looking at the efficacy of fertility suppression in free-ranging and captive stallions over the course of a single breeding season were underway at the time of the committee's review. When reviewing the options for females, the committee determined that hormone manipulation, intrauterine devices (IUDs), and surgery could be used as methods for equine contraception. However, at that time, hormone manipulation research on female equids was in its infancy, treatments were effective for only a year, IUDs required skilled fitting and frequently became dislodged, and surgery on mares in the field posed a risk of infection and required too much time. Therefore, the committee recommended a research project that would develop a method of reproductive inhibition in mares that would be at least 95-percent effective, require only one treatment in field conditions, could last for up to 7 years, could be reversed, and would not adversely affect the health or behavior of the animals. Such research was not undertaken in Phase II of the study and remained a recommendation of the committee in its 1982 report. The 1982 report also concluded that sterilization of only the dominant stallions in a harem was unlikely to successfully control populations.

The 1991 report reviewed fertility-control results of steroid treatments in corralled and free-ranging mares and vasectomies in free-ranging dominant harem stallions. Three series of experiments were conducted on corralled mares. In the three series, 18 combinations of hormone treatments were administered to 500 mares via silicone rods. The first series of steroid implants were found to be ineffective in preventing pregnancy. The results of the other two series demonstrated greater success: some hormone treatment combinations contracepted more than 90 percent of the mares through two breeding seasons.

Two of the hormone treatments used on the corralled horses were implanted into free-ranging mares on two different Herd Management Areas (HMAs) in Nevada. Foaling rates were determined with aerial surveys. The combined foaling rate in observed mares treated with either hormone implant on the two HMAs in 1988 and 1989 was 9 percent, (22 of 255 mares) compared with 51 percent (114 of 222) of observed mares given placebos (NRC, 1991).

Dominant stallions in 20 bands in northwestern Nevada were vasectomized in December 1985, and 20 more dominant stallions were vasectomized on a less mountainous HMA in Oregon in February 1986. Aerial surveys were conducted 2 years later to observe the effects on foaling rates. The efficacy of treating only dominant stallions was questionable. Reductions in foaling rates appeared to depend not only on the vasectomized stallion but on the stability of the harem band and its isolation. Fewer foals were observed in the stable bands on the more mountainous HMA in Nevada than on the flatter HMA in Oregon, where bands mingled more. The findings of the genetic study that one-third of foals were not sired by the dominant stallion also raised doubts about the efficacy of vasectomizing only dominant harem stallions as a fertility-control method.

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Sex-Ratio Adjustment

The Committee on Wild and Free-Roaming Horses and Burros focused much of its thesis on identifying "excess" horses or burros because *excess* could be related to the number of equids that exerted detrimental effects on their own welfare, the number of equids that adversely affected the ecosystem, or the number of equids that interfered with other management objectives for public rangeland. The 1980 report's research projects were designed to help BLM to determine what *excess* meant. It also suggested projects to assist BLM in determining the value of "excess" equids and the most cost-effective ways of managing them.

The 1982 report reviewed the merits of removing some sex-age classes from a herd to decrease population growth. The committee found that the theory had potential but that more thorough analysis of this management approach than had been conducted was needed.

Forage Utilization by Free-Ranging Horses and Burros

The Committee on Wild and Free-Roaming Horses and Burros reviewed the forage practices, preferences, and requirements of equids and reported that hardly any information existed on daily forage intake by horses or on the nutritional value of range-plant communities as relative to equid dietary needs. It also found that possible competition for forage between free-ranging equids and cattle or between free-ranging equids and wildlife species was poorly documented. Similarly, little empirical research existed on the effects of free-ranging equid grazing on range vegetation or hydrology. The committee determined that such information would be needed to ascertain whether free-ranging horses and burros can sustain themselves on the land without adversely affecting an ecosystem or to ascertain at what quantity free-ranging horses and burros should be managed to ensure a thriving natural ecological balance. The information was particularly necessary because most of BLM's forage allocations for livestock and wildlife had been determined before the agency became responsible for free-ranging horses and burros and few forage areas for equids had been established. The committee recommended three research projects to address the information gaps on the interaction of free-ranging equids and range ecosystems.

The research conducted in Phase II of the study was an insufficient response to the committee's call for information about the vegetation, soil, and water potential of herd areas: the number of herbivores with varied feeding types that could be carried on an area without diminishing the area's potential; the kinds and amounts of forage required by the herbivores; and the effects of herbivores on vegetation. However, three projects were undertaken that provided some data on those topics. BLM-funded research projects examined the distribution of and habitat use by cattle, free-ranging horses, and pronghorn near Rock Springs, Wyoming; the specifics of diet selection and grazing effects on forage plants in the presence of known densities of horses and cattle in the same area; and the quantity of forage consumed by free-ranging horses compared with cows and in relation to animal size and physiological status. Many questions remained to be answered, but the research provided greater specificity as to horse diets, including variation by season and nutrient-use efficiency, and as to horse dietary overlap with cattle. It also provided evidence that short grazing periods have fewer adverse effects on plant communities.

The committee also investigated research that had taken place since Phase I was completed that was not part of Phase II, particularly on the interaction on the range between free-ranging horses and burros and wildlife. Although the results were far from definitive, the

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committee found that because free-ranging horses are grazers, they generally did not compete with ungulate browsers even if they occupied the same area temporally. However, vegetation may still be adversely affected on degraded rangeland if herbivore density is high. Adverse competition between bighorn sheep and free-ranging burros seemed likely on the basis of the number of observations, but the evidence was often circumstantial. The committee recommended that conclusive research be done to determine the degree and effects of competition between bighorn sheep and free-ranging burros (NRC, 1982). It also reiterated its conclusion from the 1980 report that research on semiarid and arid rangeland needs to be conducted for 7-10 years to capture the biological and climate variation in those regions.

Societal Considerations

The committee that prepared the 1980 report recognized that little information existed about the direct costs of free-ranging horse and burro management and the indirect costs of free-ranging horse and burro management as related to other range management objectives. Range managers needed data to guide them in managing the free-ranging horses and burros in the context of these other objectives. The committee also noted that BLM should have information on the attitude of the public toward the free-ranging equids, including the public's awareness of the issue and its nonmarket valuation of the animals. The 1980 report therefore recommended six research projects on socioeconomic and political issues that included surveying interested parties and the general public for their opinions on free-ranging horses and burros. However, no requests for proposals on socioeconomic or political issues were issued by BLM after the committee recommendations. Those issues were not within the mandate of the Committee on Wild Horse and Burro Research and therefore were not addressed in the 1991 report.

REFERENCES

NRC (National Research Council). 1980. Wild and Free-Roaming Horses and Burros: Current Knowledge and Recommended Research. Phase I Report. Washington, DC: National Academy Press.

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Appendix C

Presentations to the Committee

OCTOBER 27, 2011

Presentation by Sponsor
Dean Bolstad, Bureau of Land Management

Genetic Testing of Feral Horses
E. Gus Cothran, Texas A&M University

Overview of WinEquus
Stephen Jenkins, University of Nevada, Reno

Wild Horse Management System: Population Projection and Costing Model
Charles de Seve, EconFirst Associates, LLC

JANUARY 27, 2012

U.S. Geological Survey (USGS) Science Support for Managing America's Wild Horses
Jason Ransom, USGS Fort Collins Science Center

Porcine Zona Pellucida (PZP) Vaccine for Wild Horse Contraception
John W. Turner, Jr., University of Toledo

MARCH 19, 2012

Predation on Feral Equids
Michael L. Wolfe, Utah State University

Wild Horse Population Management with Fertility Control
Allen Rutberg, Tufts University Cummings School of Veterinary Medicine

Wild Horses and Burros: Appropriate Management Levels and Social Considerations
J. Edward de Steiguer, University of Arizona

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MAY 3, 2012

SpayVac® for Wild Horses: A Long-Lasting, Single-Dose pZP Contraceptive Vaccine
Mark Fraker, TerraMar Environmental Research Ltd

MAY 14, 2012

Structured Decision-Making and Adaptive Management of Natural Resources
James D. Nichols, U.S. Geological Survey

Thinking Scientifically about Science Communication
Dan M. Kahan, Yale Law School

Behavioral Ecology of the African Wild Ass (*Equus africanus*) and Their Descendants the Feral Ass (Wild Burro)
Patricia Moehlman, IUCN/SSC Equid Specialist Group

Predation on Free-Ranging Horses by Mountain Lions in Nevada
Alyson Andreasen, University of Nevada, Reno

JUNE 12, 2012

Feral Horse Management on the Sheldon National Wildlife Refuge
Gail Collins, U.S. Fish and Wildlife Service

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Appendix D

Questions and Requests from the Committee[1]

POPULATION SURVEY TECHNIQUES

For a representative sample of six to eight of the larger Herd Management Areas (HMAs) that have received more-intense distributional-survey effort, please provide point locations from census flights (.shp, .shx, etc.) if available.

Please summarize which techniques for population enumeration and estimation have been employed across all HMAs during the last 10 years?

If not obvious from their descriptions of the techniques, have there been any HMAs during the last 10 years where efforts have been made to analytically estimate detectability (other than the current U.S. Geological Survey research program)? If so, can you please describe.

- If BLM horse and burro specialists use a static constant as a "correction factor" for "sightability,", what is the value used if one is used, and did the value vary across habitat types within a HMA (e.g., forest versus valley-bottom, low-sage habitats) or across HMAs? What factors do wild horse and burro biologists believe most strongly affect detectability (e.g., cover type, type of aircraft, elevation flown, snow versus no snow)?

What design (or factors) were used to determine which portions of an HMA were to be flown over for aerial censuses, and did those areas (or lines) change over time?

The Bureau of Land Management (BLM) spoke about using reversible and permanent contraceptives to "maintain the health of the herd" at the first committee meeting in Reno. How does contraceptive that is reversible relates to the health of the herd? How or why would reversibility provide greater health, other than to increase stochasticity due to greater numbers of applications of contraception?

POPULATION ESTIMATES

Complete spreadsheet with annual sums of horses (do not include burros) for all western rangelands at some fixed point in time in BLM's annual cycle for each of the categories below.

- Total free-ranging population
- Total number removed

[1]All questions and requests were submitted to the Bureau of Land Management except where noted.

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- Total number in short-term holding facilities
- Total number adopted
- Total number moved from short- to long-term holding facilities
- Total number 'lost' from long-term holding facilities
- 'Lost' from long-term holding facilities

Complete spreadsheet with annual sums of horses (do not include burros) for each western state at some fixed point in BLM's annual cycle for each of the categories below.

- Total free-ranging population
- Total number removed

Complete spreadsheet with the number of animals of each age-sex category removed from each HMA on a given date.

Complete spreadsheet with number of animals in each age-sex category that were adopted (removed) from short-term holding facilities each year.

Complete spreadsheet with number of animals in each age-sex category that were removed from short-term holding facilities and placed in long-term holding facilities each year.

Complete spreadsheet with number of animals in each age-sex category that were lost (removed) from long-term holding facilities each year due to deaths or any other causes.

Complete spreadsheet with herd-specific annual counts, date of count, type of craft (helicopter, fixed-wing plane, vehicle, or horseback), populations estimates, percent of HMA inventoried, and methods used for inventory for a committee-selected sample of 40 HMAs for the years 2000-2011.

Provide counts, population estimates, and removals for each HMA for the last 2 years.

Based on the census and population estimate records provided by BLM for a sample of HMAs, it is difficult to understand how these data are converted into the annual national population estimates for free-ranging horses reported by the national program office. It is important for the committee to understand the process used for converting and aggregating the HMA numbers into a national statistic. The committee requests an explanation of how this is done and some documentation of the process for the past several years.

The committee is specifically seeking documentation of the national statistics and requests that BLM provide the HMA estimates the national office received for the last 5 to 10 years that were used to generate the annual state and national estimates.

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GENETIC INFORMATION

Can BLM provide any information or impressions it has regarding genetic issues or genetic defects in the herds in any of the HMAs? Obviously quantitative data (that is, number of cases) would be best, but even information on presence or absence of genetic issues would be useful as well as just any suspicions it has about genetic issues in any of the herds.

BLM has indicated that genetic defect conditions have been observed in the past (e.g., club foot, blindness) on some HMAs, but no information about which HMAs these conditions have been observed in was provided. Can BLM tell the committee which HMAs have shown evidence of any of the conditions mentioned in the previous BLM response and, if known, how many cases of the condition were observed or when they were seen?

In previous correspondence, BLM has indicated that periodically it does move horses or burros between HMAs for genetic or other reasons. Are there any protocols in place or procedures used to determine when to translocate animals and how to get them established at their new sites? For example, are translocations only done during certain times of year? Are horses held at the destination site in captivity before being released? Are translocated horses supported in any way (supplemental feed or water)? Is there any kind of post-release monitoring in place when a translocation is done?

Please provide the committee with copies of the genetics reports submitted to BLM.[2]

In a summary table please include:

- Population name (or other identifier)
- Estimated population size
- Number of samples analyzed
- Number and identity of the genes (loci) analyzed
- Estimated allelic diversity (average number of alleles/locus)
- Estimated heterozygosity
- F_{is} value (estimated inbreeding coefficient)
- Any suspected genetically based health issues

It would be useful to know results of the estimated the degree of genetic differentiation (F_{st}) among some or all of the BLM populations if this exists.

Please provide the committee with the following information

- Report of genetic studies on burro populatioins
- Fst values based on microsatellite studies between burro herds within states and between states
- Dates of individual surveys for horse genetics reports
- Description of information provided in the fourth column of the horse genetics reports.
- Fst values based on microsatellite studies between horse herds within states and between states

[2]This question and the remaining under "Genetic Information" were submitted to Dr. Gus Cothran of Texas A&M University.

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Is any more genetic information available about herds that may have evidence of Spanish genetics that has not been provided in reports already submitted?

THE USE AND APPLICATION OF WINEQUUS

For a representative sample of six to eight HMAs throughout the western United States, please provide copies of the herd management assessments prepared prior to each roundup-removal action, fertility-control treatment, or both and respond to the following questions:

- For each HMA, what were the parameter values [survival and reproductive rates, carrying capacity (K), removal (by age/sex), contraceptive effectiveness] used each time WinEquus was used?
- How were the above parameters estimated? If based on data, how were those data used? If estimated, what were the rationales?
- What were the results of the above analyses?
- How precisely were the above results used in management, for example, to make decisions about how many females of what age class to remove or to treat with contraceptives?

APPROPRIATE MANAGEMENT LEVELS

How often have appropriate management levels (AMLs) been reset since 1971 for the subset of 40 HMAs selected by the committee? What are the reasons they were reset?

Please give the committee three more detailed examples of how the need to reset an AML was determined. What criteria and measurements were used? What was the relative importance of different criteria?

How does BLM decide between animal unit month allocation to wildlife species, horses, and livestock? Please provide three cases of how the decision was made and what data was used to make the decision.

Please provide the BLM report on acres that have been removed from Wild Horse and Burro Management Program.

Are “land health standards” defined in: a) 43 CFR § 4180.1.; b) H-4180-1 [Rel. 4-107, dated 1/19/2001; c) 60 Federal Register (FR) at 9954; d) 43 CFR § 4180.2(b); or e) are a) and b) the same document? The most concise statement seems to be found in 43 CFR § 4180.1. Is this statement the most correct for defining Land Health Standards?

FERTILITY CONTROL

Could BLM provide a list of projects and any associated reports related to work it is conducting on SpayVac with Mark Fraker/TerraMar Environmental Research Ltd?

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Appendix E

Herd Management Areas

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TABLE E-1 All Herd Management Areas (HMA) Sorted by Total Estimated Equid Population

Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
Cibola-Trigo	Both	150	367	285	805	1,172	AZ
Twin Peaks	Both	758	952	116	192	1,144	CA
Pancake	Horses	493	1,005	0	0	1,005	NV
Little Owyhee	Horses	298	936	0	0	936	NV
Adobe Town	Horses	800	886	0	0	886	WY
Black Mountain	Horses	0	0	478	800	800	AZ
Jackson Mountains	Horses	217	660	0	0	660	NV
Antelope Valley	Horses	259	608	0	0	608	NV
Clan Alpine	Horses	979	560	0	0	560	NV
Desatoya	Horses	180	543	0	0	543	NV
Beatys Butte	Horses	250	532	0	0	532	OR
Eagle	Horses	210	522	0	0	522	NV
Wassuk	Horses	165	519	0	0	519	NV
Wheeler Pass	Both	66	328	35	182	510	NV
Spruce-Pequop	Horses	82	508	0	0	508	NV
Buffalo Hills	Horses	314	498	0	0	498	NV
Maverick-Medicine	Horses	276	489	0	0	489	NV
Cedar Mountain	Horses	390	464	0	0	464	UT
New Pass-Ravenswood	Horses	566	459	0	0	459	NV
Pilot Mountain	Horses	415	442	0	0	442	NV
Augusta Mountains	Horses	308	437	0	0	437	NV
Triple B	Horses	518	415	0	0	415	NV

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Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
Lake Pleasant	Burros	0	0	208	411	411	AZ
Muskrat Basin	Horses	250	405	0	0	405	WY
Divide Basin	Horses	600	400	0	0	400	WY
Snowstorm Mountains	Horses	140	400	0	0	400	NV
Seven Troughs	Both	156	298	46	88	386	NV
Johnnie	Burros	0	86	108	290	376	NV
Lava Beds	Both	148	340	16	22	362	NV
Salt Wells Creek	Horses	365	360	0	0	360	WY
Alamo	Burros	0	0	160	351	351	AZ
Nevada Wild Horse Range	Horses	500	312	0	38	350	NV
Antelope	Horses	324	349	0	0	349	NV
Sand Wash Basin	Horses	362	327	0	0	327	CO
Challis	Horses	253	322	0	0	322	ID
Sulphur	Horses	250	320	0	0	320	UT
Swasey	Horses	100	292	0	0	292	UT
Rock Creek	Horses	250	288	0	0	288	NV
Diamond	Horses	151	287	0	0	287	NV
Fox-Lake Range	Horses	204	285	0	0	285	NV
Calico Mountains	Horses	333	267	0	0	267	NV
Silver King	Horses	128	262	0	0	262	NV
Green Mountain	Horses	300	258	0	0	258	WY
North Stillwater	Horses	205	255	0	0	255	NV
Big Sandy	Burros	0	0	139	250	250	AZ

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Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
South Shoshone	Horses	100	250	0	0	250	NV
Callaghan	Horses	237	249	0	0	249	NV
Stone Cabin	Horses	364	246	0	0	246	NV
Diamond Hills South	Horses	22	246	0	0	246	NV
Bible Spring	Horses	60	241	0	0	241	UT
South Steens	Horses	304	229	0	0	229	OR
Roberts Mountain	Horses	150	229	0	0	229	NV
Pine Nut Mountains	Horses	179	218	0	0	218	NV
Fish Creek	Horses	180	215	0	0	215	NV
Granite Range	Horses	258	207	0	0	207	NV
Onaqui Mountain	Horses	210	206	0	0	206	UT
White Mountain	Horses	300	205	0	0	205	WY
Sand Springs West	Horses	49	200	0	0	200	NV
Coyote Lake/Alvord Tules Springs	Horses	390	198	0	0	198	OR
Confusion	Horses	115	188	0	0	188	UT
Piceance-East Douglas Creek	Horses	235	183	0	0	183	CO
Range Creek	Horses	125	179	0	0	179	UT
Gold Butte	Burros	0	0	98	176	176	NV
Diamond Hills North	Horses	37	176	0	0	176	NV
Warm Springs Canyon	Both	175	140	24	34	174	NV
Massacre Lakes	Horses	35	172	0	0	172	CA
Pryor Mountain Wild Horse Range	Horses	120	170	0	0	170	MT
Warm Springs	Both	202	133	25	35	168	OR

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Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
Frisco	Horses	60	168	0	0	168	UT
Marietta Wild Burro Range	Burros	0	20	104	144	164	NV
Sheepshead/Heath Creek	Horses	302	161	0	0	161	OR
Bald Mountain	Horses	215	160	0	0	160	NV
Owyhee	Horses	231	156	0	0	156	NV
Little Fish Lake	Horses	39	154	0	0	154	NV
Paisley Desert	Horses	150	146	0	0	146	OR
Kamma Mountains	Horses	77	146	0	0	146	NV
Little Book Cliffs Wild Horse Range	Horses	150	145	0	0	145	CO
Chocolate-Mule Mountains	Burros	0	0	133	144	144	CA
Chemehuevi	Burros	0	0	121	143	143	CA
McCullough Peaks	Horses	140	143	0	0	143	WY
Nightengale Mountains	Horses	63	126	0	17	143	NV
Havasu	Burros	0	0	166	142	142	AZ
Shawave Mountains	Horses	73	140	0	0	140	NV
Rocky Hills	Horses	143	139	0	0	139	NV
Dishpan Butte	Horses	100	139	0	0	139	WY
Goshute	Horses	123	136	0	0	136	NV
Seven Mile	Horses	50	129	0	0	129	NV
Fox Hog	Horses	220	126	0	0	126	CA
Stewart Creek	Horses	175	124	0	0	124	WY
Fifteen Mile	Horses	160	122	0	0	122	WY
Conant Creek	Horses	100	123	0	0	123	WY

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Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
Red Rock	Both	27	58	49	65	123	NV
Saulsbury	Horses	40	121	0	0	121	NV
Hard Trigger	Horses	130	119	0	0	119	ID
Bullfrog	Burros	0	0	91	118	118	NV
Montezuma Peak	Horses	4	47	0	67	114	NV
Sinbad	Burros	0	0	70	113	113	UT
Centennial	Horses	34	40	0	69	109	CA
Canyon Lands	Burros	0	0	100	104	104	UT
Reveille	Horses	138	101	0	0	101	NV
Montgomery Pass	Horses	80	100	0	0	100	NV
Bordo Atravesado	Horses	60	96	0	0	96	NM
Blue Wing Mountains	Both	36	63	28	32	95	NV
Carter Reservoir	Horses	35	95	0	0	95	CA
Conger	Horses	80	91	0	0	91	UT
Cold Spring	Horses	150	90	0	0	90	OR
Buckhorn	Horses	85	88	0	0	88	CA
Muddy Creek	Horses	125	86	0	0	86	UT
Flanigan	Horses	125	80	0	0	80	NV
Garfield Flat	Horses	125	83	0	0	83	NV
Rock Creek Mountain	Horses	86	83	0	0	83	WY
High Rock	Horses	120	78	0	0	78	CA
Lost Creek	Horses	82	77	0	0	77	WY
Antelope Hills	Horses	82	76	0	0	76	WY

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Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
Silver Peak	Burros	0	75	6	0	75	NV
Jackies Butte	Horses	150	75	0	0	75	OR
Three Fingers	Horses	150	75	0	0	75	OR
Sand Springs	Horses	200	74	0	0	74	OR
Black Rock Range East	Horses	93	74	0	0	74	NV
Black Rock Range West	Horses	93	74	0	0	74	NV
Crooks Mountain	Horses	85	72	0	0	72	WY
Little Colorado	Horses	100	70	0	0	70	WY
Fort Sage	Horses	29	67	0	0	67	CA
Coppersmith	Horses	75	64	0	0	64	CA
Black Mountain	Horses	60	61	0	0	61	ID
Cerbat Mountains	Horses	90	60	0	0	60	AZ
Four Mile	Horses	60	59	0	0	59	UT
Chloride Canyon	Horses	30	59	0	0	59	UT
Hickison Summit	Burros	0	0	45	57	57	NV
Four Mile	Horses	60	54	0	0	54	ID
Murderers Creek	Horses	35	53	0	0	53	OR
Kiger	Horses	82	51	0	0	51	OR
Goldfield	Burros	0	20	37	30	50	NV
Sand Basin	Horses	64	49	0	0	49	ID
Whistler Mountain	Horses	24	49	0	0	49	NV
Stinkingwater	Horses	80	48	0	0	48	OR
Palomino Buttes	Horses	64	47	0	0	47	OR

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Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
Tilly Creek	Horses	50	46	0	0	46	UT
McGee Mountain	Burros	0	0	41	45	45	NV
Pokegama	Horses	50	45	0	0	45	OR
Hog Creek	Horses	50	43	0	0	43	OR
Spring Creek Basin	Horses	65	42	0	0	42	CO
North Hills	Horses	36	40	0	0	40	UT
Saylor Creek	Horses	50	35	0	0	35	ID
Wall Canyon	Horses	25	34	0	0	34	CA
Waucoba-Hunter Mountain	Burros	0	0	11	33	33	CA
Riddle Mountain	Horses	56	33	0	0	33	OR
Tobin Range	Horses	42	32	0	0	32	NV
Nut Mountain	Horses	55	31	0	0	31	CA
Choke Cherry	Horses	30	30	0	0	30	UT
Fish Lake Valley	Horses	54	29	0	0	29	NV
Round Mountain	Horses	10	27	0	0	27	CA
Paymaster	Horses	38	26	0	0	26	NV
New Ravendale	Horses	25	24	0	0	24	CA
Red Rock Lakes	Horses	25	23	0	0	23	CA
Little Humboldt	Horses	80	22	0	0	22	NV
North Monitor	Horses	8	22	0	0	22	NV
Hot Creek	Horses	41	21	0	0	21	NV
Liggett Table	Horses	25	20	0	0	20	OR
Lahontan	Horses	10	20	0	0	20	NV

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Herd Management Area	Species Managed on HMA	Horse AML High[a]	Estimated Horse Population	Burro AML High[a]	Estimated Burro Population	Total Estimated Equid Population	State
Stonewall	Burros	0	0	8	19	19	NV
South Stillwater	Horses	16	19	0	0	19	NV
Bitner	Horses	25	15	0	0	15	CA
Mount Elinor	Horses	25	15	0	0	15	UT
Dogskin Mountains	Horses	15	14	0	0	14	NV
Carracas Mesa	Horses	23	12	0	0	12	NM
Granite Peak	Horses	18	11	0	0	11	NV
Kingtop	Horses	40	10	0	0	10	UT
Gold Mountain	Burros	0	8	78	1	9	NV
Chicago Valley	Horses	12	6	0	0	6	CA
Muddy Mountains		0	6	0	0	6	NV
Piper Mountain	Both	17	0	82	0	0	CA
Horse Mountain	Horses	95	0	0	0	0	NV
Palmetto	Horses	76	0	0	0	0	NV
Lee Flat	Burros	0	0	15	0	0	CA
Fort Sage	Horses	36	0	0	0	0	NV
Amargosa Valley		0	0	0	0	0	NV
Ash Meadows		0	0	0	0	0	NV
El Dorado Mountains		0	0	0	0	0	NV

[a]Upper bound of appropriate management level (AML).

SOURCE: Bureau of Land Management. 2012. Wild Horse and Burro Program Data. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wo/Planning_and_Renewable_Resources/wild_horses_and_burros/statistics_and_maps.Par.13260.File.dat/HAHMAstats2012Final.pdf. Accessed October 23, 2012.

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TABLE E-2 All Horse-Only Herd Management Areas Sorted by Population-Size Estimate

Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State	Sampled
Saylor Creek	50	50	5	Sep-2010	Sep-2010	ID	
Chicago Valley	12	0	6	Jan-2011	Oct-2010	CA	
Nut Mountain	55	30	6	Jun-2010	Sep-2007	CA	
Carter Reservoir	35	25	7	Jun-2010	Sep-2009	CA	
Kingtop	40	20	10	Feb-2006	Aug-2000	UT	
Carracas Mesa	23	no low	12		Dec-2005	NM	
Mount Elinor	25	15	15	Feb-2010	Jan-2011	UT	
Fish Lake Valley	54	no low	16	Feb-2010	Feb-2005	NV	
Lahontan	10	7	17	Nov-2010	Nov-2010	NV	
Hot Creek	41	no low	18	Aug-2007	Dec-2004	NV	
Red Rock Lakes	25	16	19	Oct-2010	Feb-2011	CA	
South Stillwater	16	8	19			NV	
New Ravendale	25	10	20	Nov-2009	Sep-2009	CA	
Paymaster	38	23	20	Feb-2010	Oct-2006	NV	
Round Mountain	10	0	23		Oct-2009	CA	
Liggett Table	25	10	24	Aug-2009	Sep-2009	OR	
Tobin Range	42	25	26	Sep-2010	Nov-2009	NV	
Dogskin Mountains	15	10	30	Apr-2010	Dec-2005	NV	
Choke Cherry	30	no low	30	Dec-2009	Jan-2011	UT	
North Monitor	8	no low	31	Sep-2007	Aug-2005	NV	
North Hills	36	12	33	Feb-2011	Dec-2010	UT	
Fort Sage	29	24	34	Sep-2008	Sep-1998	CA	

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Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State	Sampled
Hog Creek	50	30	36	Sep-2009	Nov-2009	OR	
Four Mile	60	30	36	Mar-2009	Jul-2009	UT	
Palomino Buttes	64	32	39	Sep-2005	Dec-2009	OR	
Sand Basin	64	33	40	Nov-2009	Oct-2009	ID	
Stinkingwater	80	40	40	Jul-2009	Aug-2010	OR	
Four Mile	60	37	44	Nov-2009	Oct-2009	ID	
Whistler Mountain	24	14	44	Sep-2008		NV	
Pokegama	50	30	46	Oct-2004	Jun-2000	OR	
Bitner	25	15	48	Jun-2010	Sep-2007	CA	
Black Mountain	60	30	48	Nov-2010	Nov-2010	ID	
Tilly Creek	50	20	48	Mar-2009	Jul-2010	UT	
Chloride Canyon	30	15	49	Feb-2011	Sep-2009	UT	
Blue Wing Mountains	36	22	51	Nov-2005	Nov-2005	NV	ü
Bordo Atravesado	60	40	51	Jun-2009	Jan-2011	NM	
Cerbat Mountains	90	not set	60	Aug-2006	Feb-2001	AZ	
Little Humboldt	80	48	66	Apr-2011	Jul-2010	NV	ü
Riddle Mountain	56	33	68	Apr-2010	Oct-2007	OR	
Granite Peak	18	11	70	Apr-2010	Jan-2010	NV	
Black Rock Range East	93	56	71	Jun-2010	Jan-2010	NV	ü
Bible Spring	60	30	72	Mar-2009	Dec-2010	UT	
Muddy Creek	125	30	72	Jun-2009	Jul-2009	UT	
Sand Springs	200	100	72	Jun-2010	Sep-2006	OR	ü
Buckhorn	85	59	73	Nov-2009	Dec-2009	CA	

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Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State	Sampled
Coppersmith	75	50	73	Nov-2009	Dec-2009	CA	
Spring Creek Basin	65	35	74	Jun-2010	Aug-2007	CO	ü
Cold Spring	150	75	75	Mar-2010	Jul-2010	OR	
Conger	80	40	76	Mar-2011	Sep-2010	UT	
Reveille	138	83	76	Feb-2010	Sep-2010	NV	ü
Rock Creek Mountain	86	50	77	Jul-2010	Jul-2009	WY	
Montgomery Pass	0	not set	79		Sep-1998	NV	
Little Fish Lake	39	no low	85	Aug-2009	Feb-2006	NV	ü
Wall Canyon	25	15	88	Jun-2010	Sep-2007	CA	
Hard Trigger	130	66	93	Nov-2010	Nov-2010	ID	
Kiger	82	51	100	Apr-2010	Oct-2007	OR	ü
Nightengale Mountains	63	38	101	Nov-2005	Dec-2005	NV	
Fifteenmile	160	70	107	Nov-2009	Nov-2009	WY	
Garfield Flat	125	75	112	Oct-2009	Oct-2009	NV	ü
Shawave Mountains	73	44	112	Nov-2005	Nov-2005	NV	
Goshute	123	74	113	Oct-2010	Feb-2011	NV	
Rocky Hills	143	90	113	Nov-2010	Dec-2010	NV	ü
Crooks Mountain	85	65	115	Aug-2010	Aug-2006	WY	
Paisley Desert	150	60	117	Nov-2009	Dec-2009	OR	ü
Kamma Mountains	77	46	119	Nov-2005	Dec-2005	NV	ü
Conant Creek	100	60	120	Jul-2010	Jul-2009	WY	
McCullough Peaks	140	70	124	Feb-2011	Oct-2009	WY	ü
Little Book Cliffs Wild Horse Range	150	90	135	Jun-2010	Sep-2007	CO	ü

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Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State	Sampled
Bald Mountain	215	129	136	Nov-2010	Dec-2010	NV	
Frisco	60	12	140	Jan-2010	Aug-2006	UT	
Black Rock Range West	93	56	143	Jun-2010	Feb-2010	NV	ü
Diamond Hills North	37	22	145	Mar-2010	Jul-2004	NV	
Jackies Butte	150	75	147	Mar-2010	Oct-2007	OR	ü
Massacre Lakes	35	25	149	Jun-2010	Oct-1988	CA	ü
Range Creek	125	75	149	Feb-2010	Jul-2006	UT	
Dishpan Butte	100	50	155	Jul-2010	Jul-2009	WY	
Lost Creek	82	60	155	Aug-2010	Nov-2009	WY	ü
Confusion	115	70	157	Mar-2010	Sep-2010	UT	
Onaqui Mountain	210	121	159	Feb-2010	Oct-2009	UT	
Pryor Mountain Wild Horse Range	120	100	159			MT	ü
Granite Range	258	155	160	Jun-2010	Feb-2005	NV	
Antelope Hills	82	60	162	Aug-2010	Nov-2009	WY	
Seven Mile	50	no low	162	Sep-2007	Aug-2005	NV	ü
Fish Creek	180	108	163	Sep-2007	Feb-2006	NV	
Saulsbury	40	24	172	Aug-2009	Feb-2007	NV	
Owyhee	231	139	180	Apr-2011	Jul-2010	NV	ü
Pine Nut Mountains	179	118	182	Nov-2010	Dec-2010	NV	
Rock Creek	250	83	185	Apr-2011	Jul-2010	NV	
South Steens	304	159	191	Jul-2009	Nov-2009	OR	ü
Murderers Creek	35	13	198	Jan-2011	Feb-2011	OR	
Eagle	210	126	200	Oct-2010	Jan-2011	NV	

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Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State	Sampled
Silver King	128	76	200	Sep-2010	Oct-2010	NV	ü
Diamond Hills South	22	no low	202	Mar-2010	Jul-2004	NV	
Coyote Lake/Alvord Tule Springs	390	198	212	Jun-2010	Nov-2008	OR	
North Stillwater	205	123	214	Jul-2008	Jul-2008	NV	ü
Nevada Wild Horse Range	500	300	216	Sep-2009	Jul-2008	NV	
Callaghan	237	147	221	Nov-2010	Jan-2011	NV	
South Shoshone	100	60	224	Oct-2009	Jan-2009	NV	ü
Antelope	324	194	239	Oct-2010	Feb-2011	NV	
Swasey	100	60	243	Mar-2011	Jul-2007	UT	
Diamond	151	91	244	Mar-2010	Jul-2004	NV	ü
Fox-Lake Range	204	122	244	Jul-2008	Jul-2008	NV	
Roberts Mountain	150	90	248	Sep-2008	Jan-2008	NV	
Augusta Mountains	308	185	256	Jan-2011	Feb-2011	NV	ü
Little Colorado	100	69	256	Apr-2010	Dec-2007	WY	
Three Fingers	150	75	261	Mar-2010	Aug-2006	OR	
Sulphur	250	165	267	Nov-2010	Dec-2010	UT	ü
Sand Wash Basin	362	163	270	Jun-2010	Oct-2008	CO	
Challis	253	185	270	Jul-2010	Dec-2009	ID	ü
Stewart Creek	175	125	275	Aug-2010	Nov-2009	WY	ü
Lava Beds	148	89	277	Nov-2005	Dec-2005	NV	
Flanigan	125	80	278	Apr-2010	Oct-2006	NV	
Sand Springs West	49	29	285	Apr-2008	Jan-2006	NV	ü
Sheepshead/Heath Creek	302	161	293	Jun-2010	Nov-2008	OR	

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Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State	Sampled
Salt Wells Creek	365	251	300	Sep-2010	Nov-2010	WY	
Piceance-East Douglas Creek	235	135	320	Mar-2010	Oct-2010	CO	ü
Snowstorm Mountains	140	90	320	Apr-2011	Oct-2006	NV	
Muskrat Basin	250	160	359	Jul-2010	Jul-2009	WY	
Cedar Mountain	390	190	362	Feb-2009	Dec-2008	UT	ü
Wassuk	165	109	362	Apr-2010		NV	
Centennial	168	134	366	May-2010	Oct-2010	CA	
New Pass-Ravenswood	566	no low	396	Nov-2010	Jan-2011	NV	ü
Pilot Mountain	415	249	402	Jan-2011	Jan-2005	NV	
Buffalo Hills	314	188	415	Jan-2009	Jan-2009	NV	
Beatys Butte	250	100	416	Nov-2009	Sep-2009	OR	ü
Spruce-Pequop	82	49	423	Oct-2010	Feb-2011	NV	
Calico Mountains	333	200	450	Jun-2010	Feb-2010	NV	
High Rock	120	78	458	Jun-2010	Sep-2006	CA	ü
Stone Cabin	364	218	476	Aug-2009	Feb-2007	NV	
Fox Hog	220	120	479	Jun-2010	Aug-2005	CA	
Green Mountain	300	170	490	Aug-2010	Oct-2009	WY	ü
Clan Alpine	979	619	503	Dec-2010	Oct-2006	NV	
Antelope Valley	259	155	519	Oct-2010	Feb-2011	NV	
Desatoya	180	127	520	Apr-2010	Feb-2004	NV	ü
Jackson Mountains	217	130	520	Sep-2007	Sep-2007	NV	
White Mountain	300	205	545	Apr-2010	Nov-2007	WY	
Maverick-Medicine	276	166	553	Nov-2010	Aug-2006	NV	ü

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Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State	Sampled
Adobe Town	800	610	738	Sep-2010	Nov-2010	WY	
Little Owyhee	298	194	780	Apr-2011	Nov-2004	NV	
Triple B	518	312	1,217	Nov-2010		NV	ü
Pancake	493	296	1,291	Jan-2006		NV	
Divide Basin	600	415	1,355	Nov-2009	Sep-2007	WY	

[a]Upper bound of appropriate management level (AML).
[b]Lower bound of appropriate management level.

NOTE: The following HMAs were removed from Table E-1: All HMAs with zero animals, AMLs of zero, or both; all HMAs with mixed burros and horses; and all burro-only HMAs. All remaining HMAs were numerically ordered by most recent population-size estimate. All HMAs with fewer than 50 horses were excluded. Every third HMA was systematically selected, resulting in 36 HMAs. Four additional HMAs that were used in Eberhardt et al. (1982) and Garrott et al. (1991a) were added to total 40 HMAs sampled.
SOURCE: Spreadsheet and survey request based on information provided to the committee by the Bureau of Land Management in December 2011. Referenced articles are included in Chapter 4.

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TABLE E-3 Surveyed Horse Herd Management Areas Sorted by Population-Size Estimate

Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State
Blue Wing Mountains	36	22	51	Nov-2005	Nov-2005	NV
Little Humboldt	80	48	66	Apr-2011	Jul-2010	NV
Black Rock Range East	93	56	71	Jun-2010	Jan-2010	NV
Sand Springs	200	100	72	Jun-2010	Sep-2006	OR
Spring Creek Basin	65	35	74	Jun-2010	Aug-2007	CO
Reveille	138	83	76	Feb-2010	Sep-2010	NV
Little Fish Lake	39	no low	85	Aug-2009	Feb-2006	NV
Kiger	82	51	100	Apr-2010	Oct-2007	OR
Garfield Flat	125	75	112	Oct-2009	Oct-2009	NV
Rocky Hills	143	90	113	Nov-2010	Dec-2010	NV
Paisley Desert	150	60	117	Nov-2009	Dec-2009	OR
Kamma Mountains	77	46	119	Nov-2005	Dec-2005	NV
McCullough Peaks	140	70	124	Feb-2011	Oct-2009	WY
Little Book Cliffs Wild Horse Range	150	90	135	Jun-2010	Sep-2007	CO
Black Rock Range West	93	56	143	Jun-2010	Feb-2010	NV
Jackies Butte	150	75	147	Mar-2010	Oct-2007	OR
Massacre Lakes	35	25	149	Jun-2010	Oct-1988	CA
Lost Creek	82	60	155	Aug-2010	Nov-2009	WY
Pryor Mountain Wilde Horse Range	120	100	159			MT
Seven Mile	50	no low	162	Sep-2007	Aug-2005	NV
Owyhee	231	139	180	Apr-2011	Jul-2010	NV
South Steens	304	159	191	Jul-2009	Nov-2009	OR

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Herd Management Area	Horse AML High[a]	Horse AML Low[b]	Estimated Horse Population	Most Recent Inventory Month-Year	Last Gather Month-Year	State
Silver King	128	76	200	Sep-2010	Oct-2010	NV
North Stillwater	205	123	214	Jul-2008	Jul-2008	NV
South Shoshone	100	60	224	Oct-2009	Jan-2009	NV
Diamond	151	91	244	Mar-2010	Jul-2004	NV
Augusta Mountains	308	185	256	Jan-2011	Feb-2011	NV
Sulphur	250	165	267	Nov-2010	Dec-2010	UT
Challis	253	185	270	Jul-2010	Dec-2009	ID
Stewart Creek	175	125	275	Aug-2010	Nov-2009	WY
Sand Springs West	49	29	285	Apr-2008	Jan-2006	NV
Piceance-East Douglas Creek	235	135	320	Mar-2010	Oct-2010	CO
Cedar Mountain	390	190	362	Feb-2009	Dec-2008	UT
New Pass-Ravenswood	566	no low	396	Nov-2010	Jan-2011	NV
Beatys Butte	250	100	416	Nov-2009	Sep-2009	OR
High Rock	120	78	458	Jun-2010	Sep-2006	CA
Green Mountain	300	170	490	Aug-2010	Oct-2009	WY
Desatoya	180	127	520	Apr-2010	Feb-2004	NV
Maverick-Medicine	276	166	553	Nov-2010	Aug-2006	NV
Triple B	518	312	1,217	Nov-2010		NV

[a]Upper bound of appropriate management level (AML).
[b]Lower bound of appropriate management level.
SOURCE: Spreadsheet and survey request based on information provided to the committee by the Bureau of Land Management in December 2011.

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Appendix F

Pairwise Values of Genetic Distance (F_{st})

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TABLE F-1 Pairwise Values of Genetic Distance (F_{st}) Between Burro Herd Management Areas Based on 12 Polymorphic Microsatellite DNA Loci

		ki	rc	pa	bv	sv	lf	cm	co	sr	ce	si	yu	ci	pm	bw
Kingman, AZ	**ki**	0.000														
Picacho, CA	**rc**	0.094	0.000													
Pannaments, CA	**pa**	0.070	0.105	0.000												
Butte Valley, CA	**bv**	0.063	0.102	0.040	0.000											
Saline Valley, CA	**sv**	0.070	0.118	0.052	0.048	0.000										
Lee Flats, CA	**lf**	0.155	0.072	0.180	0.155	0.191	0.000									
Clark Mtn., CA	**cm**	0.101	0.078	0.064	0.064	0.079	0.150	0.000								
Chocolate Mule, CA	**co**	0.096	0.010	0.095	0.093	0.118	0.064	0.087	0.000							
Slate Range, CA	**sr**	0.055	0.078	0.036	0.035	0.033	0.143	0.049	0.087	0.000						
Centennial, CA	**ce**	0.075	0.113	0.067	0.064	0.044	0.185	0.081	0.116	0.018	0.000					
Sinbad, UT	**si**	0.093	0.078	0.110	0.097	0.115	0.158	0.108	0.069	0.087	0.136	0.000				
Yuma 1, AZ	**yu**	0.066	0.061	0.089	0.066	0.091	0.119	0.082	0.050	0.058	0.100	0.047	0.000			
Chemehuevi, CA	**ci**	0.147	0.116	0.119	0.129	0.138	0.126	0.125	0.114	0.108	0.147	0.148	0.113	0.000		
Park Moab, CA	**pm**	0.241	0.246	0.223	0.220	0.229	0.259	0.222	0.239	0.210	0.240	0.291	0.236	0.091	0.000	
Blue Wing, NV	**bw**	0.251	0.227	0.257	0.241	0.247	0.354	0.219	0.251	0.222	0.246	0.234	0.209	0.240	0.294	0.000
Seven Tanks, NV	**st**	0.168	0.147	0.194	0.163	0.159	0.219	0.123	0.157	0.137	0.159	0.176	0.124	0.220	0.293	0.161
Ed's Camp, AZ	**ec**	0.152	0.165	0.173	0.145	0.144	0.227	0.151	0.175	0.126	0.143	0.167	0.126	0.166	0.202	0.103
Cibola-Trigo 2, AZ	**ct**	0.065	0.076	0.091	0.070	0.088	0.124	0.084	0.068	0.060	0.094	0.054	0.030	0.117	0.231	0.188
Big Sandy, NV	**bs**	0.062	0.067	0.054	0.054	0.060	0.123	0.061	0.067	0.047	0.080	0.061	0.057	0.113	0.217	0.185
Havasu, AZ	**hv**	0.170	0.168	0.174	0.166	0.181	0.218	0.173	0.173	0.150	0.181	0.185	0.158	0.114	0.104	0.140
Cibola-Trigo 2, AZ	**k2**	0.185	0.200	0.180	0.174	0.189	0.257	0.180	0.203	0.159	0.193	0.199	0.166	0.125	0.107	0.139
East Mohave, CA	**em**	0.173	0.208	0.175	0.167	0.162	0.262	0.204	0.213	0.160	0.179	0.197	0.180	0.163	0.141	0.150
Montezuma, CA	**mz**	0.405	0.398	0.416	0.389	0.451	0.539	0.397	0.374	0.373	0.424	0.409	0.329	0.262	0.355	0.470
Twin Peaks, CA	**tp**	0.210	0.210	0.235	0.211	0.199	0.250	0.223	0.214	0.188	0.204	0.191	0.173	0.154	0.142	0.171
Bullfrog, NV	**bf**	0.220	0.281	0.255	0.229	0.241	0.321	0.269	0.272	0.219	0.238	0.242	0.188	0.198	0.184	0.224

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		st	ec	ct	bs	hv	k2	em	mz	tp	bf
Seven Tanks, NV	**st**	0.000									
Ed's Camp, AZ	**ec**	0.100	0.000								
Cibola-Trigo 2, AZ	**ct**	0.120	0.098	0.000							
Big Sandy, NV	**bs**	0.148	0.132	0.036	0.000						
Havasu, AZ	**hv**	0.226	0.113	0.151	0.143	0.000					
Cibola-Trigo 2, AZ	**k2**	0.210	0.085	0.153	0.159	0.021	0.000				
East Mohave, CA	**em**	0.242	0.098	0.142	0.146	0.055	0.055	0.000			
Montezuma, CA	**mz**	0.436	0.319	0.336	0.384	0.259	0.223	0.302	0.000		
Twin Peaks, CA	**tp**	0.204	0.111	0.164	0.188	0.086	0.082	0.094	0.261	0.000	
Bullfrog, NV	**bf**	0.256	0.123	0.177	0.228	0.122	0.091	0.101	0.204	0.076	0.000

SOURCE: Data provided by E. Gus Cothran. To access the data, contact the National Research Council's Public Access Records Office at paro@nas.edu.

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TABLE F-2 Pairwise Values of Genetic Distance (F_{st}) Values Between Horse Herd Management Areas Based on 12 Polymorphic Microsatellite DNA Loci

	Cibola-Trigo, AZ	Painted Rock, AZ	Bitner, CA (2011)	Buckhorn, CA	Buckhorn, CA (2010)	Carter Reservoir, CA	Centennial, CA
Cibola-Trigo, AZ	0.000						
Painted Rock, AZ	0.249	0.000					
Bitner, CA (2011)	0.149	0.147	0.000				
Buckhorn, CA	0.144	0.129	0.035	0.000			
Buckhorn, CA (2010)	0.141	0.134	0.035	0.009	0.000		
Carter Reservoir, CA	0.142	0.099	0.064	0.053	0.060	0.000	
Centennial, CA	0.134	0.158	0.058	0.048	0.039	0.071	0.000
Coppersmith, CA	0.159	0.170	0.061	0.057	0.054	0.093	0.053
Fox Hog, CA (2011)	0.123	0.144	0.041	0.028	0.023	0.063	0.040
High Rock, CA	0.103	0.120	0.037	0.027	0.023	0.046	0.033
Nut Mountain, CA (2011)	0.122	0.123	0.033	0.035	0.032	0.044	0.044
Santa Cruz Island, CA	0.161	0.212	0.153	0.108	0.104	0.149	0.143
Twin Peaks, CA	0.121	0.122	0.037	0.015	0.014	0.048	0.033
Twin Peaks, CA (All, 2011)	0.120	0.135	0.029	0.022	0.023	0.046	0.029
Twin Peaks, CA (Gilman SP)	0.129	0.141	0.039	0.031	0.032	0.053	0.029
Twin Peaks, CA (S Observa)	0.131	0.136	0.032	0.022	0.022	0.048	0.035
Twin Peaks, CA (Skeddle)	0.116	0.149	0.037	0.036	0.037	0.056	0.035
Wall Canyon, CA (2011)	0.111	0.137	0.053	0.048	0.044	0.057	0.052
Barcus Creek, CO	0.161	0.152	0.065	0.059	0.057	0.075	0.069
East Douglas, CO	0.178	0.137	0.084	0.076	0.078	0.081	0.090
Little Book Cliffs, CO	0.149	0.130	0.048	0.040	0.038	0.055	0.046
Mesa, CO	0.135	0.147	0.047	0.041	0.037	0.063	0.033
Sand Wash, CO	0.162	0.138	0.044	0.041	0.038	0.048	0.050
Spring Creek, CO	0.161	0.141	0.083	0.065	0.060	0.082	0.072
Spring Creek Basin, CO	0.161	0.150	0.074	0.063	0.059	0.079	0.069
West Douglas, CO	0.140	0.166	0.083	0.062	0.061	0.091	0.077

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	Cibola-Trigo, AZ	Painted Rock, AZ	Bitner, CA (2011)	Buckhorn, CA	Buckhorn, CA (2010)	Carter Reservoir, CA	Centennial, CA
West Douglas, CO (2006)	0.134	0.173	0.096	0.069	0.067	0.099	0.077
Black Mountain, ID	0.163	0.145	0.060	0.068	0.069	0.084	0.074
Black Mountain, ID (2010)	0.156	0.133	0.052	0.055	0.053	0.070	0.060
Challis, ID	0.142	0.139	0.050	0.037	0.039	0.061	0.056
Hard Trigger, ID	0.141	0.138	0.046	0.046	0.040	0.060	0.055
Hard Trigger, ID (2010)	0.156	0.142	0.046	0.049	0.044	0.061	0.060
Idaho, ID (BLM)	0.153	0.169	0.051	0.052	0.046	0.083	0.053
Sand Basin, ID	0.127	0.158	0.046	0.043	0.039	0.065	0.050
Saylor Creek, ID	0.154	0.136	0.037	0.037	0.037	0.063	0.058
Pryor Mountains, MT (2001)	0.146	0.175	0.077	0.072	0.069	0.088	0.078
Pryor Mountains, MT (2009)	0.121	0.140	0.049	0.040	0.038	0.058	0.055
Bordo Atravisado, NM	0.152	0.158	0.052	0.041	0.040	0.065	0.043
El Rito, NM	0.147	0.137	0.049	0.033	0.028	0.060	0.038
Jicarilla, NM	0.137	0.135	0.050	0.034	0.034	0.064	0.052
Jarita, NM	0.169	0.129	0.079	0.056	0.047	0.089	0.064
Jicarilla, NM	0.210	0.138	0.090	0.063	0.050	0.111	0.073
Antelope Valley, NV	0.138	0.135	0.046	0.030	0.032	0.053	0.045
Antelope Valley, NV (2011)	0.145	0.129	0.048	0.034	0.037	0.053	0.042
Augusta Mountains, NV	0.128	0.125	0.051	0.036	0.038	0.057	0.042
Bald Mountain, NV	0.116	0.121	0.039	0.023	0.023	0.044	0.040
Black Rock East, NV (2005)	0.145	0.148	0.050	0.051	0.048	0.066	0.066
Black Rock East, NV (2010)	0.131	0.138	0.049	0.046	0.042	0.065	0.058
Black Rock East, NV (2011)	0.140	0.123	0.053	0.041	0.039	0.060	0.047
Black Rock West, NV (2005)	0.110	0.153	0.046	0.050	0.045	0.067	0.058
Black Rock West, NV (2010)	0.113	0.159	0.047	0.050	0.043	0.073	0.053
Black Rock West, NV (2011)	0.129	0.177	0.064	0.072	0.061	0.094	0.052
Buffalo Hills, NV	0.174	0.151	0.051	0.039	0.037	0.071	0.065
Buffalo Hills, NV (2009)	0.152	0.137	0.045	0.027	0.026	0.057	0.053
Calico, NV	0.120	0.136	0.035	0.024	0.020	0.052	0.035

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	Cibola-Trigo, AZ	Painted Rock, AZ	Bitner, CA (2011)	Buckhorn, CA	Buckhorn, CA (2010)	Carter Reservoir, CA	Centennial, CA
Calico Mountains, NV	0.148	0.140	0.042	0.033	0.033	0.068	0.057
Calico Mountains, NV (2011)	0.134	0.141	0.034	0.029	0.025	0.058	0.037
Callaghan, NV (Austin Allot)	0.134	0.110	0.047	0.024	0.024	0.047	0.040
Callaghan, NV (East Allot)	0.118	0.118	0.041	0.025	0.028	0.036	0.037
Catnip Herd, NV	0.143	0.155	0.051	0.044	0.039	0.078	0.059
Chimney Creek, NV	0.129	0.150	0.050	0.046	0.042	0.064	0.057
Desatoya Mountain, NV	0.154	0.155	0.090	0.060	0.066	0.095	0.088
Dolly Varden, NV	0.128	0.144	0.052	0.037	0.029	0.067	0.035
Dry Lake, NV	0.161	0.147	0.062	0.034	0.039	0.080	0.057
Fish Creek, NV	0.135	0.124	0.055	0.039	0.039	0.061	0.044
Goshute, NV	0.167	0.172	0.067	0.047	0.046	0.078	0.046
Goshute, NV (2011)	0.150	0.155	0.062	0.049	0.049	0.069	0.047
Granite, NV	0.127	0.140	0.041	0.027	0.027	0.050	0.038
Granite Range, NV	0.125	0.145	0.044	0.030	0.025	0.052	0.042
Granite Range, NV (2011)	0.126	0.137	0.043	0.025	0.021	0.052	0.031
Grass Valley, NV	0.123	0.119	0.052	0.029	0.030	0.050	0.044
Hall Creek, NV	0.149	0.112	0.051	0.024	0.025	0.055	0.042
Jakes Wash, NV	0.161	0.151	0.078	0.060	0.066	0.081	0.083
Johnnie, NV	0.154	0.118	0.077	0.054	0.058	0.072	0.071
Lahanton Reservoir, NV	0.159	0.169	0.068	0.062	0.056	0.086	0.058
Little Fish Lake, NV	0.159	0.134	0.066	0.051	0.054	0.061	0.044
Little Highrock Canyon, NV	0.148	0.163	0.044	0.039	0.027	0.083	0.042
Little Humboldt, NV	0.168	0.128	0.057	0.045	0.050	0.061	0.068
Little Humboldt, NV (2010)	0.145	0.120	0.043	0.032	0.036	0.052	0.048
Little Owyhee, NV (Fairbanks)	0.156	0.123	0.072	0.043	0.045	0.065	0.054
Little Owyhee, NV (Lake Creek)	0.155	0.129	0.055	0.040	0.035	0.062	0.056
Little Owyhee, NV (Twin Valley)	0.105	0.140	0.057	0.038	0.035	0.065	0.048
Marvel Gap, NV (SWC 2010)	0.140	0.137	0.035	0.033	0.030	0.060	0.049
McGee Mountain, NV	0.121	0.133	0.041	0.032	0.038	0.054	0.050

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	Cibola-Trigo, AZ	Painted Rock, AZ	Bitner, CA (2011)	Buckhorn, CA	Buckhorn, CA (2010)	Carter Reservoir, CA	Centennial, CA
Miller Mountain, NV (SWC 2010)	0.139	0.123	0.044	0.030	0.030	0.044	0.043
Montezuma Peak, NV	0.165	0.176	0.056	0.053	0.046	0.094	0.041
Nellis, NV	0.122	0.120	0.043	0.030	0.036	0.042	0.041
New Pass-Ravenswood, NV	0.109	0.114	0.043	0.024	0.025	0.050	0.043
North Stillwater, NV	0.140	0.140	0.045	0.036	0.037	0.060	0.050
Paymaster, NV (2006)	0.177	0.169	0.056	0.052	0.047	0.087	0.053
Paymaster, NV (2010)	0.179	0.175	0.056	0.054	0.048	0.093	0.051
Pine Nut Mountain, NV	0.159	0.122	0.084	0.055	0.061	0.095	0.072
Powell Mountain, NV	0.203	0.158	0.088	0.067	0.070	0.084	0.067
Red Rock, NV	0.132	0.148	0.058	0.050	0.050	0.071	0.040
Reveille, NV	0.129	0.153	0.053	0.043	0.054	0.057	0.057
Roberts Mountain, NV	0.132	0.131	0.049	0.043	0.043	0.047	0.045
Rock Creek, NV (2002)	0.172	0.143	0.076	0.058	0.064	0.091	0.081
Rock Creek, NV (2010)	0.148	0.121	0.060	0.046	0.051	0.069	0.062
Rocky Hills, NV	0.136	0.149	0.053	0.038	0.036	0.070	0.046
Rodeo Creek, NV	0.131	0.121	0.039	0.025	0.026	0.047	0.034
Saulsbury, NV	0.116	0.117	0.048	0.034	0.036	0.053	0.047
Sand Springs East, NV	0.126	0.131	0.038	0.030	0.038	0.050	0.049
Seven Mile, NV	0.153	0.143	0.054	0.050	0.049	0.068	0.056
Shawave Mountains, NV	0.160	0.127	0.040	0.023	0.019	0.061	0.043
Silver Peak, NV	0.126	0.130	0.058	0.036	0.035	0.051	0.061
Snowstorm, NV (Castle Ridge)	0.169	0.144	0.050	0.037	0.040	0.064	0.056
Snowstorm, NV (Dryhill)	0.151	0.168	0.070	0.070	0.064	0.096	0.067
South Shoshone, NV	0.121	0.123	0.044	0.035	0.037	0.048	0.039
Spruce-Pequop, NV (2011)	0.145	0.153	0.070	0.050	0.048	0.083	0.050
Stillwater, NV	0.147	0.151	0.044	0.043	0.041	0.071	0.052
Stone Cabin, NV	0.121	0.117	0.043	0.030	0.034	0.040	0.046
Warm Springs, NV	0.116	0.137	0.039	0.039	0.037	0.051	0.049
Warm Springs Canyon, NV	0.102	0.130	0.033	0.030	0.028	0.053	0.044

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	Cibola-Trigo, AZ	Painted Rock, AZ	Bitner, CA (2011)	Buckhorn, CA	Buckhorn, CA (2010)	Carter Reservoir, CA	Centennial, CA
Wheeler Pass, NV	0.156	0.141	0.091	0.070	0.074	0.084	0.078
Wheeler Pass, NV (2007)	0.141	0.120	0.050	0.036	0.036	0.056	0.042
Alvord Tule, OR	0.119	0.136	0.059	0.040	0.040	0.056	0.061
Beatys Butte, OR	0.126	0.129	0.039	0.026	0.023	0.046	0.035
Beatys Butte, OR (2010)	0.145	0.133	0.036	0.026	0.020	0.051	0.031
Big Summit, OR (2010)	0.220	0.215	0.129	0.092	0.102	0.121	0.128
Cold Spring, OR	0.119	0.128	0.055	0.038	0.035	0.061	0.044
Cold Spring, OR (2010)	0.140	0.140	0.061	0.041	0.039	0.069	0.048
Coyote Lake, OR	0.125	0.132	0.067	0.043	0.047	0.052	0.062
Coyote Lake, OR (2011)	0.126	0.128	0.051	0.032	0.036	0.049	0.052
Fishnet, OR	0.140	0.147	0.045	0.041	0.041	0.065	0.050
Hog Creek, OR	0.124	0.127	0.060	0.031	0.036	0.059	0.040
Jackies Butte, OR	0.140	0.143	0.062	0.055	0.055	0.074	0.050
Jackies Butte, OR (2011)	0.118	0.140	0.045	0.042	0.041	0.068	0.041
Kiger, OR (2011)	0.163	0.133	0.055	0.039	0.038	0.062	0.060
Kiger Herd, OR (2009)	0.153	0.120	0.058	0.045	0.047	0.052	0.070
Liggett Table, OR	0.196	0.298	0.173	0.164	0.149	0.205	0.157
Murderers Creek, OR (2001)	0.197	0.128	0.088	0.079	0.076	0.091	0.094
Murderers Creek, OR (2009)	0.183	0.122	0.080	0.067	0.063	0.077	0.082
Paisley Desert, OR	0.119	0.119	0.036	0.026	0.029	0.041	0.038
Riddle Herd, OR (2009)	0.150	0.149	0.061	0.051	0.046	0.074	0.073
Riddle Mountain, OR	0.155	0.149	0.063	0.050	0.043	0.079	0.073
Riddle Mountain, OR (2011)	0.149	0.148	0.067	0.058	0.053	0.076	0.080
Sand Springs, OR (2011)	0.145	0.133	0.050	0.025	0.029	0.056	0.055
Sheepshead, OR	0.144	0.104	0.054	0.036	0.036	0.044	0.051
Sheepshead, OR (2011)	0.142	0.115	0.049	0.032	0.032	0.051	0.048
South Steens, OR	0.118	0.118	0.046	0.031	0.029	0.051	0.045
South Steens, OR (2010)	0.125	0.122	0.045	0.032	0.029	0.054	0.034
Stinkingwater, OR	0.151	0.152	0.075	0.065	0.065	0.082	0.066

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	Cibola-Trigo, AZ	Painted Rock, AZ	Bitner, CA (2011)	Buckhorn, CA	Buckhorn, CA (2010)	Carter Reservoir, CA	Centennial, CA
Three Fingers, OR	0.159	0.143	0.047	0.050	0.045	0.069	0.063
Three Fingers, OR (2011)	0.140	0.132	0.048	0.047	0.046	0.065	0.058
Warm Springs, OR	0.117	0.121	0.038	0.033	0.034	0.057	0.046
Warm Springs, OR (2010)	0.111	0.121	0.040	0.033	0.031	0.056	0.044
Blawn Wash, UT	0.135	0.191	0.085	0.075	0.076	0.096	0.064
Cedar Mountain, UT	0.096	0.129	0.065	0.046	0.046	0.061	0.053
Cedar Ridge, UT	0.176	0.161	0.086	0.069	0.068	0.096	0.093
Cedar Ridge, UT (trap)	0.182	0.170	0.091	0.069	0.069	0.102	0.092
Cold Springs, UT (2006)	0.147	0.212	0.081	0.091	0.090	0.136	0.112
Cold Springs, UT (trap)	0.132	0.176	0.071	0.065	0.072	0.099	0.086
Delta, UT	0.136	0.107	0.048	0.027	0.031	0.042	0.042
Hill Creek, UT	0.141	0.128	0.048	0.033	0.034	0.056	0.052
Muddy Creek, UT	0.179	0.196	0.108	0.078	0.089	0.109	0.087
North Hills, UT	0.162	0.145	0.092	0.072	0.070	0.089	0.081
Range Creek, UT	0.127	0.149	0.051	0.046	0.045	0.080	0.069
Sinbad, UT	0.201	0.149	0.090	0.056	0.064	0.091	0.086
Sulphur, UT	0.212	0.185	0.118	0.100	0.101	0.104	0.097
Sulphur Herd, UT (South, 2006)	0.163	0.122	0.071	0.051	0.049	0.073	0.083
Tilley Creek, UT	0.199	0.211	0.076	0.070	0.066	0.103	0.070
Winter Ridge, UT	0.159	0.117	0.051	0.036	0.034	0.054	0.040
Adobe Town, WY	0.154	0.129	0.043	0.028	0.030	0.053	0.040
Adobe Town, WY (2011)	0.138	0.137	0.029	0.026	0.021	0.055	0.033
Antelope Hills, WY	0.144	0.135	0.057	0.038	0.037	0.062	0.062
Conant Creek, WY (Lander)	0.180	0.162	0.076	0.062	0.064	0.070	0.065
Cooper Creek, WY	0.134	0.120	0.053	0.034	0.038	0.049	0.046
Dishpan Butte, WY (Lander)	0.168	0.150	0.064	0.042	0.047	0.067	0.057
Divide Basin, WY	0.127	0.110	0.042	0.021	0.022	0.044	0.041
Divide Basin, WY (2011)	0.137	0.113	0.043	0.022	0.025	0.046	0.040
Eagles Nest, WY	0.159	0.143	0.078	0.050	0.054	0.062	0.072

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	Cibola-Trigo, AZ	Painted Rock, AZ	Bitner, CA (2011)	Buckhorn, CA	Buckhorn, CA (2010)	Carter Reservoir, CA	Centennial, CA
Happy Creek Springs, WY	0.169	0.152	0.068	0.046	0.052	0.071	0.077
Little Colorado, WY	0.130	0.139	0.050	0.042	0.037	0.066	0.050
Little Colorado, WY (2011)	0.130	0.134	0.047	0.039	0.033	0.064	0.043
Lost Creek, WY	0.126	0.107	0.054	0.027	0.028	0.045	0.045
Lost Creek, WY (combined)	0.127	0.115	0.054	0.027	0.030	0.048	0.046
McCullough Peaks, WY	0.151	0.128	0.058	0.040	0.041	0.060	0.064
Muskrat Basin, WY (Lander)	0.161	0.146	0.069	0.046	0.052	0.059	0.062
Salt Wells, WY (East)	0.116	0.134	0.040	0.030	0.027	0.051	0.029
Salt Wells, WY (West)	0.139	0.117	0.044	0.028	0.029	0.046	0.045
Stewart Creek, WY	0.132	0.115	0.064	0.038	0.039	0.051	0.063
Stewart Creek, WY (2009)	0.150	0.125	0.058	0.038	0.041	0.047	0.059
White Mountain, WY (2011)	0.160	0.147	0.049	0.039	0.033	0.060	0.028

	Coppersmith, CA	Fox Hog, CA (2011)	High Rock, CA	Nut Mountain, CA (2011)	Santa Cruz Island, CA	Twin Peaks, CA	Twin Peaks, CA (All, 2011)
Coppersmith, CA	0.000						
Fox Hog, CA (2011)	0.059	0.000					
High Rock, CA	0.052	0.021	0.000				
Nut Mountain, CA (2011)	0.060	0.031	0.013	0.000			
Santa Cruz Island, CA	0.143	0.119	0.102	0.114	0.000		
Twin Peaks, CA	0.041	0.021	0.018	0.024	0.095	0.000	
Twin Peaks, CA (All, 2011)	0.042	0.027	0.019	0.025	0.109	0.009	0.000
Twin Peaks, CA (Gilman SP)	0.048	0.030	0.024	0.032	0.128	0.021	0.012
Twin Peaks, CA (S Observa)	0.047	0.031	0.024	0.029	0.110	0.010	0.003
Twin Peaks, CA (Skeddle)	0.048	0.034	0.025	0.031	0.116	0.020	0.006
Wall Canyon, CA (2011)	0.070	0.048	0.018	0.022	0.106	0.036	0.037
Barcus Creek, CO	0.078	0.057	0.054	0.066	0.152	0.051	0.043
East Douglas, CO	0.096	0.075	0.073	0.071	0.163	0.064	0.070
Little Book Cliffs, CO	0.059	0.043	0.033	0.044	0.121	0.028	0.024
Mesa, CO	0.044	0.040	0.033	0.042	0.116	0.024	0.019

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	Coppersmith, CA	Fox Hog, CA (2011)	High Rock, CA	Nut Mountain, CA (2011)	Santa Cruz Island, CA	Twin Peaks, CA	Twin Peaks, CA (All, 2011)
Sand Wash, CO	0.064	0.037	0.040	0.043	0.151	0.034	0.030
Spring Creek, CO	0.085	0.059	0.042	0.050	0.115	0.052	0.059
Spring Creek Basin, CO	0.076	0.057	0.045	0.046	0.120	0.049	0.056
West Douglas, CO	0.093	0.063	0.051	0.063	0.117	0.050	0.054
West Douglas, CO (2006)	0.089	0.075	0.056	0.070	0.109	0.054	0.059
Black Mountain, ID	0.075	0.073	0.054	0.052	0.151	0.057	0.059
Black Mountain, ID (2010)	0.067	0.057	0.045	0.044	0.153	0.043	0.047
Challis, ID	0.071	0.035	0.034	0.033	0.102	0.028	0.030
Hard Trigger, ID	0.056	0.047	0.039	0.038	0.139	0.037	0.044
Hard Trigger, ID (2010)	0.059	0.053	0.042	0.036	0.148	0.042	0.048
Idaho, ID (BLM)	0.057	0.052	0.049	0.046	0.154	0.045	0.050
Sand Basin, ID	0.056	0.039	0.036	0.041	0.149	0.039	0.042
Saylor Creek, ID	0.064	0.046	0.039	0.036	0.144	0.032	0.035
Pryor Mountains, MT (2001)	0.092	0.062	0.056	0.059	0.145	0.061	0.063
Pryor Mountains, MT (2009)	0.073	0.034	0.031	0.037	0.123	0.034	0.036
Bordo Atravisado, NM	0.059	0.040	0.040	0.046	0.112	0.028	0.031
El Rito, NM	0.059	0.043	0.032	0.044	0.133	0.027	0.032
Jicarilla, NM	0.059	0.039	0.032	0.039	0.135	0.029	0.035
Jarita, NM	0.081	0.066	0.055	0.069	0.157	0.048	0.055
Jicarilla, NM	0.097	0.076	0.070	0.087	0.174	0.056	0.072
Antelope Valley, NV	0.060	0.037	0.035	0.038	0.101	0.026	0.028
Antelope Valley, NV (2011)	0.060	0.044	0.035	0.041	0.109	0.027	0.031
Augusta Mountains, NV	0.061	0.046	0.035	0.048	0.108	0.026	0.029
Bald Mountain, NV	0.050	0.032	0.023	0.030	0.098	0.014	0.016
Black Rock East, NV (2005)	0.072	0.059	0.041	0.040	0.113	0.032	0.031
Black Rock East, NV (2010)	0.064	0.052	0.036	0.038	0.104	0.028	0.029
Black Rock East, NV (2011)	0.061	0.047	0.034	0.040	0.111	0.025	0.028
Black Rock West, NV (2005)	0.067	0.049	0.028	0.027	0.106	0.033	0.034
Black Rock West, NV (2010)	0.068	0.048	0.030	0.031	0.102	0.031	0.031

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	Coppersmith, CA	Fox Hog, CA (2011)	High Rock, CA	Nut Mountain, CA (2011)	Santa Cruz Island, CA	Twin Peaks, CA	Twin Peaks, CA (All, 2011)
Black Rock West, NV (2011)	0.081	0.069	0.040	0.043	0.136	0.055	0.053
Buffalo Hills, NV	0.067	0.032	0.048	0.056	0.143	0.038	0.036
Buffalo Hills, NV (2009)	0.063	0.024	0.036	0.049	0.127	0.028	0.029
Calico, NV	0.052	0.008	0.016	0.026	0.111	0.015	0.018
Calico Mountains, NV	0.078	0.022	0.033	0.045	0.132	0.030	0.036
Calico Mountains, NV (2011)	0.067	0.013	0.019	0.030	0.136	0.024	0.023
Callaghan, NV (Austin Allot)	0.052	0.029	0.026	0.036	0.105	0.015	0.018
Callaghan, NV (East Allot)	0.047	0.033	0.022	0.029	0.104	0.017	0.016
Catnip Herd, NV	0.075	0.039	0.035	0.044	0.124	0.036	0.042
Chimney Creek, NV	0.055	0.033	0.032	0.042	0.128	0.033	0.035
Desatoya Mountain, NV	0.094	0.074	0.065	0.071	0.130	0.048	0.064
Dolly Varden, NV	0.057	0.037	0.029	0.036	0.104	0.025	0.031
Dry Lake, NV	0.061	0.034	0.041	0.053	0.137	0.027	0.032
Fish Creek, NV	0.057	0.035	0.028	0.039	0.123	0.021	0.027
Goshute, NV	0.067	0.049	0.046	0.052	0.137	0.034	0.041
Goshute, NV (2011)	0.064	0.048	0.040	0.046	0.133	0.034	0.038
Granite, NV	0.065	0.021	0.027	0.033	0.124	0.018	0.018
Granite Range, NV	0.066	0.019	0.028	0.037	0.118	0.020	0.022
Granite Range, NV (2011)	0.058	0.015	0.021	0.031	0.119	0.015	0.015
Grass Valley, NV	0.059	0.034	0.029	0.039	0.107	0.022	0.028
Hall Creek, NV	0.057	0.037	0.034	0.043	0.107	0.020	0.021
Jakes Wash, NV	0.099	0.073	0.058	0.068	0.136	0.051	0.050
Johnnie, NV	0.074	0.065	0.042	0.050	0.112	0.039	0.045
Lahanton Reservoir, NV	0.070	0.058	0.059	0.060	0.149	0.044	0.048
Little Fish Lake, NV	0.068	0.054	0.050	0.059	0.157	0.037	0.039
Little Highrock Canyon, NV	0.052	0.025	0.031	0.043	0.137	0.029	0.032
Little Humboldt, NV	0.071	0.064	0.060	0.056	0.143	0.040	0.043
Little Humboldt, NV (2010)	0.058	0.044	0.040	0.038	0.120	0.029	0.029
Little Owyhee, NV (Fairbanks)	0.087	0.046	0.045	0.063	0.130	0.041	0.041

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	Coppersmith, CA	Fox Hog, CA (2011)	High Rock, CA	Nut Mountain, CA (2011)	Santa Cruz Island, CA	Twin Peaks, CA	Twin Peaks, CA (All, 2011)
Little Owyhee, NV (Lake Creek)	0.065	0.048	0.042	0.054	0.134	0.041	0.045
Little Owyhee, NV (Twin Valley)	0.062	0.038	0.031	0.035	0.115	0.028	0.032
Marvel Gap, NV (SWC 2010)	0.045	0.042	0.033	0.034	0.123	0.025	0.030
McGee Mountain, NV	0.065	0.038	0.032	0.034	0.119	0.027	0.027
Miller Mountain, NV (SWC 2010)	0.053	0.040	0.027	0.037	0.117	0.023	0.021
Montezuma Peak, NV	0.068	0.045	0.044	0.054	0.157	0.042	0.041
Nellis, NV	0.052	0.032	0.028	0.033	0.115	0.019	0.018
New Pass-Ravenswood, NV	0.048	0.027	0.023	0.030	0.090	0.013	0.018
North Stillwater, NV	0.063	0.037	0.030	0.047	0.124	0.034	0.031
Paymaster, NV (2006)	0.077	0.051	0.052	0.055	0.167	0.041	0.041
Paymaster, NV (2010)	0.074	0.044	0.052	0.056	0.167	0.042	0.041
Pine Nut Mountain, NV	0.086	0.063	0.051	0.067	0.140	0.046	0.054
Powell Mountain, NV	0.095	0.069	0.070	0.072	0.156	0.057	0.054
Red Rock, NV	0.068	0.053	0.044	0.052	0.131	0.033	0.033
Reveille, NV	0.067	0.056	0.049	0.054	0.128	0.038	0.029
Roberts Mountain, NV	0.067	0.047	0.032	0.042	0.136	0.031	0.031
Rock Creek, NV (2002)	0.088	0.075	0.055	0.053	0.137	0.051	0.054
Rock Creek, NV (2010)	0.070	0.061	0.044	0.042	0.119	0.038	0.040
Rocky Hills, NV	0.057	0.041	0.032	0.038	0.122	0.022	0.027
Rodeo Creek, NV	0.053	0.032	0.025	0.032	0.111	0.020	0.018
Saulsbury, NV	0.061	0.032	0.033	0.040	0.104	0.024	0.025
Sand Springs East, NV	0.064	0.038	0.033	0.034	0.123	0.027	0.026
Seven Mile, NV	0.073	0.043	0.041	0.045	0.149	0.040	0.045
Shawave Mountains, NV	0.058	0.030	0.031	0.040	0.113	0.022	0.029
Silver Peak, NV	0.073	0.041	0.033	0.045	0.123	0.029	0.030
Snowstorm, NV (Castle Ridge)	0.061	0.050	0.046	0.043	0.141	0.033	0.031
Snowstorm, NV (Dryhill)	0.065	0.062	0.056	0.063	0.153	0.062	0.055
South Shoshone, NV	0.051	0.040	0.028	0.034	0.122	0.023	0.025
Spruce-Pequop, NV (2011)	0.080	0.055	0.045	0.058	0.106	0.038	0.045

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	Coppersmith, CA	Fox Hog, CA (2011)	High Rock, CA	Nut Mountain, CA (2011)	Santa Cruz Island, CA	Twin Peaks, CA	Twin Peaks, CA (All, 2011)
Stillwater, NV	0.064	0.049	0.036	0.052	0.127	0.041	0.038
Stone Cabin, NV	0.058	0.035	0.028	0.033	0.117	0.023	0.023
Warm Springs, NV	0.063	0.041	0.020	0.021	0.120	0.029	0.025
Warm Springs Canyon, NV	0.056	0.030	0.014	0.022	0.098	0.021	0.021
Wheeler Pass, NV	0.087	0.082	0.057	0.066	0.136	0.053	0.055
Wheeler Pass, NV (2007)	0.055	0.042	0.031	0.041	0.122	0.023	0.025
Alvord Tule, OR	0.082	0.038	0.027	0.031	0.097	0.034	0.036
Beatys Butte, OR	0.052	0.028	0.026	0.033	0.112	0.016	0.019
Beatys Butte, OR (2010)	0.047	0.028	0.026	0.030	0.122	0.020	0.027
Big Summit, OR (2010)	0.125	0.117	0.110	0.116	0.182	0.093	0.103
Cold Spring, OR	0.056	0.038	0.029	0.042	0.098	0.021	0.025
Cold Spring, OR (2010)	0.055	0.046	0.036	0.047	0.110	0.025	0.029
Coyote Lake, OR	0.076	0.041	0.034	0.043	0.105	0.031	0.036
Coyote Lake, OR (2011)	0.062	0.031	0.026	0.031	0.098	0.022	0.025
Fishnet, OR	0.062	0.041	0.035	0.043	0.139	0.031	0.026
Hog Creek, OR	0.058	0.037	0.029	0.038	0.109	0.024	0.026
Jackies Butte, OR	0.063	0.044	0.040	0.043	0.126	0.040	0.037
Jackies Butte, OR (2011)	0.055	0.030	0.025	0.029	0.114	0.030	0.027
Kiger, OR (2011)	0.083	0.040	0.044	0.046	0.140	0.031	0.029
Kiger Herd, OR (2009)	0.086	0.044	0.042	0.045	0.134	0.036	0.034
Liggett Table, OR	0.179	0.157	0.131	0.139	0.219	0.142	0.148
Murderers Creek, OR (2001)	0.109	0.082	0.077	0.079	0.166	0.070	0.075
Murderers Creek, OR (2009)	0.098	0.059	0.066	0.071	0.161	0.056	0.062
Paisley Desert, OR	0.049	0.028	0.023	0.030	0.107	0.017	0.015
Riddle Herd, OR (2009)	0.095	0.052	0.047	0.047	0.134	0.040	0.038
Riddle Mountain, OR	0.093	0.054	0.046	0.045	0.126	0.036	0.039
Riddle Mountain, OR (2011)	0.102	0.060	0.053	0.054	0.148	0.046	0.044
Sand Springs, OR (2011)	0.069	0.031	0.032	0.040	0.117	0.021	0.028
Sheepshead, OR	0.073	0.036	0.030	0.037	0.119	0.024	0.032

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	Coppersmith, CA	Fox Hog, CA (2011)	High Rock, CA	Nut Mountain, CA (2011)	Santa Cruz Island, CA	Twin Peaks, CA	Twin Peaks, CA (All, 2011)
Sheepshead, OR (2011)	0.059	0.038	0.029	0.036	0.114	0.019	0.023
South Steens, OR	0.053	0.031	0.020	0.028	0.098	0.023	0.027
South Steens, OR (2010)	0.055	0.024	0.019	0.029	0.114	0.025	0.026
Stinkingwater, OR	0.074	0.070	0.048	0.052	0.125	0.051	0.053
Three Fingers, OR	0.075	0.054	0.048	0.049	0.162	0.036	0.036
Three Fingers, OR (2011)	0.069	0.054	0.041	0.041	0.146	0.033	0.034
Warm Springs, OR	0.053	0.033	0.025	0.028	0.110	0.023	0.026
Warm Springs, OR (2010)	0.049	0.033	0.027	0.030	0.108	0.020	0.024
Blawn Wash, UT	0.092	0.066	0.058	0.069	0.158	0.060	0.051
Cedar Mountain, UT	0.070	0.041	0.035	0.049	0.109	0.034	0.034
Cedar Ridge, UT	0.104	0.067	0.067	0.066	0.155	0.059	0.064
Cedar Ridge, UT (trap)	0.107	0.074	0.071	0.074	0.146	0.067	0.068
Cold Springs, UT (2006)	0.104	0.076	0.080	0.087	0.168	0.084	0.091
Cold Springs, UT (trap)	0.088	0.062	0.060	0.066	0.130	0.062	0.062
Delta, UT	0.060	0.038	0.030	0.037	0.109	0.021	0.023
Hill Creek, UT	0.061	0.040	0.037	0.047	0.120	0.032	0.033
Muddy Creek, UT	0.110	0.087	0.085	0.100	0.158	0.071	0.070
North Hills, UT	0.082	0.077	0.077	0.077	0.147	0.053	0.066
Range Creek, UT	0.072	0.038	0.041	0.044	0.124	0.039	0.044
Sinbad, UT	0.110	0.066	0.064	0.071	0.150	0.055	0.064
Sulphur, UT	0.115	0.098	0.100	0.115	0.206	0.083	0.088
Sulphur Herd, UT (South, 2006)	0.081	0.058	0.055	0.063	0.132	0.043	0.052
Tilley Creek, UT	0.084	0.074	0.072	0.077	0.191	0.057	0.050
Winter Ridge, UT	0.055	0.039	0.033	0.041	0.136	0.029	0.034
Adobe Town, WY	0.053	0.047	0.036	0.040	0.121	0.027	0.028
Adobe Town, WY (2011)	0.040	0.030	0.027	0.031	0.119	0.021	0.022
Antelope Hills, WY	0.079	0.040	0.040	0.042	0.116	0.032	0.040
Conant Creek, WY (Lander)	0.095	0.070	0.051	0.068	0.169	0.055	0.045
Cooper Creek, WY	0.062	0.039	0.034	0.042	0.125	0.022	0.025

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	Coppersmith, CA	Fox Hog, CA (2011)	High Rock, CA	Nut Mountain, CA (2011)	Santa Cruz Island, CA	Twin Peaks, CA	Twin Peaks, CA (All, 2011)
Dishpan Butte, WY (Lander)	0.075	0.062	0.042	0.049	0.143	0.035	0.033
Divide Basin, WY	0.051	0.027	0.024	0.026	0.103	0.013	0.020
Divide Basin, WY (2011)	0.052	0.033	0.027	0.033	0.112	0.016	0.022
Eagles Nest, WY	0.085	0.068	0.050	0.057	0.129	0.047	0.053
Happy Creek Springs, WY	0.081	0.051	0.047	0.054	0.154	0.038	0.046
Little Colorado, WY	0.063	0.046	0.031	0.035	0.117	0.031	0.033
Little Colorado, WY (2011)	0.055	0.038	0.026	0.029	0.117	0.025	0.028
Lost Creek, WY	0.057	0.035	0.025	0.031	0.105	0.021	0.027
Lost Creek, WY (combined)	0.060	0.038	0.024	0.033	0.110	0.022	0.027
McCullough Peaks, WY	0.065	0.044	0.029	0.036	0.133	0.032	0.034
Muskrat Basin, WY (Lander)	0.082	0.064	0.047	0.054	0.136	0.038	0.037
Salt Wells, WY (East)	0.043	0.028	0.023	0.030	0.111	0.022	0.021
Salt Wells, WY (West)	0.059	0.041	0.033	0.041	0.110	0.020	0.020
Stewart Creek, WY	0.077	0.041	0.031	0.038	0.113	0.031	0.037
Stewart Creek, WY (2009)	0.072	0.048	0.037	0.039	0.133	0.032	0.036
White Mountain, WY (2011)	0.059	0.033	0.033	0.035	0.149	0.028	0.027

	Twin Peaks, CA (Gilman SP)	Twin Peaks, CA (S Observa)	Twin Peaks, CA (Skeddle)	Wall Canyon, CA (2011)	Barcus Creek, CO	East Douglas, CO	Little Book Cliffs, CO
Twin Peaks, CA (Gilman SP)	0.000						
Twin Peaks, CA (S Observa)	0.023	0.000					
Twin Peaks, CA (Skeddle)	0.016	0.016	0.000				
Wall Canyon, CA (2011)	0.043	0.042	0.043	0.000			
Barcus Creek, CO	0.056	0.047	0.048	0.073	0.000		
East Douglas, CO	0.073	0.073	0.079	0.077	0.094	0.000	
Little Book Cliffs, CO	0.039	0.025	0.032	0.060	0.048	0.089	0.000
Mesa, CO	0.032	0.023	0.022	0.048	0.035	0.074	0.030
Sand Wash, CO	0.035	0.035	0.037	0.065	0.059	0.067	0.045
Spring Creek, CO	0.060	0.062	0.070	0.059	0.087	0.106	0.067
Spring Creek Basin, CO	0.059	0.058	0.067	0.060	0.087	0.099	0.071

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	Twin Peaks, CA (Gilman SP)	Twin Peaks, CA (S Observa)	Twin Peaks, CA (Skeddle)	Wall Canyon, CA (2011)	Barcus Creek, CO	East Douglas, CO	Little Book Cliffs, CO
West Douglas, CO	0.052	0.062	0.059	0.067	0.096	0.076	0.076
West Douglas, CO (2006)	0.059	0.065	0.065	0.072	0.105	0.094	0.076
Black Mountain, ID	0.069	0.060	0.071	0.067	0.096	0.082	0.077
Black Mountain, ID (2010)	0.056	0.048	0.058	0.060	0.075	0.080	0.059
Challis, ID	0.041	0.032	0.039	0.044	0.066	0.070	0.047
Hard Trigger, ID	0.043	0.048	0.055	0.054	0.091	0.076	0.062
Hard Trigger, ID (2010)	0.051	0.053	0.057	0.056	0.090	0.080	0.066
Idaho, ID (BLM)	0.053	0.053	0.060	0.068	0.085	0.086	0.063
Sand Basin, ID	0.046	0.046	0.049	0.066	0.075	0.103	0.053
Saylor Creek, ID	0.039	0.039	0.044	0.052	0.070	0.060	0.059
Pryor Mountains, MT (2001)	0.063	0.071	0.065	0.070	0.094	0.079	0.067
Pryor Mountains, MT (2009)	0.035	0.044	0.040	0.049	0.073	0.075	0.058
Bordo Atravisado, NM	0.035	0.034	0.039	0.051	0.063	0.078	0.047
El Rito, NM	0.032	0.037	0.039	0.060	0.063	0.081	0.040
Jicarilla, NM	0.032	0.041	0.044	0.059	0.076	0.076	0.046
Jarita, NM	0.055	0.060	0.065	0.082	0.088	0.105	0.067
Jicarilla, NM	0.077	0.074	0.085	0.101	0.101	0.125	0.073
Antelope Valley, NV	0.039	0.031	0.036	0.057	0.059	0.086	0.035
Antelope Valley, NV (2011)	0.038	0.035	0.038	0.055	0.060	0.086	0.036
Augusta Mountains, NV	0.034	0.034	0.035	0.056	0.057	0.067	0.046
Bald Mountain, NV	0.025	0.020	0.020	0.036	0.046	0.063	0.030
Black Rock East, NV (2005)	0.047	0.033	0.038	0.038	0.071	0.074	0.059
Black Rock East, NV (2010)	0.040	0.031	0.036	0.035	0.068	0.071	0.056
Black Rock East, NV (2011)	0.034	0.031	0.036	0.039	0.065	0.057	0.052
Black Rock West, NV (2005)	0.045	0.038	0.038	0.021	0.078	0.074	0.066
Black Rock West, NV (2010)	0.046	0.035	0.034	0.027	0.073	0.081	0.061
Black Rock West, NV (2011)	0.061	0.060	0.054	0.033	0.102	0.118	0.083
Buffalo Hills, NV	0.043	0.041	0.043	0.074	0.050	0.102	0.048
Buffalo Hills, NV (2009)	0.031	0.034	0.037	0.063	0.048	0.081	0.040

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	Twin Peaks, CA (Gilman SP)	Twin Peaks, CA (S Observa)	Twin Peaks, CA (Skeddle)	Wall Canyon, CA (2011)	Barcus Creek, CO	East Douglas, CO	Little Book Cliffs, CO
Calico, NV	0.028	0.020	0.026	0.039	0.047	0.068	0.032
Calico Mountains, NV	0.039	0.039	0.046	0.062	0.059	0.080	0.049
Calico Mountains, NV (2011)	0.030	0.027	0.031	0.043	0.046	0.075	0.036
Callaghan, NV (Austin Allot)	0.022	0.022	0.025	0.046	0.048	0.055	0.038
Callaghan, NV (East Allot)	0.024	0.021	0.022	0.037	0.051	0.070	0.031
Catnip Herd, NV	0.044	0.049	0.046	0.053	0.070	0.074	0.070
Chimney Creek, NV	0.041	0.042	0.039	0.045	0.076	0.064	0.059
Desatoya Mountain, NV	0.064	0.070	0.071	0.078	0.114	0.079	0.093
Dolly Varden, NV	0.037	0.036	0.036	0.047	0.058	0.089	0.040
Dry Lake, NV	0.040	0.036	0.037	0.066	0.075	0.071	0.056
Fish Creek, NV	0.031	0.031	0.033	0.054	0.063	0.075	0.041
Goshute, NV	0.049	0.046	0.047	0.062	0.078	0.095	0.057
Goshute, NV (2011)	0.045	0.044	0.041	0.057	0.071	0.093	0.057
Granite, NV	0.026	0.020	0.027	0.044	0.048	0.073	0.038
Granite Range, NV	0.030	0.023	0.033	0.055	0.059	0.088	0.037
Granite Range, NV (2011)	0.024	0.018	0.023	0.047	0.044	0.080	0.030
Grass Valley, NV	0.029	0.033	0.034	0.046	0.057	0.067	0.045
Hall Creek, NV	0.028	0.024	0.030	0.051	0.053	0.056	0.042
Jakes Wash, NV	0.063	0.055	0.051	0.080	0.080	0.094	0.068
Johnnie, NV	0.047	0.048	0.056	0.054	0.078	0.081	0.050
Lahanton Reservoir, NV	0.058	0.054	0.051	0.078	0.098	0.089	0.076
Little Fish Lake, NV	0.037	0.046	0.046	0.068	0.076	0.077	0.059
Little Highrock Canyon, NV	0.042	0.034	0.041	0.063	0.067	0.095	0.038
Little Humboldt, NV	0.051	0.044	0.054	0.076	0.076	0.089	0.058
Little Humboldt, NV (2010)	0.041	0.030	0.040	0.062	0.067	0.070	0.042
Little Owyhee, NV (Fairbanks)	0.044	0.045	0.050	0.064	0.066	0.082	0.058
Little Owyhee, NV (Lake Creek)	0.044	0.049	0.054	0.061	0.078	0.080	0.057
Little Owyhee, NV (Twin Valley)	0.039	0.035	0.040	0.047	0.073	0.086	0.049
Marvel Gap, NV (SWC 2010)	0.032	0.034	0.039	0.051	0.053	0.064	0.045

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	Twin Peaks, CA (Gilman SP)	Twin Peaks, CA (S Observa)	Twin Peaks, CA (Skeddle)	Wall Canyon, CA (2011)	Barcus Creek, CO	East Douglas, CO	Little Book Cliffs, CO
McGee Mountain, NV	0.031	0.032	0.034	0.043	0.066	0.065	0.052
Miller Mountain, NV (SWC 2010)	0.025	0.027	0.026	0.045	0.057	0.067	0.038
Montezuma Peak, NV	0.046	0.048	0.045	0.073	0.075	0.125	0.060
Nellis, NV	0.026	0.023	0.023	0.042	0.054	0.064	0.043
New Pass-Ravenswood, NV	0.031	0.021	0.025	0.038	0.058	0.056	0.038
North Stillwater, NV	0.034	0.038	0.035	0.059	0.051	0.092	0.038
Paymaster, NV (2006)	0.050	0.046	0.046	0.077	0.075	0.114	0.059
Paymaster, NV (2010)	0.049	0.047	0.044	0.079	0.074	0.115	0.063
Pine Nut Mountain, NV	0.064	0.057	0.062	0.076	0.082	0.097	0.061
Powell Mountain, NV	0.067	0.055	0.064	0.093	0.088	0.079	0.075
Red Rock, NV	0.036	0.038	0.039	0.059	0.060	0.101	0.040
Reveille, NV	0.036	0.034	0.033	0.060	0.084	0.080	0.057
Roberts Mountain, NV	0.039	0.035	0.039	0.048	0.054	0.068	0.046
Rock Creek, NV (2002)	0.070	0.054	0.066	0.080	0.092	0.096	0.066
Rock Creek, NV (2010)	0.050	0.043	0.049	0.065	0.073	0.073	0.057
Rocky Hills, NV	0.036	0.031	0.033	0.054	0.067	0.069	0.048
Rodeo Creek, NV	0.025	0.022	0.025	0.048	0.057	0.081	0.030
Saulsbury, NV	0.032	0.032	0.026	0.048	0.064	0.061	0.043
Sand Springs East, NV	0.030	0.030	0.033	0.045	0.065	0.065	0.050
Seven Mile, NV	0.045	0.052	0.050	0.062	0.073	0.081	0.056
Shawave Mountains, NV	0.034	0.030	0.040	0.051	0.063	0.071	0.039
Silver Peak, NV	0.039	0.035	0.035	0.056	0.058	0.089	0.050
Snowstorm, NV (Castle Ridge)	0.051	0.031	0.039	0.070	0.070	0.075	0.050
Snowstorm, NV (Dryhill)	0.064	0.060	0.060	0.076	0.072	0.126	0.075
South Shoshone, NV	0.031	0.030	0.033	0.046	0.052	0.070	0.038
Spruce-Pequop, NV (2011)	0.051	0.051	0.050	0.063	0.083	0.104	0.055
Stillwater, NV	0.043	0.044	0.041	0.066	0.068	0.105	0.045
Stone Cabin, NV	0.030	0.028	0.027	0.044	0.057	0.072	0.037
Warm Springs, NV	0.036	0.028	0.030	0.016	0.063	0.076	0.050

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	Twin Peaks, CA (Gilman SP)	Twin Peaks, CA (S Observa)	Twin Peaks, CA (Skeddle)	Wall Canyon, CA (2011)	Barcus Creek, CO	East Douglas, CO	Little Book Cliffs, CO
Warm Springs Canyon, NV	0.027	0.027	0.026	0.018	0.065	0.071	0.043
Wheeler Pass, NV	0.054	0.062	0.061	0.076	0.092	0.111	0.066
Wheeler Pass, NV (2007)	0.030	0.028	0.035	0.050	0.048	0.067	0.035
Alvord Tule, OR	0.042	0.039	0.043	0.041	0.053	0.067	0.053
Beatys Butte, OR	0.026	0.024	0.024	0.044	0.057	0.059	0.038
Beatys Butte, OR (2010)	0.029	0.031	0.034	0.039	0.065	0.064	0.043
Big Summit, OR (2010)	0.112	0.104	0.116	0.138	0.136	0.170	0.117
Cold Spring, OR	0.036	0.028	0.032	0.051	0.064	0.071	0.043
Cold Spring, OR (2010)	0.036	0.032	0.036	0.060	0.069	0.083	0.045
Coyote Lake, OR	0.039	0.042	0.041	0.052	0.062	0.070	0.056
Coyote Lake, OR (2011)	0.030	0.029	0.032	0.045	0.052	0.061	0.047
Fishnet, OR	0.035	0.033	0.027	0.057	0.052	0.075	0.044
Hog Creek, OR	0.031	0.030	0.034	0.049	0.067	0.080	0.045
Jackies Butte, OR	0.043	0.043	0.041	0.056	0.068	0.070	0.067
Jackies Butte, OR (2011)	0.032	0.033	0.032	0.040	0.060	0.078	0.049
Kiger, OR (2011)	0.036	0.034	0.036	0.062	0.060	0.077	0.043
Kiger Herd, OR (2009)	0.040	0.039	0.041	0.055	0.060	0.071	0.048
Liggett Table, OR	0.144	0.159	0.148	0.137	0.219	0.210	0.189
Murderers Creek, OR (2001)	0.075	0.082	0.079	0.098	0.108	0.112	0.084
Murderers Creek, OR (2009)	0.064	0.070	0.066	0.090	0.096	0.089	0.075
Paisley Desert, OR	0.016	0.021	0.022	0.043	0.048	0.063	0.032
Riddle Herd, OR (2009)	0.048	0.041	0.045	0.059	0.080	0.096	0.052
Riddle Mountain, OR	0.051	0.041	0.046	0.059	0.089	0.093	0.055
Riddle Mountain, OR (2011)	0.056	0.046	0.052	0.067	0.083	0.103	0.053
Sand Springs, OR (2011)	0.039	0.029	0.039	0.057	0.056	0.076	0.046
Sheepshead, OR	0.036	0.035	0.042	0.053	0.058	0.062	0.038
Sheepshead, OR (2011)	0.034	0.024	0.033	0.053	0.054	0.063	0.031
South Steens, OR	0.028	0.031	0.035	0.035	0.051	0.071	0.037
South Steens, OR (2010)	0.029	0.032	0.033	0.036	0.056	0.074	0.039

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	Twin Peaks, CA (Gilman SP)	Twin Peaks, CA (S Observa)	Twin Peaks, CA (Skeddle)	Wall Canyon, CA (2011)	Barcus Creek, CO	East Douglas, CO	Little Book Cliffs, CO
Stinkingwater, OR	0.057	0.060	0.058	0.054	0.096	0.067	0.087
Three Fingers, OR	0.051	0.038	0.045	0.065	0.059	0.079	0.059
Three Fingers, OR (2011)	0.043	0.037	0.042	0.055	0.053	0.069	0.059
Warm Springs, OR	0.032	0.032	0.029	0.040	0.059	0.060	0.047
Warm Springs, OR (2010)	0.031	0.030	0.028	0.038	0.058	0.061	0.049
Blawn Wash, UT	0.076	0.056	0.049	0.080	0.091	0.112	0.062
Cedar Mountain, UT	0.039	0.041	0.038	0.058	0.068	0.090	0.044
Cedar Ridge, UT	0.070	0.067	0.075	0.091	0.099	0.112	0.090
Cedar Ridge, UT (trap)	0.072	0.070	0.080	0.098	0.097	0.137	0.084
Cold Springs, UT (2006)	0.106	0.097	0.092	0.086	0.111	0.141	0.110
Cold Springs, UT (trap)	0.073	0.067	0.065	0.064	0.080	0.114	0.072
Delta, UT	0.028	0.025	0.034	0.050	0.049	0.065	0.029
Hill Creek, UT	0.030	0.038	0.041	0.062	0.052	0.093	0.035
Muddy Creek, UT	0.078	0.075	0.075	0.105	0.099	0.144	0.090
North Hills, UT	0.064	0.071	0.074	0.095	0.107	0.096	0.082
Range Creek, UT	0.054	0.048	0.050	0.056	0.069	0.090	0.066
Sinbad, UT	0.073	0.066	0.076	0.086	0.103	0.104	0.067
Sulphur, UT	0.097	0.090	0.099	0.126	0.120	0.117	0.106
Sulphur Herd, UT (South, 2006)	0.058	0.050	0.069	0.080	0.079	0.098	0.058
Tilley Creek, UT	0.068	0.051	0.060	0.107	0.096	0.125	0.058
Winter Ridge, UT	0.032	0.039	0.043	0.056	0.056	0.074	0.040
Adobe Town, WY	0.026	0.032	0.036	0.059	0.067	0.073	0.044
Adobe Town, WY (2011)	0.025	0.026	0.029	0.049	0.054	0.078	0.033
Antelope Hills, WY	0.045	0.042	0.052	0.057	0.086	0.068	0.060
Conant Creek, WY (Lander)	0.062	0.047	0.052	0.076	0.075	0.113	0.048
Cooper Creek, WY	0.031	0.028	0.034	0.053	0.061	0.064	0.044
Dishpan Butte, WY (Lander)	0.037	0.035	0.046	0.061	0.068	0.083	0.053
Divide Basin, WY	0.025	0.024	0.027	0.043	0.061	0.061	0.036
Divide Basin, WY (2011)	0.028	0.025	0.030	0.048	0.060	0.067	0.036

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	Twin Peaks, CA (Gilman SP)	Twin Peaks, CA (S Observa)	Twin Peaks, CA (Skeddle)	Wall Canyon, CA (2011)	Barcus Creek, CO	East Douglas, CO	Little Book Cliffs, CO
Eagles Nest, WY	0.062	0.055	0.063	0.067	0.093	0.101	0.071
Happy Creek Springs, WY	0.047	0.052	0.052	0.069	0.086	0.072	0.068
Little Colorado, WY	0.038	0.036	0.041	0.044	0.064	0.072	0.053
Little Colorado, WY (2011)	0.032	0.033	0.034	0.042	0.060	0.066	0.048
Lost Creek, WY	0.033	0.030	0.034	0.041	0.060	0.064	0.041
Lost Creek, WY (combined)	0.032	0.030	0.037	0.040	0.060	0.071	0.039
McCullough Peaks, WY	0.043	0.036	0.044	0.044	0.074	0.063	0.048
Muskrat Basin, WY (Lander)	0.047	0.038	0.047	0.064	0.056	0.084	0.056
Salt Wells, WY (East)	0.023	0.029	0.024	0.046	0.056	0.069	0.037
Salt Wells, WY (West)	0.035	0.021	0.029	0.050	0.058	0.064	0.034
Stewart Creek, WY	0.045	0.039	0.046	0.047	0.061	0.070	0.051
Stewart Creek, WY (2009)	0.038	0.040	0.044	0.048	0.078	0.072	0.051
White Mountain, WY (2011)	0.035	0.030	0.036	0.051	0.063	0.077	0.042

	Mesa, CO	Sand Wash, CO	Spring Creek, CO	Spring Creek Basin, CO	West Douglas, CO	West Douglas, CO (2006)	Black Mountain, ID
Mesa, CO	0.000						
Sand Wash, CO	0.042	0.000					
Spring Creek, CO	0.062	0.083	0.000				
Spring Creek Basin, CO	0.060	0.078	0.013	0.000			
West Douglas, CO	0.070	0.064	0.072	0.073	0.000		
West Douglas, CO (2006)	0.072	0.078	0.071	0.075	0.011	0.000	
Black Mountain, ID	0.066	0.060	0.080	0.077	0.092	0.097	0.000
Black Mountain, ID (2010)	0.051	0.042	0.072	0.075	0.073	0.082	0.018
Challis, ID	0.044	0.040	0.061	0.062	0.058	0.071	0.066
Hard Trigger, ID	0.057	0.041	0.072	0.068	0.076	0.083	0.036
Hard Trigger, ID (2010)	0.057	0.046	0.073	0.068	0.079	0.086	0.035
Idaho, ID (BLM)	0.054	0.047	0.087	0.079	0.080	0.082	0.048
Sand Basin, ID	0.051	0.037	0.083	0.077	0.071	0.079	0.059

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	Mesa, CO	Sand Wash, CO	Spring Creek, CO	Spring Creek Basin, CO	West Douglas, CO	West Douglas, CO (2006)	Black Mountain, ID
Saylor Creek, ID	0.051	0.038	0.079	0.076	0.054	0.071	0.055
Pryor Mountains, MT (2001)	0.067	0.069	0.110	0.096	0.079	0.091	0.105
Pryor Mountains, MT (2009)	0.047	0.042	0.080	0.072	0.057	0.071	0.077
Bordo Atravisado, NM	0.041	0.046	0.075	0.069	0.067	0.074	0.071
El Rito, NM	0.042	0.039	0.073	0.068	0.059	0.065	0.074
Jicarilla, NM	0.053	0.044	0.081	0.077	0.061	0.070	0.082
Jarita, NM	0.070	0.067	0.100	0.101	0.085	0.090	0.103
Jicarilla, NM	0.083	0.079	0.104	0.110	0.106	0.111	0.106
Antelope Valley, NV	0.033	0.034	0.069	0.066	0.062	0.068	0.057
Antelope Valley, NV (2011)	0.034	0.044	0.061	0.058	0.062	0.066	0.064
Augusta Mountains, NV	0.035	0.045	0.074	0.071	0.061	0.067	0.063
Bald Mountain, NV	0.026	0.037	0.060	0.058	0.050	0.057	0.067
Black Rock East, NV (2005)	0.039	0.058	0.085	0.082	0.074	0.084	0.072
Black Rock East, NV (2010)	0.036	0.062	0.070	0.067	0.067	0.074	0.069
Black Rock East, NV (2011)	0.035	0.052	0.064	0.062	0.051	0.060	0.055
Black Rock West, NV (2005)	0.043	0.065	0.070	0.062	0.069	0.077	0.069
Black Rock West, NV (2010)	0.040	0.064	0.070	0.064	0.069	0.074	0.070
Black Rock West, NV (2011)	0.061	0.089	0.092	0.084	0.096	0.097	0.093
Buffalo Hills, NV	0.044	0.048	0.076	0.076	0.086	0.097	0.096
Buffalo Hills, NV (2009)	0.040	0.034	0.072	0.072	0.066	0.078	0.086
Calico, NV	0.027	0.032	0.054	0.053	0.063	0.073	0.064
Calico Mountains, NV	0.049	0.047	0.073	0.071	0.073	0.086	0.080
Calico Mountains, NV (2011)	0.036	0.037	0.067	0.066	0.070	0.082	0.071
Callaghan, NV (Austin Allot)	0.030	0.028	0.056	0.056	0.049	0.059	0.053
Callaghan, NV (East Allot)	0.028	0.034	0.047	0.044	0.048	0.053	0.061
Catnip Herd, NV	0.046	0.057	0.062	0.054	0.058	0.074	0.083
Chimney Creek, NV	0.042	0.044	0.087	0.083	0.064	0.082	0.071
Desatoya Mountain, NV	0.088	0.086	0.098	0.097	0.067	0.082	0.109
Dolly Varden, NV	0.034	0.045	0.068	0.065	0.064	0.065	0.066

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	Mesa, CO	Sand Wash, CO	Spring Creek, CO	Spring Creek Basin, CO	West Douglas, CO	West Douglas, CO (2006)	Black Mountain, ID
Dry Lake, NV	0.045	0.045	0.083	0.084	0.049	0.064	0.072
Fish Creek, NV	0.040	0.043	0.063	0.064	0.071	0.082	0.061
Goshute, NV	0.048	0.054	0.083	0.069	0.080	0.085	0.080
Goshute, NV (2011)	0.047	0.051	0.081	0.067	0.074	0.078	0.076
Granite, NV	0.034	0.036	0.071	0.070	0.080	0.090	0.076
Granite Range, NV	0.036	0.039	0.067	0.066	0.072	0.081	0.080
Granite Range, NV (2011)	0.024	0.030	0.062	0.063	0.069	0.077	0.070
Grass Valley, NV	0.038	0.040	0.053	0.053	0.045	0.054	0.066
Hall Creek, NV	0.035	0.032	0.067	0.065	0.049	0.061	0.058
Jakes Wash, NV	0.066	0.071	0.097	0.096	0.071	0.083	0.093
Johnnie, NV	0.057	0.070	0.058	0.069	0.057	0.060	0.065
Lahanton Reservoir, NV	0.060	0.066	0.089	0.073	0.081	0.090	0.092
Little Fish Lake, NV	0.049	0.041	0.088	0.080	0.067	0.075	0.083
Little Highrock Canyon, NV	0.041	0.043	0.078	0.073	0.065	0.066	0.078
Little Humboldt, NV	0.056	0.049	0.095	0.090	0.083	0.090	0.078
Little Humboldt, NV (2010)	0.044	0.039	0.077	0.072	0.072	0.076	0.070
Little Owyhee, NV (Fairbanks)	0.049	0.060	0.089	0.088	0.077	0.088	0.082
Little Owyhee, NV (Lake Creek)	0.049	0.046	0.081	0.078	0.077	0.088	0.072
Little Owyhee, NV (Twin Valley)	0.048	0.059	0.076	0.072	0.077	0.081	0.063
Marvel Gap, NV (SWC 2010)	0.037	0.035	0.055	0.051	0.059	0.068	0.049
McGee Mountain, NV	0.042	0.042	0.071	0.064	0.051	0.066	0.065
Miller Mountain, NV (SWC 2010)	0.037	0.037	0.072	0.068	0.062	0.071	0.062
Montezuma Peak, NV	0.052	0.054	0.083	0.074	0.088	0.090	0.085
Nellis, NV	0.029	0.034	0.057	0.056	0.057	0.068	0.064
New Pass-Ravenswood, NV	0.031	0.038	0.053	0.051	0.040	0.045	0.052
North Stillwater, NV	0.043	0.037	0.074	0.072	0.068	0.076	0.075
Paymaster, NV (2006)	0.055	0.049	0.090	0.084	0.082	0.087	0.080
Paymaster, NV (2010)	0.053	0.048	0.089	0.082	0.079	0.085	0.083
Pine Nut Mountain, NV	0.069	0.079	0.087	0.099	0.080	0.093	0.093

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	Mesa, CO	Sand Wash, CO	Spring Creek, CO	Spring Creek Basin, CO	West Douglas, CO	West Douglas, CO (2006)	Black Mountain, ID
Powell Mountain, NV	0.058	0.052	0.113	0.101	0.084	0.098	0.077
Red Rock, NV	0.039	0.061	0.075	0.073	0.065	0.068	0.075
Reveille, NV	0.055	0.056	0.092	0.088	0.076	0.089	0.080
Roberts Mountain, NV	0.034	0.049	0.065	0.063	0.069	0.078	0.064
Rock Creek, NV (2002)	0.065	0.079	0.070	0.071	0.079	0.081	0.080
Rock Creek, NV (2010)	0.053	0.056	0.066	0.062	0.062	0.066	0.062
Rocky Hills, NV	0.036	0.045	0.056	0.054	0.043	0.051	0.063
Rodeo Creek, NV	0.035	0.031	0.057	0.056	0.049	0.053	0.073
Saulsbury, NV	0.041	0.032	0.072	0.071	0.041	0.052	0.071
Sand Springs East, NV	0.042	0.039	0.074	0.066	0.055	0.070	0.063
Seven Mile, NV	0.054	0.051	0.065	0.062	0.048	0.065	0.075
Shawave Mountains, NV	0.044	0.036	0.066	0.062	0.061	0.069	0.067
Silver Peak, NV	0.047	0.052	0.073	0.077	0.079	0.083	0.086
Snowstorm, NV (Castle Ridge)	0.045	0.042	0.086	0.076	0.081	0.090	0.072
Snowstorm, NV (Dryhill)	0.061	0.083	0.102	0.092	0.122	0.124	0.099
South Shoshone, NV	0.034	0.031	0.058	0.053	0.052	0.057	0.048
Spruce-Pequop, NV (2011)	0.052	0.066	0.086	0.085	0.072	0.076	0.077
Stillwater, NV	0.050	0.050	0.086	0.082	0.079	0.083	0.080
Stone Cabin, NV	0.030	0.033	0.064	0.064	0.055	0.065	0.064
Warm Springs, NV	0.037	0.052	0.071	0.067	0.074	0.081	0.074
Warm Springs Canyon, NV	0.036	0.046	0.060	0.056	0.053	0.060	0.066
Wheeler Pass, NV	0.073	0.085	0.085	0.095	0.080	0.078	0.090
Wheeler Pass, NV (2007)	0.031	0.035	0.066	0.068	0.050	0.056	0.054
Alvord Tule, OR	0.051	0.046	0.059	0.061	0.050	0.062	0.075
Beatys Butte, OR	0.026	0.034	0.061	0.059	0.051	0.060	0.061
Beatys Butte, OR (2010)	0.035	0.035	0.071	0.066	0.066	0.073	0.058
Big Summit, OR (2010)	0.125	0.117	0.143	0.146	0.143	0.136	0.149
Cold Spring, OR	0.033	0.047	0.053	0.055	0.047	0.047	0.054
Cold Spring, OR (2010)	0.040	0.051	0.061	0.062	0.060	0.053	0.062

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	Mesa, CO	Sand Wash, CO	Spring Creek, CO	Spring Creek Basin, CO	West Douglas, CO	West Douglas, CO (2006)	Black Mountain, ID
Coyote Lake, OR	0.052	0.049	0.062	0.062	0.057	0.071	0.071
Coyote Lake, OR (2011)	0.039	0.034	0.059	0.057	0.055	0.068	0.058
Fishnet, OR	0.034	0.043	0.074	0.072	0.074	0.088	0.075
Hog Creek, OR	0.039	0.050	0.054	0.059	0.063	0.066	0.066
Jackies Butte, OR	0.050	0.054	0.079	0.074	0.059	0.070	0.067
Jackies Butte, OR (2011)	0.040	0.049	0.064	0.061	0.053	0.062	0.061
Kiger, OR (2011)	0.042	0.043	0.075	0.076	0.070	0.085	0.096
Kiger Herd, OR (2009)	0.048	0.053	0.068	0.073	0.073	0.083	0.093
Liggett Table, OR	0.168	0.199	0.173	0.162	0.195	0.199	0.188
Murderers Creek, OR (2001)	0.074	0.082	0.089	0.085	0.109	0.111	0.113
Murderers Creek, OR (2009)	0.062	0.059	0.086	0.079	0.087	0.097	0.104
Paisley Desert, OR	0.029	0.031	0.055	0.054	0.048	0.055	0.052
Riddle Herd, OR (2009)	0.054	0.057	0.082	0.085	0.082	0.092	0.099
Riddle Mountain, OR	0.055	0.058	0.084	0.083	0.067	0.078	0.090
Riddle Mountain, OR (2011)	0.059	0.064	0.087	0.092	0.087	0.097	0.104
Sand Springs, OR (2011)	0.042	0.033	0.077	0.073	0.065	0.076	0.063
Sheepshead, OR	0.038	0.034	0.058	0.058	0.049	0.061	0.057
Sheepshead, OR (2011)	0.034	0.032	0.058	0.056	0.045	0.053	0.054
South Steens, OR	0.038	0.040	0.048	0.048	0.046	0.056	0.054
South Steens, OR (2010)	0.038	0.041	0.057	0.056	0.051	0.063	0.061
Stinkingwater, OR	0.058	0.076	0.072	0.069	0.065	0.072	0.070
Three Fingers, OR	0.043	0.042	0.081	0.078	0.085	0.102	0.066
Three Fingers, OR (2011)	0.038	0.043	0.073	0.071	0.070	0.083	0.052
Warm Springs, OR	0.034	0.040	0.062	0.058	0.041	0.050	0.042
Warm Springs, OR (2010)	0.032	0.040	0.064	0.061	0.047	0.055	0.048
Blawn Wash, UT	0.055	0.079	0.113	0.112	0.084	0.089	0.094
Cedar Mountain, UT	0.048	0.059	0.074	0.081	0.072	0.079	0.080
Cedar Ridge, UT	0.073	0.062	0.074	0.076	0.093	0.100	0.096
Cedar Ridge, UT (trap)	0.079	0.070	0.074	0.083	0.101	0.101	0.106

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	Mesa, CO	Sand Wash, CO	Spring Creek, CO	Spring Creek Basin, CO	West Douglas, CO	West Douglas, CO (2006)	Black Mountain, ID
Cold Springs, UT (2006)	0.084	0.111	0.118	0.118	0.132	0.140	0.123
Cold Springs, UT (trap)	0.054	0.082	0.090	0.091	0.089	0.095	0.098
Delta, UT	0.032	0.034	0.054	0.057	0.057	0.063	0.062
Hill Creek, UT	0.044	0.044	0.064	0.067	0.070	0.073	0.078
Muddy Creek, UT	0.087	0.102	0.111	0.104	0.097	0.105	0.132
North Hills, UT	0.067	0.081	0.087	0.089	0.083	0.086	0.100
Range Creek, UT	0.045	0.051	0.060	0.062	0.077	0.084	0.075
Sinbad, UT	0.081	0.073	0.118	0.122	0.088	0.104	0.112
Sulphur, UT	0.097	0.090	0.150	0.150	0.122	0.134	0.135
Sulphur Herd, UT (South, 2006)	0.074	0.067	0.089	0.089	0.084	0.090	0.097
Tilley Creek, UT	0.057	0.065	0.102	0.104	0.109	0.111	0.091
Winter Ridge, UT	0.043	0.039	0.058	0.061	0.077	0.079	0.064
Adobe Town, WY	0.044	0.038	0.066	0.062	0.064	0.071	0.053
Adobe Town, WY (2011)	0.032	0.031	0.059	0.054	0.064	0.071	0.051
Antelope Hills, WY	0.056	0.048	0.070	0.067	0.070	0.087	0.089
Conant Creek, WY (Lander)	0.050	0.058	0.097	0.098	0.102	0.112	0.094
Cooper Creek, WY	0.043	0.039	0.071	0.072	0.054	0.066	0.066
Dishpan Butte, WY (Lander)	0.048	0.051	0.074	0.072	0.071	0.078	0.075
Divide Basin, WY	0.034	0.029	0.052	0.049	0.048	0.053	0.059
Divide Basin, WY (2011)	0.031	0.031	0.056	0.055	0.054	0.058	0.062
Eagles Nest, WY	0.069	0.065	0.077	0.069	0.081	0.084	0.093
Happy Creek Springs, WY	0.065	0.056	0.080	0.080	0.071	0.083	0.084
Little Colorado, WY	0.036	0.053	0.051	0.050	0.054	0.054	0.050
Little Colorado, WY (2011)	0.031	0.048	0.047	0.045	0.051	0.052	0.049
Lost Creek, WY	0.040	0.037	0.058	0.056	0.054	0.060	0.067
Lost Creek, WY (combined)	0.042	0.040	0.058	0.055	0.048	0.051	0.068
McCullough Peaks, WY	0.044	0.047	0.075	0.073	0.069	0.080	0.067
Muskrat Basin, WY (Lander)	0.044	0.054	0.075	0.074	0.077	0.082	0.078
Salt Wells, WY (East)	0.029	0.030	0.061	0.057	0.049	0.056	0.058

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	Mesa, CO	Sand Wash, CO	Spring Creek, CO	Spring Creek Basin, CO	West Douglas, CO	West Douglas, CO (2006)	Black Mountain, ID
Salt Wells, WY (West)	0.035	0.038	0.066	0.063	0.061	0.066	0.054
Stewart Creek, WY	0.055	0.050	0.064	0.064	0.056	0.065	0.082
Stewart Creek, WY (2009)	0.059	0.039	0.076	0.070	0.058	0.065	0.068
White Mountain, WY (2011)	0.038	0.033	0.076	0.068	0.076	0.082	0.075

	Black Mountain, ID (2010)	Challis, ID	Hard Trigger, ID	Hard Trigger, ID (2010)	Idaho, ID (BLM)	Sand Basin, ID	Saylor Creek, ID
Black Mountain, ID (2010)	0.000						
Challis, ID	0.049	0.000					
Hard Trigger, ID	0.035	0.044	0.000				
Hard Trigger, ID (2010)	0.036	0.051	0.013	0.000			
Idaho, ID (BLM)	0.041	0.054	0.033	0.032	0.000		
Sand Basin, ID	0.041	0.051	0.037	0.033	0.033	0.000	
Saylor Creek, ID	0.040	0.034	0.035	0.032	0.043	0.044	0.000
Pryor Mountains, MT (2001)	0.088	0.065	0.073	0.079	0.070	0.071	0.061
Pryor Mountains, MT (2009)	0.060	0.044	0.047	0.052	0.061	0.042	0.041
Bordo Atravisado, NM	0.057	0.035	0.046	0.053	0.050	0.057	0.040
El Rito, NM	0.057	0.051	0.043	0.052	0.052	0.041	0.047
Jicarilla, NM	0.065	0.050	0.047	0.056	0.062	0.044	0.046
Jarita, NM	0.081	0.071	0.073	0.085	0.083	0.073	0.072
Jicarilla, NM	0.082	0.088	0.085	0.094	0.090	0.081	0.083
Antelope Valley, NV	0.041	0.034	0.044	0.052	0.051	0.039	0.045
Antelope Valley, NV (2011)	0.048	0.042	0.048	0.059	0.056	0.050	0.050
Augusta Mountains, NV	0.056	0.048	0.055	0.062	0.062	0.052	0.049
Bald Mountain, NV	0.052	0.028	0.044	0.048	0.051	0.045	0.033
Black Rock East, NV (2005)	0.059	0.048	0.060	0.064	0.075	0.073	0.043
Black Rock East, NV (2010)	0.059	0.042	0.051	0.057	0.072	0.068	0.044
Black Rock East, NV (2011)	0.045	0.042	0.044	0.045	0.062	0.058	0.035
Black Rock West, NV (2005)	0.063	0.047	0.054	0.057	0.068	0.065	0.049

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	Black Mountain, ID (2010)	Challis, ID	Hard Trigger, ID	Hard Trigger, ID (2010)	Idaho, ID (BLM)	Sand Basin, ID	Saylor Creek, ID
Black Rock West, NV (2010)	0.061	0.047	0.056	0.061	0.067	0.064	0.049
Black Rock West, NV (2011)	0.087	0.078	0.072	0.077	0.081	0.080	0.076
Buffalo Hills, NV	0.070	0.066	0.071	0.073	0.075	0.064	0.063
Buffalo Hills, NV (2009)	0.063	0.049	0.056	0.065	0.069	0.054	0.046
Calico, NV	0.047	0.031	0.043	0.050	0.053	0.038	0.040
Calico Mountains, NV	0.066	0.046	0.054	0.060	0.062	0.053	0.043
Calico Mountains, NV (2011)	0.052	0.038	0.052	0.057	0.052	0.041	0.043
Callaghan, NV (Austin Allot)	0.041	0.033	0.040	0.048	0.049	0.046	0.032
Callaghan, NV (East Allot)	0.047	0.029	0.040	0.043	0.048	0.039	0.037
Catnip Herd, NV	0.075	0.055	0.061	0.066	0.069	0.063	0.056
Chimney Creek, NV	0.062	0.048	0.043	0.047	0.060	0.047	0.041
Desatoya Mountain, NV	0.091	0.071	0.083	0.095	0.096	0.096	0.068
Dolly Varden, NV	0.053	0.046	0.046	0.056	0.049	0.045	0.052
Dry Lake, NV	0.052	0.051	0.063	0.067	0.067	0.056	0.044
Fish Creek, NV	0.051	0.043	0.050	0.055	0.066	0.048	0.045
Goshute, NV	0.068	0.060	0.065	0.072	0.072	0.062	0.063
Goshute, NV (2011)	0.064	0.056	0.058	0.064	0.068	0.058	0.056
Granite, NV	0.060	0.031	0.049	0.059	0.063	0.051	0.044
Granite Range, NV	0.059	0.039	0.048	0.061	0.061	0.046	0.050
Granite Range, NV (2011)	0.048	0.031	0.047	0.055	0.052	0.037	0.045
Grass Valley, NV	0.053	0.040	0.044	0.049	0.048	0.044	0.037
Hall Creek, NV	0.042	0.036	0.052	0.056	0.054	0.052	0.033
Jakes Wash, NV	0.080	0.067	0.083	0.094	0.092	0.079	0.071
Johnnie, NV	0.056	0.056	0.066	0.073	0.087	0.073	0.060
Lahanton Reservoir, NV	0.082	0.068	0.066	0.071	0.069	0.070	0.067
Little Fish Lake, NV	0.068	0.051	0.055	0.066	0.062	0.057	0.047
Little Highrock Canyon, NV	0.059	0.051	0.053	0.060	0.046	0.046	0.052
Little Humboldt, NV	0.065	0.046	0.049	0.059	0.056	0.057	0.047
Little Humboldt, NV (2010)	0.061	0.036	0.046	0.052	0.045	0.042	0.040

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	Black Mountain, ID (2010)	Challis, ID	Hard Trigger, ID	Hard Trigger, ID (2010)	Idaho, ID (BLM)	Sand Basin, ID	Saylor Creek, ID
Little Owyhee, NV (Fairbanks)	0.075	0.061	0.071	0.079	0.084	0.074	0.060
Little Owyhee, NV (Lake Creek)	0.071	0.059	0.047	0.050	0.060	0.051	0.055
Little Owyhee, NV (Twin Valley)	0.058	0.045	0.048	0.053	0.061	0.048	0.058
Marvel Gap, NV (SWC 2010)	0.038	0.039	0.032	0.039	0.037	0.039	0.036
McGee Mountain, NV	0.054	0.033	0.047	0.055	0.059	0.047	0.031
Miller Mountain, NV (SWC 2010)	0.053	0.040	0.045	0.048	0.057	0.048	0.040
Montezuma Peak, NV	0.074	0.064	0.068	0.071	0.057	0.054	0.064
Nellis, NV	0.050	0.033	0.047	0.049	0.057	0.044	0.036
New Pass-Ravenswood, NV	0.044	0.033	0.047	0.048	0.050	0.041	0.038
North Stillwater, NV	0.055	0.049	0.057	0.059	0.068	0.040	0.051
Paymaster, NV (2006)	0.065	0.063	0.067	0.065	0.062	0.058	0.055
Paymaster, NV (2010)	0.067	0.065	0.072	0.070	0.063	0.058	0.057
Pine Nut Mountain, NV	0.068	0.061	0.087	0.095	0.103	0.085	0.058
Powell Mountain, NV	0.060	0.060	0.077	0.082	0.074	0.074	0.065
Red Rock, NV	0.061	0.057	0.064	0.068	0.067	0.059	0.056
Reveille, NV	0.067	0.049	0.059	0.068	0.072	0.064	0.054
Roberts Mountain, NV	0.050	0.049	0.052	0.054	0.060	0.055	0.037
Rock Creek, NV (2002)	0.078	0.063	0.079	0.078	0.078	0.079	0.061
Rock Creek, NV (2010)	0.058	0.047	0.058	0.059	0.059	0.060	0.040
Rocky Hills, NV	0.048	0.040	0.046	0.048	0.047	0.049	0.036
Rodeo Creek, NV	0.052	0.035	0.048	0.055	0.052	0.044	0.035
Saulsbury, NV	0.054	0.026	0.050	0.057	0.055	0.048	0.034
Sand Springs East, NV	0.052	0.033	0.045	0.052	0.057	0.045	0.031
Seven Mile, NV	0.056	0.043	0.048	0.054	0.051	0.044	0.043
Shawave Mountains, NV	0.057	0.035	0.045	0.051	0.051	0.049	0.036
Silver Peak, NV	0.068	0.053	0.060	0.063	0.068	0.056	0.055
Snowstorm, NV (Castle Ridge)	0.062	0.039	0.052	0.050	0.052	0.047	0.045
Snowstorm, NV (Dryhill)	0.097	0.089	0.081	0.081	0.082	0.069	0.089
South Shoshone, NV	0.034	0.039	0.044	0.049	0.050	0.033	0.042

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	Black Mountain, ID (2010)	Challis, ID	Hard Trigger, ID	Hard Trigger, ID (2010)	Idaho, ID (BLM)	Sand Basin, ID	Saylor Creek, ID
Spruce-Pequop, NV (2011)	0.070	0.065	0.072	0.079	0.079	0.068	0.070
Stillwater, NV	0.066	0.061	0.060	0.060	0.069	0.045	0.056
Stone Cabin, NV	0.047	0.032	0.043	0.045	0.051	0.041	0.031
Warm Springs, NV	0.061	0.042	0.056	0.058	0.064	0.058	0.048
Warm Springs Canyon, NV	0.056	0.033	0.044	0.049	0.055	0.047	0.036
Wheeler Pass, NV	0.079	0.078	0.080	0.088	0.091	0.084	0.071
Wheeler Pass, NV (2007)	0.037	0.034	0.047	0.054	0.054	0.046	0.036
Alvord Tule, OR	0.059	0.036	0.065	0.068	0.068	0.054	0.052
Beatys Butte, OR	0.047	0.035	0.039	0.044	0.049	0.041	0.035
Beatys Butte, OR (2010)	0.044	0.042	0.036	0.040	0.039	0.037	0.037
Big Summit, OR (2010)	0.133	0.105	0.106	0.113	0.102	0.117	0.105
Cold Spring, OR	0.047	0.039	0.041	0.048	0.054	0.053	0.046
Cold Spring, OR (2010)	0.056	0.046	0.047	0.051	0.053	0.058	0.053
Coyote Lake, OR	0.064	0.043	0.058	0.066	0.076	0.058	0.050
Coyote Lake, OR (2011)	0.049	0.029	0.047	0.053	0.059	0.044	0.036
Fishnet, OR	0.062	0.058	0.065	0.060	0.074	0.052	0.054
Hog Creek, OR	0.052	0.045	0.055	0.058	0.057	0.048	0.055
Jackies Butte, OR	0.051	0.049	0.060	0.059	0.063	0.055	0.047
Jackies Butte, OR (2011)	0.047	0.038	0.051	0.050	0.052	0.039	0.042
Kiger, OR (2011)	0.069	0.048	0.070	0.075	0.075	0.068	0.055
Kiger Herd, OR (2009)	0.069	0.052	0.073	0.080	0.082	0.075	0.061
Liggett Table, OR	0.195	0.170	0.160	0.168	0.168	0.174	0.177
Murderers Creek, OR (2001)	0.107	0.092	0.083	0.093	0.093	0.098	0.097
Murderers Creek, OR (2009)	0.088	0.074	0.073	0.084	0.081	0.082	0.076
Paisley Desert, OR	0.039	0.035	0.038	0.046	0.052	0.041	0.033
Riddle Herd, OR (2009)	0.076	0.051	0.072	0.081	0.082	0.072	0.066
Riddle Mountain, OR	0.068	0.048	0.069	0.074	0.075	0.068	0.060
Riddle Mountain, OR (2011)	0.079	0.058	0.081	0.088	0.089	0.075	0.075
Sand Springs, OR (2011)	0.046	0.038	0.051	0.055	0.056	0.043	0.044

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	Black Mountain, ID (2010)	Challis, ID	Hard Trigger, ID	Hard Trigger, ID (2010)	Idaho, ID (BLM)	Sand Basin, ID	Saylor Creek, ID
Sheepshead, OR	0.039	0.035	0.043	0.049	0.052	0.045	0.038
Sheepshead, OR (2011)	0.037	0.029	0.043	0.048	0.050	0.046	0.034
South Steens, OR	0.043	0.039	0.043	0.048	0.054	0.038	0.044
South Steens, OR (2010)	0.047	0.041	0.048	0.051	0.055	0.039	0.046
Stinkingwater, OR	0.074	0.074	0.067	0.066	0.091	0.080	0.068
Three Fingers, OR	0.047	0.050	0.048	0.050	0.060	0.058	0.039
Three Fingers, OR (2011)	0.041	0.043	0.041	0.041	0.050	0.047	0.032
Warm Springs, OR	0.037	0.035	0.036	0.035	0.041	0.039	0.029
Warm Springs, OR (2010)	0.040	0.037	0.036	0.035	0.042	0.039	0.030
Blawn Wash, UT	0.071	0.077	0.096	0.089	0.089	0.068	0.079
Cedar Mountain, UT	0.070	0.051	0.062	0.066	0.070	0.048	0.065
Cedar Ridge, UT	0.080	0.052	0.069	0.069	0.076	0.067	0.066
Cedar Ridge, UT (trap)	0.089	0.063	0.081	0.080	0.077	0.072	0.080
Cold Springs, UT (2006)	0.111	0.090	0.104	0.110	0.112	0.100	0.100
Cold Springs, UT (trap)	0.081	0.060	0.088	0.093	0.089	0.073	0.080
Delta, UT	0.048	0.033	0.048	0.056	0.056	0.051	0.039
Hill Creek, UT	0.058	0.051	0.056	0.063	0.059	0.044	0.054
Muddy Creek, UT	0.113	0.082	0.111	0.122	0.121	0.104	0.102
North Hills, UT	0.091	0.076	0.066	0.074	0.077	0.086	0.075
Range Creek, UT	0.061	0.036	0.053	0.055	0.060	0.049	0.048
Sinbad, UT	0.089	0.054	0.094	0.097	0.095	0.085	0.063
Sulphur, UT	0.113	0.113	0.104	0.115	0.108	0.111	0.092
Sulphur Herd, UT (South, 2006)	0.088	0.068	0.067	0.082	0.078	0.070	0.070
Tilley Creek, UT	0.078	0.070	0.077	0.078	0.066	0.071	0.080
Winter Ridge, UT	0.051	0.050	0.045	0.054	0.043	0.051	0.049
Adobe Town, WY	0.045	0.046	0.035	0.042	0.046	0.044	0.035
Adobe Town, WY (2011)	0.039	0.040	0.031	0.034	0.033	0.027	0.036
Antelope Hills, WY	0.073	0.039	0.051	0.064	0.071	0.062	0.044
Conant Creek, WY (Lander)	0.073	0.072	0.081	0.085	0.092	0.074	0.075

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	Black Mountain, ID (2010)	Challis, ID	Hard Trigger, ID	Hard Trigger, ID (2010)	Idaho, ID (BLM)	Sand Basin, ID	Saylor Creek, ID
Cooper Creek, WY	0.051	0.042	0.046	0.056	0.059	0.052	0.034
Dishpan Butte, WY (Lander)	0.063	0.046	0.063	0.070	0.075	0.065	0.048
Divide Basin, WY	0.050	0.027	0.035	0.041	0.044	0.039	0.032
Divide Basin, WY (2011)	0.049	0.029	0.036	0.039	0.045	0.041	0.027
Eagles Nest, WY	0.080	0.060	0.071	0.074	0.076	0.065	0.063
Happy Creek Springs, WY	0.069	0.060	0.062	0.065	0.073	0.069	0.042
Little Colorado, WY	0.041	0.044	0.044	0.044	0.047	0.053	0.036
Little Colorado, WY (2011)	0.041	0.041	0.043	0.044	0.045	0.050	0.036
Lost Creek, WY	0.053	0.034	0.048	0.053	0.046	0.043	0.039
Lost Creek, WY (combined)	0.055	0.036	0.050	0.055	0.047	0.042	0.038
McCullough Peaks, WY	0.055	0.050	0.055	0.061	0.069	0.058	0.051
Muskrat Basin, WY (Lander)	0.065	0.046	0.067	0.070	0.075	0.065	0.047
Salt Wells, WY (East)	0.039	0.033	0.034	0.038	0.035	0.027	0.035
Salt Wells, WY (West)	0.045	0.040	0.044	0.047	0.054	0.052	0.038
Stewart Creek, WY	0.065	0.039	0.062	0.067	0.067	0.054	0.045
Stewart Creek, WY (2009)	0.057	0.043	0.051	0.056	0.053	0.056	0.042
White Mountain, WY (2011)	0.057	0.045	0.053	0.061	0.054	0.051	0.048

	Pryor Mountains, MT (2001)	Pryor Mountains, MT (2009)	Bordo Atravisado, NM	El Rito, NM	Jicarilla, NM	Jarita, NM	JicarillA, NM
Pryor Mountains, MT (2001)	0.000						
Pryor Mountains, MT (2009)	0.035	0.000					
Bordo Atravisado, NM	0.063	0.045	0.000				
El Rito, NM	0.058	0.040	0.048	0.000			
Jicarilla, NM	0.054	0.039	0.056	0.018	0.000		
Jarita, NM	0.084	0.061	0.091	0.027	0.033	0.000	
Jicarilla, NM	0.119	0.090	0.098	0.032	0.060	0.034	0.000
Antelope Valley, NV	0.068	0.042	0.036	0.039	0.043	0.068	0.077
Antelope Valley, NV (2011)	0.073	0.045	0.034	0.036	0.048	0.070	0.073
Augusta Mountains, NV	0.073	0.048	0.044	0.031	0.039	0.057	0.068

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	Pryor Mountains, MT (2001)	Pryor Mountains, MT (2009)	Bordo Atravisado, NM	El Rito, NM	Jicarilla, NM	Jarita, NM	JicarillA, NM
Bald Mountain, NV	0.060	0.034	0.026	0.030	0.034	0.058	0.068
Black Rock East, NV (2005)	0.079	0.060	0.052	0.059	0.063	0.089	0.095
Black Rock East, NV (2010)	0.072	0.056	0.052	0.050	0.055	0.074	0.083
Black Rock East, NV (2011)	0.068	0.048	0.045	0.039	0.050	0.066	0.068
Black Rock West, NV (2005)	0.067	0.050	0.054	0.059	0.059	0.089	0.100
Black Rock West, NV (2010)	0.072	0.056	0.053	0.055	0.062	0.085	0.092
Black Rock West, NV (2011)	0.088	0.073	0.076	0.068	0.077	0.097	0.108
Buffalo Hills, NV	0.091	0.057	0.059	0.051	0.059	0.076	0.078
Buffalo Hills, NV (2009)	0.069	0.039	0.042	0.037	0.039	0.061	0.071
Calico, NV	0.058	0.032	0.035	0.035	0.037	0.057	0.068
Calico Mountains, NV	0.075	0.048	0.040	0.051	0.047	0.080	0.091
Calico Mountains, NV (2011)	0.067	0.039	0.039	0.037	0.041	0.064	0.070
Callaghan, NV (Austin Allot)	0.062	0.035	0.033	0.030	0.035	0.049	0.060
Callaghan, NV (East Allot)	0.060	0.036	0.030	0.028	0.035	0.058	0.071
Catnip Herd, NV	0.077	0.043	0.057	0.054	0.059	0.082	0.099
Chimney Creek, NV	0.062	0.042	0.051	0.049	0.048	0.076	0.093
Desatoya Mountain, NV	0.092	0.068	0.073	0.060	0.065	0.080	0.087
Dolly Varden, NV	0.069	0.040	0.042	0.036	0.048	0.061	0.067
Dry Lake, NV	0.084	0.056	0.053	0.050	0.047	0.071	0.078
Fish Creek, NV	0.069	0.042	0.049	0.040	0.041	0.061	0.071
Goshute, NV	0.081	0.057	0.054	0.048	0.064	0.079	0.079
Goshute, NV (2011)	0.072	0.045	0.049	0.050	0.065	0.080	0.090
Granite, NV	0.066	0.041	0.038	0.042	0.041	0.063	0.078
Granite Range, NV	0.063	0.038	0.043	0.041	0.038	0.057	0.080
Granite Range, NV (2011)	0.063	0.035	0.039	0.030	0.036	0.049	0.060
Grass Valley, NV	0.062	0.036	0.032	0.033	0.037	0.061	0.071
Hall Creek, NV	0.066	0.040	0.036	0.036	0.040	0.053	0.060
Jakes Wash, NV	0.089	0.063	0.075	0.057	0.066	0.073	0.104
Johnnie, NV	0.096	0.067	0.067	0.059	0.061	0.084	0.089

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	Pryor Mountains, MT (2001)	Pryor Mountains, MT (2009)	Bordo Atravisado, NM	El Rito, NM	Jicarilla, NM	Jarita, NM	JicarillA, NM
Lahanton Reservoir, NV	0.098	0.074	0.072	0.054	0.075	0.088	0.084
Little Fish Lake, NV	0.072	0.050	0.043	0.043	0.051	0.061	0.088
Little Highrock Canyon, NV	0.070	0.050	0.050	0.037	0.044	0.060	0.066
Little Humboldt, NV	0.088	0.060	0.052	0.059	0.061	0.077	0.099
Little Humboldt, NV (2010)	0.072	0.050	0.047	0.043	0.045	0.068	0.084
Little Owyhee, NV (Fairbanks)	0.084	0.051	0.056	0.050	0.056	0.073	0.085
Little Owyhee, NV (Lake Creek)	0.087	0.053	0.059	0.040	0.042	0.060	0.077
Little Owyhee, NV (Twin Valley)	0.070	0.044	0.060	0.043	0.035	0.054	0.080
Marvel Gap, NV (SWC 2010)	0.063	0.039	0.036	0.037	0.042	0.064	0.079
McGee Mountain, NV	0.053	0.035	0.044	0.044	0.043	0.069	0.091
Miller Mountain, NV (SWC 2010)	0.065	0.041	0.037	0.037	0.039	0.065	0.078
Montezuma Peak, NV	0.089	0.067	0.056	0.049	0.061	0.077	0.089
Nellis, NV	0.064	0.036	0.034	0.043	0.046	0.072	0.088
New Pass-Ravenswood, NV	0.064	0.038	0.040	0.038	0.042	0.058	0.069
North Stillwater, NV	0.068	0.042	0.053	0.033	0.038	0.056	0.068
Paymaster, NV (2006)	0.087	0.067	0.057	0.053	0.065	0.078	0.091
Paymaster, NV (2010)	0.087	0.067	0.058	0.055	0.064	0.080	0.092
Pine Nut Mountain, NV	0.098	0.072	0.077	0.059	0.062	0.067	0.073
Powell Mountain, NV	0.076	0.066	0.064	0.063	0.071	0.093	0.100
Red Rock, NV	0.080	0.053	0.047	0.044	0.056	0.073	0.083
Reveille, NV	0.080	0.055	0.046	0.058	0.060	0.091	0.109
Roberts Mountain, NV	0.062	0.043	0.043	0.043	0.052	0.076	0.087
Rock Creek, NV (2002)	0.094	0.077	0.081	0.066	0.065	0.090	0.106
Rock Creek, NV (2010)	0.078	0.057	0.060	0.051	0.052	0.073	0.089
Rocky Hills, NV	0.066	0.047	0.043	0.040	0.049	0.072	0.074
Rodeo Creek, NV	0.061	0.040	0.037	0.033	0.034	0.056	0.070
Saulsbury, NV	0.061	0.038	0.039	0.037	0.038	0.055	0.071
Sand Springs East, NV	0.054	0.035	0.043	0.045	0.043	0.070	0.093
Seven Mile, NV	0.071	0.053	0.049	0.041	0.051	0.069	0.077

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	Pryor Mountains, MT (2001)	Pryor Mountains, MT (2009)	Bordo Atravisado, NM	El Rito, NM	Jicarilla, NM	Jarita, NM	JicarillA, NM
Shawave Mountains, NV	0.069	0.041	0.041	0.034	0.039	0.052	0.059
Silver Peak, NV	0.084	0.053	0.063	0.051	0.050	0.060	0.083
Snowstorm, NV (Castle Ridge)	0.084	0.058	0.052	0.049	0.053	0.081	0.094
Snowstorm, NV (Dryhill)	0.102	0.075	0.089	0.075	0.077	0.082	0.113
South Shoshone, NV	0.063	0.038	0.040	0.031	0.039	0.059	0.068
Spruce-Pequop, NV (2011)	0.092	0.059	0.052	0.056	0.068	0.081	0.087
Stillwater, NV	0.073	0.050	0.058	0.037	0.048	0.059	0.076
Stone Cabin, NV	0.059	0.034	0.034	0.034	0.035	0.065	0.077
Warm Springs, NV	0.063	0.042	0.055	0.052	0.050	0.072	0.093
Warm Springs Canyon, NV	0.055	0.033	0.039	0.041	0.039	0.063	0.084
Wheeler Pass, NV	0.109	0.081	0.078	0.073	0.081	0.106	0.108
Wheeler Pass, NV (2007)	0.075	0.047	0.036	0.037	0.045	0.066	0.067
Alvord Tule, OR	0.066	0.042	0.050	0.051	0.044	0.073	0.100
Beatys Butte, OR	0.060	0.035	0.038	0.032	0.037	0.057	0.064
Beatys Butte, OR (2010)	0.062	0.036	0.034	0.031	0.033	0.058	0.063
Big Summit, OR (2010)	0.152	0.123	0.100	0.115	0.127	0.145	0.157
Cold Spring, OR	0.072	0.045	0.039	0.042	0.046	0.056	0.081
Cold Spring, OR (2010)	0.077	0.057	0.039	0.045	0.052	0.064	0.084
Coyote Lake, OR	0.074	0.047	0.046	0.053	0.044	0.083	0.106
Coyote Lake, OR (2011)	0.058	0.035	0.037	0.043	0.038	0.069	0.092
Fishnet, OR	0.078	0.047	0.064	0.052	0.056	0.081	0.094
Hog Creek, OR	0.078	0.051	0.048	0.045	0.044	0.063	0.083
Jackies Butte, OR	0.064	0.041	0.050	0.054	0.056	0.076	0.090
Jackies Butte, OR (2011)	0.058	0.033	0.046	0.046	0.046	0.070	0.082
Kiger, OR (2011)	0.078	0.048	0.062	0.053	0.048	0.065	0.079
Kiger Herd, OR (2009)	0.080	0.051	0.067	0.063	0.056	0.076	0.092
Liggett Table, OR	0.162	0.161	0.183	0.172	0.166	0.190	0.224
Murderers Creek, OR (2001)	0.111	0.080	0.093	0.075	0.087	0.099	0.118
Murderers Creek, OR (2009)	0.082	0.056	0.078	0.061	0.071	0.080	0.102

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	Pryor Mountains, MT (2001)	Pryor Mountains, MT (2009)	Bordo Atravisado, NM	El Rito, NM	Jicarilla, NM	Jarita, NM	JicarillA, NM
Paisley Desert, OR	0.056	0.031	0.034	0.030	0.032	0.059	0.074
Riddle Herd, OR (2009)	0.083	0.056	0.077	0.062	0.057	0.072	0.090
Riddle Mountain, OR	0.083	0.052	0.072	0.061	0.056	0.073	0.088
Riddle Mountain, OR (2011)	0.091	0.063	0.086	0.067	0.059	0.076	0.096
Sand Springs, OR (2011)	0.076	0.044	0.044	0.043	0.041	0.068	0.083
Sheepshead, OR	0.064	0.040	0.040	0.036	0.038	0.063	0.074
Sheepshead, OR (2011)	0.065	0.043	0.036	0.035	0.038	0.060	0.073
South Steens, OR	0.059	0.038	0.042	0.030	0.024	0.049	0.072
South Steens, OR (2010)	0.060	0.039	0.045	0.030	0.029	0.048	0.066
Stinkingwater, OR	0.094	0.057	0.079	0.073	0.073	0.103	0.125
Three Fingers, OR	0.081	0.052	0.050	0.060	0.068	0.087	0.098
Three Fingers, OR (2011)	0.066	0.044	0.049	0.050	0.059	0.075	0.091
Warm Springs, OR	0.052	0.029	0.044	0.033	0.036	0.048	0.070
Warm Springs, OR (2010)	0.055	0.031	0.043	0.034	0.038	0.049	0.070
Blawn Wash, UT	0.095	0.081	0.083	0.081	0.082	0.116	0.120
Cedar Mountain, UT	0.082	0.051	0.059	0.052	0.051	0.069	0.086
Cedar Ridge, UT	0.108	0.071	0.066	0.085	0.077	0.109	0.127
Cedar Ridge, UT (trap)	0.119	0.081	0.073	0.085	0.087	0.112	0.125
Cold Springs, UT (2006)	0.113	0.088	0.107	0.115	0.107	0.131	0.157
Cold Springs, UT (trap)	0.082	0.067	0.080	0.088	0.080	0.107	0.136
Delta, UT	0.068	0.042	0.039	0.033	0.037	0.051	0.068
Hill Creek, UT	0.078	0.055	0.051	0.037	0.041	0.070	0.067
Muddy Creek, UT	0.132	0.086	0.075	0.091	0.102	0.119	0.144
North Hills, UT	0.106	0.071	0.079	0.078	0.070	0.093	0.122
Range Creek, UT	0.076	0.046	0.052	0.066	0.058	0.086	0.106
Sinbad, UT	0.087	0.075	0.068	0.070	0.070	0.086	0.094
Sulphur, UT	0.134	0.105	0.096	0.088	0.091	0.120	0.132
Sulphur Herd, UT (South, 2006)	0.090	0.063	0.078	0.057	0.053	0.068	0.091
Tilley Creek, UT	0.116	0.095	0.086	0.072	0.076	0.095	0.105

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	Pryor Mountains, MT (2001)	Pryor Mountains, MT (2009)	Bordo Atravisado, NM	El Rito, NM	Jicarilla, NM	Jarita, NM	JicarillA, NM
Winter Ridge, UT	0.080	0.057	0.046	0.035	0.046	0.062	0.058
Adobe Town, WY	0.063	0.040	0.033	0.030	0.038	0.059	0.072
Adobe Town, WY (2011)	0.058	0.031	0.028	0.027	0.036	0.054	0.063
Antelope Hills, WY	0.063	0.036	0.052	0.050	0.050	0.073	0.088
Conant Creek, WY (Lander)	0.094	0.067	0.073	0.066	0.075	0.093	0.107
Cooper Creek, WY	0.066	0.042	0.045	0.032	0.032	0.056	0.070
Dishpan Butte, WY (Lander)	0.088	0.058	0.056	0.056	0.052	0.075	0.102
Divide Basin, WY	0.061	0.031	0.035	0.029	0.029	0.047	0.063
Divide Basin, WY (2011)	0.064	0.034	0.030	0.031	0.033	0.052	0.066
Eagles Nest, WY	0.089	0.057	0.067	0.064	0.070	0.088	0.107
Happy Creek Springs, WY	0.082	0.055	0.057	0.064	0.059	0.096	0.107
Little Colorado, WY	0.077	0.047	0.042	0.056	0.058	0.085	0.098
Little Colorado, WY (2011)	0.072	0.043	0.046	0.049	0.050	0.072	0.088
Lost Creek, WY	0.052	0.030	0.039	0.039	0.042	0.057	0.076
Lost Creek, WY (combined)	0.053	0.034	0.041	0.035	0.039	0.051	0.074
McCullough Peaks, WY	0.077	0.046	0.062	0.054	0.044	0.082	0.096
Muskrat Basin, WY (Lander)	0.087	0.060	0.053	0.062	0.066	0.087	0.111
Salt Wells, WY (East)	0.051	0.027	0.027	0.027	0.032	0.055	0.072
Salt Wells, WY (West)	0.079	0.054	0.034	0.042	0.052	0.072	0.071
Stewart Creek, WY	0.059	0.038	0.052	0.053	0.049	0.069	0.092
Stewart Creek, WY (2009)	0.069	0.044	0.044	0.049	0.044	0.069	0.089
White Mountain, WY (2011)	0.076	0.057	0.047	0.039	0.046	0.066	0.071

	Antelope Valley, NV	Antelope Valley, NV (2011)	Augusta Mountains, NV	Bald Mountain, NV	Black Rock East, NV (2005)	Black Rock East, NV (2010)	Black Rock East, NV (2011)
Antelope Valley, NV	0.000						
Antelope Valley, NV (2011)	0.009	0.000					
Augusta Mountains, NV	0.031	0.033	0.000				
Bald Mountain, NV	0.026	0.027	0.027	0.000			

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	Antelope Valley, NV	Antelope Valley, NV (2011)	Augusta Mountains, NV	Bald Mountain, NV	Black Rock East, NV (2005)	Black Rock East, NV (2010)	Black Rock East, NV (2011)
Black Rock East, NV (2005)	0.050	0.053	0.047	0.038	0.000		
Black Rock East, NV (2010)	0.046	0.047	0.041	0.035	0.012	0.000	
Black Rock East, NV (2011)	0.041	0.042	0.034	0.031	0.026	0.013	0.000
Black Rock West, NV (2005)	0.052	0.054	0.050	0.037	0.018	0.015	0.028
Black Rock West, NV (2010)	0.049	0.050	0.048	0.039	0.013	0.013	0.027
Black Rock West, NV (2011)	0.076	0.071	0.074	0.061	0.052	0.045	0.052
Buffalo Hills, NV	0.047	0.050	0.062	0.046	0.062	0.064	0.060
Buffalo Hills, NV (2009)	0.033	0.036	0.046	0.033	0.055	0.055	0.048
Calico, NV	0.030	0.035	0.035	0.024	0.044	0.039	0.036
Calico Mountains, NV	0.045	0.049	0.047	0.037	0.065	0.058	0.050
Calico Mountains, NV (2011)	0.039	0.041	0.041	0.031	0.052	0.048	0.043
Callaghan, NV (Austin Allot)	0.035	0.036	0.031	0.018	0.048	0.041	0.029
Callaghan, NV (East Allot)	0.026	0.025	0.032	0.013	0.047	0.038	0.030
Catnip Herd, NV	0.049	0.047	0.044	0.038	0.065	0.058	0.056
Chimney Creek, NV	0.044	0.054	0.046	0.038	0.041	0.035	0.033
Desatoya Mountain, NV	0.076	0.071	0.057	0.055	0.073	0.068	0.058
Dolly Varden, NV	0.019	0.019	0.037	0.028	0.057	0.047	0.042
Dry Lake, NV	0.048	0.052	0.048	0.039	0.055	0.053	0.041
Fish Creek, NV	0.046	0.047	0.037	0.032	0.058	0.053	0.043
Goshute, NV	0.035	0.035	0.052	0.043	0.060	0.053	0.046
Goshute, NV (2011)	0.038	0.037	0.054	0.040	0.060	0.051	0.044
Granite, NV	0.033	0.040	0.038	0.024	0.047	0.039	0.038
Granite Range, NV	0.032	0.040	0.042	0.030	0.054	0.045	0.045
Granite Range, NV (2011)	0.028	0.035	0.035	0.024	0.044	0.039	0.037
Grass Valley, NV	0.035	0.033	0.034	0.018	0.059	0.050	0.036
Hall Creek, NV	0.035	0.038	0.035	0.020	0.047	0.045	0.032
Jakes Wash, NV	0.067	0.063	0.055	0.055	0.082	0.079	0.070
Johnnie, NV	0.048	0.047	0.053	0.045	0.054	0.045	0.035
Lahanton Reservoir, NV	0.073	0.064	0.064	0.053	0.071	0.061	0.054

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	Antelope Valley, NV	Antelope Valley, NV (2011)	Augusta Mountains, NV	Bald Mountain, NV	Black Rock East, NV (2005)	Black Rock East, NV (2010)	Black Rock East, NV (2011)
Little Fish Lake, NV	0.052	0.049	0.048	0.036	0.072	0.069	0.056
Little Highrock Canyon, NV	0.045	0.049	0.054	0.038	0.064	0.060	0.052
Little Humboldt, NV	0.042	0.046	0.050	0.038	0.070	0.065	0.062
Little Humboldt, NV (2010)	0.034	0.036	0.035	0.029	0.060	0.054	0.049
Little Owyhee, NV (Fairbanks)	0.052	0.052	0.045	0.039	0.062	0.055	0.042
Little Owyhee, NV (Lake Creek)	0.048	0.056	0.047	0.038	0.062	0.061	0.054
Little Owyhee, NV (Twin Valley)	0.043	0.053	0.048	0.038	0.061	0.049	0.048
Marvel Gap, NV (SWC 2010)	0.033	0.031	0.034	0.032	0.052	0.047	0.044
McGee Mountain, NV	0.037	0.038	0.038	0.028	0.043	0.040	0.038
Miller Mountain, NV (SWC 2010)	0.043	0.045	0.035	0.023	0.052	0.045	0.036
Montezuma Peak, NV	0.053	0.053	0.061	0.051	0.081	0.079	0.075
Nellis, NV	0.036	0.034	0.030	0.025	0.038	0.037	0.031
New Pass-Ravenswood, NV	0.031	0.035	0.027	0.022	0.038	0.035	0.028
North Stillwater, NV	0.039	0.046	0.037	0.035	0.056	0.053	0.048
Paymaster, NV (2006)	0.058	0.060	0.069	0.050	0.076	0.075	0.069
Paymaster, NV (2010)	0.057	0.059	0.070	0.054	0.076	0.078	0.071
Pine Nut Mountain, NV	0.069	0.069	0.055	0.053	0.074	0.073	0.062
Powell Mountain, NV	0.049	0.056	0.060	0.062	0.074	0.067	0.051
Red Rock, NV	0.041	0.035	0.045	0.037	0.055	0.049	0.043
Reveille, NV	0.050	0.051	0.041	0.036	0.052	0.051	0.044
Roberts Mountain, NV	0.046	0.040	0.038	0.032	0.048	0.042	0.036
Rock Creek, NV (2002)	0.069	0.068	0.070	0.054	0.085	0.074	0.069
Rock Creek, NV (2010)	0.047	0.047	0.049	0.037	0.065	0.056	0.048
Rocky Hills, NV	0.044	0.039	0.044	0.031	0.051	0.042	0.031
Rodeo Creek, NV	0.023	0.024	0.034	0.019	0.051	0.046	0.039
Saulsbury, NV	0.036	0.039	0.035	0.020	0.049	0.044	0.035
Sand Springs East, NV	0.034	0.036	0.037	0.028	0.043	0.040	0.038
Seven Mile, NV	0.044	0.040	0.047	0.036	0.071	0.060	0.051
Shawave Mountains, NV	0.032	0.035	0.043	0.027	0.057	0.052	0.043

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	Antelope Valley, NV	Antelope Valley, NV (2011)	Augusta Mountains, NV	Bald Mountain, NV	Black Rock East, NV (2005)	Black Rock East, NV (2010)	Black Rock East, NV (2011)
Silver Peak, NV	0.054	0.062	0.047	0.037	0.060	0.055	0.054
Snowstorm, NV (Castle Ridge)	0.044	0.049	0.051	0.030	0.066	0.062	0.056
Snowstorm, NV (Dryhill)	0.079	0.088	0.076	0.073	0.088	0.085	0.084
South Shoshone, NV	0.032	0.031	0.030	0.028	0.053	0.050	0.041
Spruce-Pequop, NV (2011)	0.031	0.032	0.040	0.042	0.063	0.058	0.050
Stillwater, NV	0.049	0.053	0.039	0.042	0.064	0.061	0.057
Stone Cabin, NV	0.031	0.033	0.031	0.017	0.044	0.040	0.034
Warm Springs, NV	0.050	0.052	0.050	0.031	0.032	0.034	0.041
Warm Springs Canyon, NV	0.038	0.040	0.035	0.023	0.030	0.027	0.032
Wheeler Pass, NV	0.059	0.056	0.065	0.052	0.068	0.058	0.048
Wheeler Pass, NV (2007)	0.028	0.027	0.031	0.022	0.038	0.036	0.028
Alvord Tule, OR	0.040	0.045	0.039	0.033	0.062	0.056	0.051
Beatys Butte, OR	0.027	0.028	0.031	0.020	0.040	0.034	0.030
Beatys Butte, OR (2010)	0.032	0.035	0.037	0.023	0.047	0.047	0.040
Big Summit, OR (2010)	0.104	0.096	0.121	0.095	0.138	0.131	0.120
Cold Spring, OR	0.039	0.040	0.032	0.031	0.054	0.045	0.038
Cold Spring, OR (2010)	0.047	0.047	0.040	0.038	0.062	0.055	0.045
Coyote Lake, OR	0.044	0.049	0.033	0.032	0.064	0.057	0.051
Coyote Lake, OR (2011)	0.031	0.039	0.029	0.027	0.048	0.045	0.038
Fishnet, OR	0.055	0.059	0.046	0.038	0.063	0.058	0.049
Hog Creek, OR	0.044	0.043	0.039	0.036	0.061	0.054	0.042
Jackies Butte, OR	0.051	0.052	0.055	0.046	0.058	0.048	0.034
Jackies Butte, OR (2011)	0.042	0.045	0.050	0.037	0.049	0.040	0.032
Kiger, OR (2011)	0.051	0.052	0.058	0.036	0.062	0.060	0.056
Kiger Herd, OR (2009)	0.058	0.057	0.061	0.041	0.063	0.061	0.056
Liggett Table, OR	0.193	0.193	0.175	0.157	0.176	0.152	0.169
Murderers Creek, OR (2001)	0.089	0.081	0.079	0.069	0.111	0.096	0.085
Murderers Creek, OR (2009)	0.073	0.069	0.070	0.058	0.097	0.084	0.070
Paisley Desert, OR	0.025	0.027	0.028	0.019	0.041	0.035	0.029

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	Antelope Valley, NV	Antelope Valley, NV (2011)	Augusta Mountains, NV	Bald Mountain, NV	Black Rock East, NV (2005)	Black Rock East, NV (2010)	Black Rock East, NV (2011)
Riddle Herd, OR (2009)	0.064	0.069	0.076	0.045	0.065	0.063	0.066
Riddle Mountain, OR	0.059	0.065	0.070	0.042	0.061	0.061	0.061
Riddle Mountain, OR (2011)	0.070	0.076	0.078	0.047	0.077	0.074	0.075
Sand Springs, OR (2011)	0.034	0.043	0.037	0.032	0.054	0.055	0.046
Sheepshead, OR	0.032	0.034	0.033	0.027	0.051	0.046	0.036
Sheepshead, OR (2011)	0.033	0.034	0.032	0.023	0.044	0.043	0.035
South Steens, OR	0.029	0.033	0.031	0.028	0.050	0.041	0.037
South Steens, OR (2010)	0.031	0.035	0.036	0.031	0.052	0.043	0.035
Stinkingwater, OR	0.076	0.070	0.054	0.058	0.067	0.059	0.053
Three Fingers, OR	0.056	0.057	0.055	0.040	0.055	0.053	0.049
Three Fingers, OR (2011)	0.049	0.051	0.043	0.037	0.051	0.045	0.038
Warm Springs, OR	0.035	0.038	0.034	0.026	0.047	0.039	0.029
Warm Springs, OR (2010)	0.036	0.041	0.032	0.025	0.045	0.035	0.026
Blawn Wash, UT	0.066	0.076	0.075	0.057	0.076	0.070	0.064
Cedar Mountain, UT	0.042	0.052	0.040	0.033	0.069	0.061	0.055
Cedar Ridge, UT	0.070	0.081	0.081	0.056	0.104	0.097	0.084
Cedar Ridge, UT (trap)	0.069	0.080	0.088	0.062	0.117	0.112	0.095
Cold Springs, UT (2006)	0.101	0.108	0.103	0.087	0.107	0.103	0.114
Cold Springs, UT (trap)	0.064	0.072	0.074	0.062	0.080	0.077	0.081
Delta, UT	0.028	0.025	0.031	0.023	0.054	0.048	0.039
Hill Creek, UT	0.040	0.041	0.046	0.030	0.062	0.056	0.053
Muddy Creek, UT	0.080	0.074	0.084	0.069	0.110	0.101	0.095
North Hills, UT	0.063	0.062	0.067	0.058	0.095	0.083	0.073
Range Creek, UT	0.052	0.061	0.058	0.038	0.071	0.066	0.065
Sinbad, UT	0.073	0.077	0.071	0.063	0.079	0.082	0.073
Sulphur, UT	0.094	0.092	0.083	0.086	0.117	0.116	0.097
Sulphur Herd, UT (South, 2006)	0.066	0.068	0.059	0.058	0.084	0.071	0.069
Tilley Creek, UT	0.065	0.076	0.082	0.067	0.095	0.084	0.084
Winter Ridge, UT	0.038	0.034	0.046	0.035	0.060	0.056	0.047

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	Antelope Valley, NV	Antelope Valley, NV (2011)	Augusta Mountains, NV	Bald Mountain, NV	Black Rock East, NV (2005)	Black Rock East, NV (2010)	Black Rock East, NV (2011)
Adobe Town, WY	0.034	0.032	0.035	0.031	0.059	0.051	0.040
Adobe Town, WY (2011)	0.027	0.026	0.036	0.027	0.051	0.046	0.039
Antelope Hills, WY	0.052	0.052	0.051	0.040	0.055	0.050	0.046
Conant Creek, WY (Lander)	0.069	0.072	0.076	0.054	0.074	0.076	0.073
Cooper Creek, WY	0.040	0.039	0.035	0.029	0.049	0.045	0.034
Dishpan Butte, WY (Lander)	0.055	0.057	0.053	0.039	0.063	0.061	0.057
Divide Basin, WY	0.025	0.029	0.030	0.017	0.045	0.040	0.037
Divide Basin, WY (2011)	0.025	0.028	0.029	0.016	0.045	0.042	0.036
Eagles Nest, WY	0.062	0.059	0.055	0.053	0.085	0.078	0.068
Happy Creek Springs, WY	0.072	0.070	0.060	0.048	0.068	0.064	0.052
Little Colorado, WY	0.041	0.043	0.044	0.029	0.050	0.046	0.040
Little Colorado, WY (2011)	0.040	0.041	0.042	0.028	0.047	0.042	0.037
Lost Creek, WY	0.037	0.035	0.033	0.025	0.050	0.047	0.040
Lost Creek, WY (combined)	0.040	0.040	0.039	0.029	0.054	0.051	0.042
McCullough Peaks, WY	0.055	0.058	0.051	0.036	0.051	0.054	0.049
Muskrat Basin, WY (Lander)	0.050	0.053	0.046	0.036	0.062	0.061	0.057
Salt Wells, WY (East)	0.026	0.026	0.030	0.021	0.050	0.043	0.036
Salt Wells, WY (West)	0.037	0.039	0.035	0.022	0.043	0.042	0.030
Stewart Creek, WY	0.050	0.052	0.043	0.035	0.064	0.057	0.050
Stewart Creek, WY (2009)	0.049	0.050	0.048	0.039	0.060	0.062	0.053
White Mountain, WY (2011)	0.045	0.044	0.050	0.041	0.056	0.053	0.047

	Black Rock West, NV (2005)	Black Rock West, NV (2010)	Black Rock West, NV (2011)	Buffalo Hills, NV	Buffalo Hills, NV (2009)	Calico, NV	Calico Mountains, NV
Black Rock West, NV (2005)	0.000						
Black Rock West, NV (2010)	0.007	0.000					
Black Rock West, NV (2011)	0.025	0.026	0.000				
Buffalo Hills, NV	0.074	0.067	0.100	0.000			

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	Black Rock West, NV (2005)	Black Rock West, NV (2010)	Black Rock West, NV (2011)	Buffalo Hills, NV	Buffalo Hills, NV (2009)	Calico, NV	Calico Mountains, NV
Buffalo Hills, NV (2009)	0.063	0.059	0.088	0.017	0.000		
Calico, NV	0.039	0.037	0.060	0.035	0.023	0.000	
Calico Mountains, NV	0.065	0.061	0.084	0.050	0.030	0.021	0.000
Calico Mountains, NV (2011)	0.049	0.044	0.062	0.039	0.028	0.009	0.015
Callaghan, NV (Austin Allot)	0.050	0.049	0.068	0.044	0.030	0.026	0.035
Callaghan, NV (East Allot)	0.043	0.043	0.059	0.047	0.034	0.029	0.039
Catnip Herd, NV	0.044	0.052	0.067	0.065	0.052	0.040	0.048
Chimney Creek, NV	0.035	0.039	0.056	0.059	0.042	0.029	0.048
Desatoya Mountain, NV	0.074	0.075	0.102	0.084	0.073	0.066	0.086
Dolly Varden, NV	0.049	0.047	0.058	0.051	0.041	0.033	0.052
Dry Lake, NV	0.062	0.059	0.088	0.053	0.039	0.031	0.046
Fish Creek, NV	0.061	0.060	0.080	0.059	0.045	0.028	0.044
Goshute, NV	0.056	0.052	0.069	0.061	0.055	0.040	0.069
Goshute, NV (2011)	0.052	0.051	0.063	0.064	0.056	0.039	0.064
Granite, NV	0.045	0.044	0.068	0.048	0.032	0.013	0.028
Granite Range, NV	0.051	0.050	0.071	0.043	0.027	0.014	0.028
Granite Range, NV (2011)	0.045	0.040	0.063	0.035	0.027	0.009	0.030
Grass Valley, NV	0.053	0.055	0.071	0.049	0.034	0.035	0.039
Hall Creek, NV	0.054	0.052	0.074	0.050	0.034	0.033	0.044
Jakes Wash, NV	0.088	0.080	0.107	0.081	0.075	0.060	0.072
Johnnie, NV	0.058	0.057	0.086	0.074	0.060	0.053	0.068
Lahanton Reservoir, NV	0.067	0.062	0.079	0.079	0.073	0.057	0.081
Little Fish Lake, NV	0.073	0.072	0.088	0.073	0.049	0.047	0.057
Little Highrock Canyon, NV	0.061	0.057	0.071	0.050	0.040	0.023	0.042
Little Humboldt, NV	0.078	0.077	0.101	0.071	0.062	0.057	0.058
Little Humboldt, NV (2010)	0.061	0.058	0.078	0.065	0.051	0.038	0.042
Little Owyhee, NV (Fairbanks)	0.069	0.068	0.084	0.060	0.042	0.043	0.052
Little Owyhee, NV (Lake Creek)	0.065	0.067	0.081	0.060	0.045	0.047	0.056
Little Owyhee, NV (Twin Valley)	0.051	0.053	0.065	0.065	0.053	0.036	0.059

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	Black Rock West, NV (2005)	Black Rock West, NV (2010)	Black Rock West, NV (2011)	Buffalo Hills, NV	Buffalo Hills, NV (2009)	Calico, NV	Calico Mountains, NV
Marvel Gap, NV (SWC 2010)	0.048	0.049	0.074	0.048	0.040	0.038	0.051
McGee Mountain, NV	0.040	0.043	0.061	0.062	0.042	0.031	0.045
Miller Mountain, NV (SWC 2010)	0.049	0.051	0.066	0.057	0.037	0.034	0.041
Montezuma Peak, NV	0.078	0.071	0.078	0.061	0.055	0.050	0.065
Nellis, NV	0.041	0.040	0.067	0.042	0.033	0.026	0.041
New Pass-Ravenswood, NV	0.037	0.035	0.061	0.049	0.039	0.021	0.041
North Stillwater, NV	0.059	0.056	0.077	0.048	0.033	0.030	0.045
Paymaster, NV (2006)	0.081	0.073	0.088	0.059	0.055	0.054	0.066
Paymaster, NV (2010)	0.082	0.071	0.087	0.052	0.050	0.050	0.061
Pine Nut Mountain, NV	0.085	0.079	0.111	0.074	0.063	0.050	0.069
Powell Mountain, NV	0.080	0.082	0.105	0.091	0.067	0.063	0.080
Red Rock, NV	0.054	0.051	0.068	0.056	0.048	0.045	0.065
Reveille, NV	0.058	0.057	0.085	0.067	0.055	0.046	0.062
Roberts Mountain, NV	0.048	0.047	0.068	0.056	0.047	0.037	0.049
Rock Creek, NV (2002)	0.077	0.078	0.093	0.105	0.087	0.065	0.076
Rock Creek, NV (2010)	0.061	0.060	0.078	0.083	0.066	0.051	0.061
Rocky Hills, NV	0.048	0.045	0.074	0.058	0.047	0.037	0.051
Rodeo Creek, NV	0.050	0.048	0.060	0.043	0.026	0.029	0.037
Saulsbury, NV	0.048	0.047	0.069	0.059	0.037	0.030	0.044
Sand Springs East, NV	0.042	0.045	0.063	0.059	0.041	0.032	0.045
Seven Mile, NV	0.062	0.065	0.086	0.064	0.051	0.042	0.055
Shawave Mountains, NV	0.055	0.055	0.068	0.044	0.028	0.030	0.039
Silver Peak, NV	0.060	0.056	0.078	0.049	0.047	0.037	0.049
Snowstorm, NV (Castle Ridge)	0.066	0.066	0.087	0.069	0.066	0.044	0.060
Snowstorm, NV (Dryhill)	0.085	0.083	0.100	0.065	0.079	0.057	0.086
South Shoshone, NV	0.049	0.047	0.070	0.054	0.045	0.029	0.047
Spruce-Pequop, NV (2011)	0.066	0.059	0.079	0.072	0.059	0.047	0.064
Stillwater, NV	0.066	0.061	0.071	0.058	0.045	0.042	0.054
Stone Cabin, NV	0.045	0.047	0.067	0.047	0.034	0.030	0.042

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	Black Rock West, NV (2005)	Black Rock West, NV (2010)	Black Rock West, NV (2011)	Buffalo Hills, NV	Buffalo Hills, NV (2009)	Calico, NV	Calico Mountains, NV
Warm Springs, NV	0.019	0.023	0.028	0.059	0.051	0.032	0.057
Warm Springs Canyon, NV	0.017	0.019	0.029	0.054	0.040	0.023	0.037
Wheeler Pass, NV	0.071	0.067	0.091	0.088	0.074	0.073	0.083
Wheeler Pass, NV (2007)	0.045	0.044	0.072	0.056	0.038	0.033	0.044
Alvord Tule, OR	0.053	0.057	0.081	0.066	0.048	0.037	0.050
Beatys Butte, OR	0.039	0.038	0.059	0.044	0.031	0.024	0.038
Beatys Butte, OR (2010)	0.045	0.044	0.056	0.045	0.035	0.025	0.039
Big Summit, OR (2010)	0.147	0.141	0.171	0.131	0.113	0.115	0.100
Cold Spring, OR	0.052	0.047	0.071	0.056	0.043	0.032	0.044
Cold Spring, OR (2010)	0.063	0.056	0.079	0.057	0.047	0.041	0.050
Coyote Lake, OR	0.060	0.062	0.091	0.071	0.048	0.040	0.045
Coyote Lake, OR (2011)	0.050	0.050	0.080	0.055	0.037	0.028	0.037
Fishnet, OR	0.057	0.057	0.078	0.056	0.053	0.035	0.052
Hog Creek, OR	0.059	0.056	0.075	0.055	0.047	0.032	0.050
Jackies Butte, OR	0.049	0.052	0.073	0.065	0.054	0.043	0.061
Jackies Butte, OR (2011)	0.036	0.040	0.056	0.052	0.044	0.031	0.047
Kiger, OR (2011)	0.063	0.064	0.085	0.047	0.040	0.038	0.054
Kiger Herd, OR (2009)	0.062	0.065	0.088	0.049	0.044	0.042	0.056
Liggett Table, OR	0.134	0.137	0.138	0.209	0.198	0.163	0.179
Murderers Creek, OR (2001)	0.101	0.102	0.104	0.097	0.082	0.079	0.074
Murderers Creek, OR (2009)	0.089	0.090	0.101	0.074	0.060	0.059	0.060
Paisley Desert, OR	0.045	0.044	0.069	0.035	0.028	0.023	0.033
Riddle Herd, OR (2009)	0.062	0.062	0.078	0.071	0.059	0.048	0.069
Riddle Mountain, OR	0.059	0.060	0.078	0.077	0.065	0.050	0.069
Riddle Mountain, OR (2011)	0.075	0.076	0.091	0.081	0.070	0.056	0.076
Sand Springs, OR (2011)	0.059	0.058	0.087	0.047	0.039	0.029	0.037
Sheepshead, OR	0.053	0.054	0.078	0.053	0.039	0.032	0.038
Sheepshead, OR (2011)	0.052	0.049	0.078	0.050	0.039	0.031	0.043
South Steens, OR	0.046	0.048	0.066	0.046	0.037	0.029	0.042

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	Black Rock West, NV (2005)	Black Rock West, NV (2010)	Black Rock West, NV (2011)	Buffalo Hills, NV	Buffalo Hills, NV (2009)	Calico, NV	Calico Mountains, NV
South Steens, OR (2010)	0.047	0.047	0.059	0.044	0.035	0.026	0.041
Stinkingwater, OR	0.051	0.062	0.081	0.101	0.084	0.063	0.083
Three Fingers, OR	0.058	0.059	0.086	0.064	0.055	0.047	0.057
Three Fingers, OR (2011)	0.051	0.052	0.076	0.064	0.057	0.046	0.058
Warm Springs, OR	0.040	0.041	0.058	0.055	0.044	0.028	0.040
Warm Springs, OR (2010)	0.039	0.039	0.055	0.053	0.044	0.026	0.040
Blawn Wash, UT	0.068	0.064	0.082	0.101	0.086	0.056	0.084
Cedar Mountain, UT	0.063	0.063	0.088	0.064	0.051	0.038	0.054
Cedar Ridge, UT	0.100	0.103	0.127	0.096	0.080	0.067	0.063
Cedar Ridge, UT (trap)	0.115	0.114	0.135	0.092	0.079	0.074	0.070
Cold Springs, UT (2006)	0.084	0.088	0.114	0.115	0.097	0.070	0.097
Cold Springs, UT (trap)	0.068	0.068	0.093	0.090	0.073	0.053	0.072
Delta, UT	0.060	0.058	0.079	0.047	0.028	0.029	0.037
Hill Creek, UT	0.064	0.062	0.081	0.041	0.034	0.042	0.049
Muddy Creek, UT	0.104	0.104	0.135	0.108	0.095	0.080	0.103
North Hills, UT	0.095	0.098	0.122	0.086	0.073	0.076	0.074
Range Creek, UT	0.060	0.063	0.088	0.070	0.055	0.036	0.045
Sinbad, UT	0.093	0.089	0.115	0.092	0.070	0.062	0.065
Sulphur, UT	0.129	0.127	0.145	0.108	0.087	0.094	0.092
Sulphur Herd, UT (South, 2006)	0.082	0.084	0.101	0.072	0.057	0.058	0.060
Tilley Creek, UT	0.096	0.090	0.117	0.092	0.086	0.066	0.089
Winter Ridge, UT	0.060	0.055	0.072	0.046	0.037	0.037	0.047
Adobe Town, WY	0.059	0.059	0.073	0.055	0.039	0.042	0.050
Adobe Town, WY (2011)	0.048	0.047	0.062	0.037	0.032	0.027	0.043
Antelope Hills, WY	0.053	0.057	0.087	0.063	0.046	0.032	0.047
Conant Creek, WY (Lander)	0.081	0.080	0.092	0.081	0.067	0.055	0.070
Cooper Creek, WY	0.057	0.054	0.074	0.049	0.035	0.034	0.041
Dishpan Butte, WY (Lander)	0.068	0.069	0.086	0.073	0.057	0.054	0.059
Divide Basin, WY	0.042	0.043	0.065	0.046	0.032	0.022	0.035

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	Black Rock West, NV (2005)	Black Rock West, NV (2010)	Black Rock West, NV (2011)	Buffalo Hills, NV	Buffalo Hills, NV (2009)	Calico, NV	Calico Mountains, NV
Divide Basin, WY (2011)	0.046	0.047	0.071	0.049	0.031	0.026	0.036
Eagles Nest, WY	0.080	0.077	0.103	0.079	0.073	0.061	0.070
Happy Creek Springs, WY	0.069	0.068	0.103	0.071	0.055	0.047	0.041
Little Colorado, WY	0.046	0.044	0.067	0.063	0.052	0.039	0.045
Little Colorado, WY (2011)	0.042	0.039	0.062	0.058	0.049	0.032	0.043
Lost Creek, WY	0.048	0.047	0.072	0.051	0.037	0.031	0.043
Lost Creek, WY (combined)	0.054	0.051	0.073	0.054	0.040	0.033	0.042
McCullough Peaks, WY	0.054	0.058	0.080	0.061	0.053	0.038	0.053
Muskrat Basin, WY (Lander)	0.068	0.065	0.087	0.073	0.060	0.053	0.060
Salt Wells, WY (East)	0.045	0.045	0.059	0.045	0.030	0.026	0.038
Salt Wells, WY (West)	0.051	0.047	0.074	0.052	0.042	0.032	0.043
Stewart Creek, WY	0.059	0.061	0.085	0.066	0.050	0.037	0.047
Stewart Creek, WY (2009)	0.061	0.061	0.084	0.066	0.049	0.043	0.051
White Mountain, WY (2011)	0.053	0.048	0.060	0.058	0.043	0.028	0.049

	Calico Mountains, NV (2011)	Callaghan, NV (Austin Allot)	Callaghan, NV (East Allot)	Catnip Herd, NV	Chimney Creek, NV	Desatoya Mountain, NV	Dolly Varden, NV
Calico Mountains, NV (2011)	0.000						
Callaghan, NV (Austin Allot)	0.031	0.000					
Callaghan, NV (East Allot)	0.035	0.014	0.000				
Catnip Herd, NV	0.046	0.044	0.042	0.000			
Chimney Creek, NV	0.042	0.037	0.037	0.043	0.000		
Desatoya Mountain, NV	0.081	0.054	0.061	0.076	0.068	0.000	
Dolly Varden, NV	0.037	0.037	0.031	0.047	0.050	0.077	0.000
Dry Lake, NV	0.040	0.027	0.040	0.058	0.040	0.058	0.055
Fish Creek, NV	0.037	0.024	0.033	0.058	0.047	0.063	0.044
Goshute, NV	0.051	0.048	0.044	0.059	0.053	0.070	0.028
Goshute, NV (2011)	0.049	0.043	0.038	0.055	0.050	0.069	0.028
Granite, NV	0.018	0.027	0.030	0.053	0.041	0.074	0.037

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	Calico Mountains, NV (2011)	Callaghan, NV (Austin Allot)	Callaghan, NV (East Allot)	Catnip Herd, NV	Chimney Creek, NV	Desatoya Mountain, NV	Dolly Varden, NV
Granite Range, NV	0.025	0.030	0.030	0.050	0.039	0.075	0.038
Granite Range, NV (2011)	0.014	0.023	0.027	0.045	0.038	0.071	0.029
Grass Valley, NV	0.042	0.013	0.012	0.042	0.041	0.054	0.033
Hall Creek, NV	0.038	0.007	0.020	0.049	0.045	0.059	0.039
Jakes Wash, NV	0.065	0.047	0.055	0.070	0.081	0.080	0.071
Johnnie, NV	0.060	0.046	0.047	0.073	0.063	0.068	0.054
Lahanton Reservoir, NV	0.063	0.051	0.050	0.061	0.063	0.077	0.063
Little Fish Lake, NV	0.057	0.033	0.033	0.056	0.053	0.074	0.055
Little Highrock Canyon, NV	0.025	0.043	0.044	0.064	0.052	0.091	0.038
Little Humboldt, NV	0.063	0.045	0.042	0.066	0.068	0.088	0.047
Little Humboldt, NV (2010)	0.042	0.034	0.030	0.055	0.054	0.080	0.040
Little Owyhee, NV (Fairbanks)	0.044	0.029	0.040	0.072	0.055	0.083	0.049
Little Owyhee, NV (Lake Creek)	0.054	0.036	0.038	0.061	0.042	0.085	0.053
Little Owyhee, NV (Twin Valley)	0.045	0.036	0.036	0.065	0.045	0.069	0.042
Marvel Gap, NV (SWC 2010)	0.044	0.029	0.028	0.036	0.047	0.068	0.036
McGee Mountain, NV	0.041	0.030	0.030	0.044	0.034	0.058	0.046
Miller Mountain, NV (SWC 2010)	0.036	0.017	0.022	0.050	0.041	0.065	0.047
Montezuma Peak, NV	0.053	0.049	0.045	0.067	0.070	0.100	0.047
Nellis, NV	0.036	0.021	0.019	0.043	0.034	0.055	0.044
New Pass-Ravenswood, NV	0.033	0.020	0.024	0.040	0.034	0.048	0.037
North Stillwater, NV	0.034	0.033	0.033	0.058	0.050	0.082	0.048
Paymaster, NV (2006)	0.055	0.044	0.048	0.074	0.071	0.097	0.055
Paymaster, NV (2010)	0.051	0.045	0.050	0.070	0.070	0.097	0.056
Pine Nut Mountain, NV	0.061	0.051	0.060	0.082	0.072	0.063	0.074
Powell Mountain, NV	0.068	0.048	0.056	0.090	0.073	0.103	0.060
Red Rock, NV	0.051	0.045	0.040	0.063	0.062	0.078	0.039
Reveille, NV	0.054	0.040	0.037	0.076	0.056	0.059	0.065
Roberts Mountain, NV	0.042	0.030	0.028	0.060	0.052	0.072	0.047
Rock Creek, NV (2002)	0.074	0.050	0.049	0.076	0.078	0.096	0.072

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	Calico Mountains, NV (2011)	Callaghan, NV (Austin Allot)	Callaghan, NV (East Allot)	Catnip Herd, NV	Chimney Creek, NV	Desatoya Mountain, NV	Dolly Varden, NV
Rock Creek, NV (2010)	0.061	0.035	0.036	0.063	0.060	0.075	0.051
Rocky Hills, NV	0.046	0.026	0.023	0.045	0.043	0.064	0.041
Rodeo Creek, NV	0.033	0.023	0.015	0.048	0.045	0.067	0.028
Saulsbury, NV	0.037	0.020	0.021	0.051	0.036	0.057	0.039
Sand Springs East, NV	0.041	0.029	0.029	0.046	0.036	0.059	0.045
Seven Mile, NV	0.048	0.043	0.035	0.041	0.046	0.063	0.047
Shawave Mountains, NV	0.033	0.026	0.029	0.045	0.046	0.067	0.030
Silver Peak, NV	0.043	0.031	0.036	0.056	0.053	0.073	0.050
Snowstorm, NV (Castle Ridge)	0.049	0.035	0.033	0.059	0.057	0.087	0.051
Snowstorm, NV (Dryhill)	0.067	0.076	0.073	0.086	0.080	0.126	0.072
South Shoshone, NV	0.036	0.025	0.023	0.045	0.048	0.068	0.038
Spruce-Pequop, NV (2011)	0.053	0.051	0.047	0.066	0.064	0.076	0.023
Stillwater, NV	0.046	0.042	0.041	0.064	0.054	0.084	0.051
Stone Cabin, NV	0.037	0.020	0.015	0.051	0.035	0.053	0.040
Warm Springs, NV	0.034	0.041	0.035	0.046	0.037	0.075	0.046
Warm Springs Canyon, NV	0.027	0.032	0.027	0.036	0.028	0.059	0.036
Wheeler Pass, NV	0.079	0.058	0.055	0.092	0.075	0.079	0.059
Wheeler Pass, NV (2007)	0.033	0.027	0.030	0.052	0.050	0.067	0.035
Alvord Tule, OR	0.040	0.036	0.033	0.049	0.058	0.072	0.040
Beatys Butte, OR	0.031	0.023	0.022	0.033	0.032	0.056	0.029
Beatys Butte, OR (2010)	0.028	0.027	0.029	0.043	0.038	0.065	0.030
Big Summit, OR (2010)	0.116	0.103	0.087	0.145	0.137	0.154	0.096
Cold Spring, OR	0.042	0.024	0.028	0.045	0.046	0.063	0.038
Cold Spring, OR (2010)	0.047	0.031	0.034	0.057	0.059	0.074	0.046
Coyote Lake, OR	0.046	0.027	0.030	0.050	0.053	0.072	0.051
Coyote Lake, OR (2011)	0.035	0.021	0.025	0.045	0.042	0.066	0.039
Fishnet, OR	0.040	0.031	0.037	0.045	0.049	0.092	0.053
Hog Creek, OR	0.039	0.029	0.031	0.062	0.055	0.069	0.049
Jackies Butte, OR	0.047	0.040	0.039	0.063	0.052	0.072	0.049

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	Calico Mountains, NV (2011)	Callaghan, NV (Austin Allot)	Callaghan, NV (East Allot)	Catnip Herd, NV	Chimney Creek, NV	Desatoya Mountain, NV	Dolly Varden, NV
Jackies Butte, OR (2011)	0.033	0.036	0.032	0.051	0.043	0.073	0.038
Kiger, OR (2011)	0.043	0.031	0.040	0.050	0.060	0.082	0.049
Kiger Herd, OR (2009)	0.046	0.035	0.043	0.058	0.068	0.081	0.057
Liggett Table, OR	0.167	0.149	0.153	0.135	0.164	0.180	0.167
Murderers Creek, OR (2001)	0.078	0.063	0.064	0.075	0.096	0.126	0.083
Murderers Creek, OR (2009)	0.064	0.045	0.052	0.064	0.072	0.099	0.071
Paisley Desert, OR	0.029	0.019	0.019	0.046	0.041	0.053	0.030
Riddle Herd, OR (2009)	0.053	0.041	0.049	0.066	0.067	0.095	0.062
Riddle Mountain, OR	0.057	0.040	0.049	0.060	0.064	0.086	0.057
Riddle Mountain, OR (2011)	0.061	0.046	0.051	0.077	0.077	0.105	0.067
Sand Springs, OR (2011)	0.033	0.025	0.033	0.054	0.049	0.069	0.041
Sheepshead, OR	0.036	0.022	0.026	0.043	0.045	0.062	0.040
Sheepshead, OR (2011)	0.037	0.021	0.024	0.047	0.047	0.061	0.040
South Steens, OR	0.036	0.025	0.024	0.048	0.041	0.060	0.032
South Steens, OR (2010)	0.030	0.028	0.026	0.045	0.035	0.064	0.033
Stinkingwater, OR	0.073	0.057	0.060	0.046	0.068	0.093	0.070
Three Fingers, OR	0.053	0.037	0.039	0.049	0.052	0.087	0.058
Three Fingers, OR (2011)	0.051	0.031	0.036	0.047	0.046	0.079	0.049
Warm Springs, OR	0.035	0.022	0.024	0.041	0.033	0.057	0.035
Warm Springs, OR (2010)	0.036	0.021	0.024	0.043	0.029	0.055	0.035
Blawn Wash, UT	0.062	0.068	0.059	0.091	0.066	0.118	0.074
Cedar Mountain, UT	0.047	0.039	0.034	0.060	0.047	0.073	0.046
Cedar Ridge, UT	0.072	0.056	0.054	0.076	0.088	0.125	0.079
Cedar Ridge, UT (trap)	0.075	0.064	0.057	0.093	0.105	0.138	0.077
Cold Springs, UT (2006)	0.087	0.100	0.098	0.091	0.090	0.146	0.105
Cold Springs, UT (trap)	0.065	0.072	0.066	0.080	0.075	0.120	0.077
Delta, UT	0.034	0.021	0.022	0.052	0.053	0.056	0.033
Hill Creek, UT	0.042	0.029	0.028	0.067	0.062	0.078	0.043
Muddy Creek, UT	0.090	0.079	0.070	0.092	0.114	0.109	0.084

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	Calico Mountains, NV (2011)	Callaghan, NV (Austin Allot)	Callaghan, NV (East Allot)	Catnip Herd, NV	Chimney Creek, NV	Desatoya Mountain, NV	Dolly Varden, NV
North Hills, UT	0.089	0.061	0.058	0.074	0.083	0.094	0.065
Range Creek, UT	0.045	0.043	0.042	0.049	0.056	0.101	0.059
Sinbad, UT	0.063	0.058	0.068	0.096	0.078	0.090	0.084
Sulphur, UT	0.101	0.081	0.082	0.114	0.096	0.111	0.098
Sulphur Herd, UT (South, 2006)	0.064	0.046	0.050	0.070	0.067	0.085	0.064
Tilley Creek, UT	0.073	0.066	0.061	0.095	0.083	0.134	0.074
Winter Ridge, UT	0.035	0.030	0.030	0.058	0.057	0.081	0.037
Adobe Town, WY	0.046	0.022	0.027	0.052	0.052	0.064	0.037
Adobe Town, WY (2011)	0.030	0.026	0.024	0.045	0.041	0.070	0.028
Antelope Hills, WY	0.045	0.044	0.046	0.051	0.051	0.057	0.058
Conant Creek, WY (Lander)	0.059	0.048	0.047	0.085	0.074	0.117	0.074
Cooper Creek, WY	0.038	0.021	0.027	0.059	0.044	0.048	0.044
Dishpan Butte, WY (Lander)	0.057	0.033	0.038	0.061	0.068	0.079	0.055
Divide Basin, WY	0.030	0.020	0.021	0.035	0.038	0.053	0.028
Divide Basin, WY (2011)	0.036	0.023	0.020	0.040	0.038	0.061	0.031
Eagles Nest, WY	0.067	0.053	0.047	0.071	0.088	0.087	0.063
Happy Creek Springs, WY	0.047	0.038	0.049	0.064	0.067	0.079	0.073
Little Colorado, WY	0.044	0.034	0.033	0.046	0.055	0.081	0.041
Little Colorado, WY (2011)	0.037	0.030	0.032	0.041	0.049	0.078	0.038
Lost Creek, WY	0.036	0.023	0.023	0.045	0.049	0.054	0.036
Lost Creek, WY (combined)	0.036	0.025	0.024	0.050	0.054	0.059	0.040
McCullough Peaks, WY	0.043	0.035	0.041	0.060	0.048	0.083	0.056
Muskrat Basin, WY (Lander)	0.057	0.035	0.039	0.062	0.069	0.082	0.053
Salt Wells, WY (East)	0.029	0.021	0.017	0.042	0.036	0.061	0.027
Salt Wells, WY (West)	0.038	0.020	0.024	0.057	0.047	0.063	0.044
Stewart Creek, WY	0.043	0.032	0.034	0.052	0.058	0.070	0.050
Stewart Creek, WY (2009)	0.042	0.033	0.035	0.064	0.062	0.072	0.051
White Mountain, WY (2011)	0.027	0.037	0.039	0.060	0.054	0.091	0.037

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	Dry Lake, NV	Fish Creek, NV	Goshute, NV	Goshute, NV (2011)	Granite, NV	Granite Range, NV	Granite Range, NV (2011)
Dry Lake, NV	0.000						
Fish Creek, NV	0.043	0.000					
Goshute, NV	0.056	0.055	0.000				
Goshute, NV (2011)	0.057	0.053	0.009	0.000			
Granite, NV	0.045	0.027	0.048	0.047	0.000		
Granite Range, NV	0.042	0.038	0.050	0.049	0.015	0.000	
Granite Range, NV (2011)	0.036	0.030	0.040	0.041	0.011	0.011	0.000
Grass Valley, NV	0.039	0.035	0.051	0.047	0.038	0.037	0.037
Hall Creek, NV	0.031	0.031	0.051	0.049	0.034	0.039	0.030
Jakes Wash, NV	0.058	0.067	0.077	0.068	0.073	0.069	0.061
Johnnie, NV	0.053	0.052	0.063	0.059	0.063	0.066	0.059
Lahanton Reservoir, NV	0.061	0.060	0.059	0.062	0.066	0.069	0.052
Little Fish Lake, NV	0.050	0.052	0.054	0.046	0.047	0.049	0.044
Little Highrock Canyon, NV	0.044	0.050	0.056	0.054	0.041	0.036	0.029
Little Humboldt, NV	0.067	0.060	0.072	0.065	0.050	0.047	0.049
Little Humboldt, NV (2010)	0.055	0.048	0.061	0.056	0.036	0.036	0.035
Little Owyhee, NV (Fairbanks)	0.055	0.046	0.060	0.057	0.041	0.047	0.043
Little Owyhee, NV (Lake Creek)	0.059	0.054	0.069	0.071	0.054	0.050	0.046
Little Owyhee, NV (Twin Valley)	0.054	0.032	0.059	0.058	0.036	0.038	0.033
Marvel Gap, NV (SWC 2010)	0.054	0.040	0.058	0.055	0.043	0.042	0.038
McGee Mountain, NV	0.039	0.032	0.046	0.041	0.032	0.034	0.036
Miller Mountain, NV (SWC 2010)	0.039	0.030	0.060	0.053	0.032	0.037	0.034
Montezuma Peak, NV	0.062	0.052	0.056	0.056	0.055	0.056	0.044
Nellis, NV	0.032	0.026	0.047	0.041	0.029	0.036	0.030
New Pass-Ravenswood, NV	0.028	0.029	0.042	0.042	0.031	0.034	0.025
North Stillwater, NV	0.053	0.040	0.055	0.054	0.036	0.035	0.027
Paymaster, NV (2006)	0.053	0.055	0.061	0.055	0.057	0.057	0.048
Paymaster, NV (2010)	0.048	0.056	0.058	0.054	0.058	0.057	0.046

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	Dry Lake, NV	Fish Creek, NV	Goshute, NV	Goshute, NV (2011)	Granite, NV	Granite Range, NV	Granite Range, NV (2011)
Pine Nut Mountain, NV	0.048	0.046	0.085	0.083	0.064	0.067	0.054
Powell Mountain, NV	0.062	0.061	0.071	0.069	0.060	0.062	0.053
Red Rock, NV	0.056	0.050	0.051	0.045	0.050	0.050	0.045
Reveille, NV	0.049	0.042	0.070	0.066	0.040	0.049	0.050
Roberts Mountain, NV	0.055	0.036	0.057	0.050	0.037	0.040	0.039
Rock Creek, NV (2002)	0.066	0.064	0.085	0.077	0.072	0.070	0.068
Rock Creek, NV (2010)	0.055	0.052	0.062	0.053	0.055	0.056	0.054
Rocky Hills, NV	0.035	0.038	0.050	0.046	0.045	0.046	0.039
Rodeo Creek, NV	0.041	0.034	0.047	0.043	0.029	0.025	0.027
Saulsbury, NV	0.030	0.039	0.053	0.047	0.033	0.038	0.030
Sand Springs East, NV	0.040	0.032	0.046	0.041	0.030	0.032	0.035
Seven Mile, NV	0.046	0.055	0.053	0.051	0.054	0.048	0.045
Shawave Mountains, NV	0.043	0.038	0.043	0.045	0.035	0.037	0.034
Silver Peak, NV	0.051	0.049	0.066	0.062	0.040	0.034	0.029
Snowstorm, NV (Castle Ridge)	0.053	0.052	0.060	0.054	0.044	0.051	0.040
Snowstorm, NV (Dryhill)	0.094	0.075	0.091	0.083	0.070	0.073	0.061
South Shoshone, NV	0.045	0.034	0.043	0.038	0.037	0.038	0.030
Spruce-Pequop, NV (2011)	0.065	0.050	0.036	0.041	0.053	0.058	0.048
Stillwater, NV	0.065	0.045	0.060	0.058	0.050	0.045	0.039
Stone Cabin, NV	0.036	0.034	0.048	0.043	0.033	0.036	0.031
Warm Springs, NV	0.059	0.048	0.058	0.054	0.034	0.042	0.033
Warm Springs Canyon, NV	0.046	0.040	0.050	0.045	0.032	0.034	0.030
Wheeler Pass, NV	0.071	0.072	0.072	0.062	0.075	0.074	0.071
Wheeler Pass, NV (2007)	0.038	0.036	0.050	0.046	0.035	0.042	0.030
Alvord Tule, OR	0.057	0.044	0.071	0.066	0.038	0.041	0.038
Beatys Butte, OR	0.032	0.030	0.041	0.041	0.028	0.028	0.022
Beatys Butte, OR (2010)	0.041	0.037	0.042	0.044	0.031	0.032	0.026
Big Summit, OR (2010)	0.123	0.124	0.142	0.129	0.114	0.112	0.109
Cold Spring, OR	0.040	0.037	0.055	0.048	0.042	0.039	0.034

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	Dry Lake, NV	Fish Creek, NV	Goshute, NV	Goshute, NV (2011)	Granite, NV	Granite Range, NV	Granite Range, NV (2011)
Cold Spring, OR (2010)	0.049	0.044	0.063	0.057	0.047	0.047	0.038
Coyote Lake, OR	0.051	0.036	0.070	0.065	0.040	0.043	0.043
Coyote Lake, OR (2011)	0.045	0.024	0.056	0.052	0.027	0.033	0.028
Fishnet, OR	0.047	0.034	0.063	0.059	0.041	0.052	0.037
Hog Creek, OR	0.036	0.032	0.065	0.066	0.035	0.040	0.032
Jackies Butte, OR	0.047	0.053	0.066	0.052	0.051	0.051	0.044
Jackies Butte, OR (2011)	0.040	0.043	0.056	0.045	0.041	0.040	0.034
Kiger, OR (2011)	0.043	0.046	0.064	0.065	0.039	0.040	0.034
Kiger Herd, OR (2009)	0.049	0.046	0.079	0.075	0.043	0.045	0.042
Liggett Table, OR	0.192	0.155	0.180	0.171	0.162	0.160	0.155
Murderers Creek, OR (2001)	0.097	0.088	0.107	0.098	0.084	0.078	0.074
Murderers Creek, OR (2009)	0.070	0.073	0.083	0.074	0.068	0.057	0.055
Paisley Desert, OR	0.037	0.026	0.043	0.037	0.025	0.024	0.022
Riddle Herd, OR (2009)	0.061	0.051	0.079	0.079	0.047	0.047	0.042
Riddle Mountain, OR	0.052	0.053	0.073	0.073	0.054	0.049	0.044
Riddle Mountain, OR (2011)	0.069	0.056	0.089	0.088	0.053	0.052	0.048
Sand Springs, OR (2011)	0.034	0.034	0.054	0.053	0.032	0.031	0.025
Sheepshead, OR	0.039	0.039	0.052	0.046	0.040	0.034	0.031
Sheepshead, OR (2011)	0.036	0.033	0.048	0.043	0.039	0.037	0.029
South Steens, OR	0.042	0.033	0.051	0.049	0.037	0.033	0.032
South Steens, OR (2010)	0.034	0.033	0.047	0.047	0.035	0.032	0.029
Stinkingwater, OR	0.066	0.058	0.086	0.078	0.075	0.078	0.072
Three Fingers, OR	0.061	0.047	0.069	0.058	0.047	0.046	0.043
Three Fingers, OR (2011)	0.059	0.040	0.062	0.049	0.046	0.052	0.044
Warm Springs, OR	0.032	0.033	0.048	0.040	0.039	0.038	0.033
Warm Springs, OR (2010)	0.034	0.030	0.050	0.044	0.034	0.034	0.031
Blawn Wash, UT	0.057	0.078	0.078	0.075	0.067	0.064	0.054
Cedar Mountain, UT	0.060	0.042	0.075	0.071	0.039	0.040	0.034
Cedar Ridge, UT	0.089	0.065	0.109	0.099	0.065	0.072	0.066

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	Dry Lake, NV	Fish Creek, NV	Goshute, NV	Goshute, NV (2011)	Granite, NV	Granite Range, NV	Granite Range, NV (2011)
Cedar Ridge, UT (trap)	0.100	0.074	0.120	0.110	0.073	0.080	0.072
Cold Springs, UT (2006)	0.108	0.100	0.125	0.118	0.086	0.091	0.089
Cold Springs, UT (trap)	0.078	0.078	0.097	0.091	0.064	0.067	0.063
Delta, UT	0.039	0.028	0.052	0.050	0.030	0.031	0.028
Hill Creek, UT	0.057	0.044	0.063	0.061	0.043	0.042	0.037
Muddy Creek, UT	0.084	0.099	0.091	0.078	0.085	0.085	0.076
North Hills, UT	0.077	0.076	0.101	0.098	0.080	0.070	0.076
Range Creek, UT	0.064	0.048	0.083	0.075	0.041	0.047	0.043
Sinbad, UT	0.059	0.062	0.089	0.091	0.069	0.070	0.061
Sulphur, UT	0.094	0.097	0.124	0.119	0.094	0.089	0.093
Sulphur Herd, UT (South, 2006)	0.070	0.065	0.084	0.074	0.065	0.048	0.055
Tilley Creek, UT	0.077	0.084	0.086	0.089	0.069	0.064	0.054
Winter Ridge, UT	0.058	0.046	0.054	0.055	0.040	0.047	0.032
Adobe Town, WY	0.046	0.037	0.053	0.048	0.043	0.042	0.040
Adobe Town, WY (2011)	0.045	0.036	0.044	0.041	0.034	0.033	0.028
Antelope Hills, WY	0.055	0.045	0.068	0.063	0.038	0.034	0.038
Conant Creek, WY (Lander)	0.070	0.063	0.078	0.069	0.058	0.049	0.047
Cooper Creek, WY	0.033	0.032	0.059	0.054	0.035	0.034	0.033
Dishpan Butte, WY (Lander)	0.054	0.045	0.061	0.056	0.049	0.046	0.045
Divide Basin, WY	0.034	0.032	0.040	0.036	0.028	0.028	0.024
Divide Basin, WY (2011)	0.036	0.035	0.044	0.039	0.031	0.031	0.029
Eagles Nest, WY	0.080	0.060	0.077	0.069	0.067	0.062	0.059
Happy Creek Springs, WY	0.049	0.054	0.078	0.070	0.057	0.058	0.052
Little Colorado, WY	0.050	0.051	0.064	0.057	0.047	0.043	0.042
Little Colorado, WY (2011)	0.043	0.043	0.055	0.051	0.041	0.038	0.034
Lost Creek, WY	0.044	0.036	0.051	0.043	0.036	0.035	0.028
Lost Creek, WY (combined)	0.044	0.041	0.052	0.044	0.041	0.038	0.031
McCullough Peaks, WY	0.044	0.040	0.065	0.065	0.048	0.048	0.041
Muskrat Basin, WY (Lander)	0.065	0.046	0.059	0.052	0.047	0.051	0.046

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	Dry Lake, NV	Fish Creek, NV	Goshute, NV	Goshute, NV (2011)	Granite, NV	Granite Range, NV	Granite Range, NV (2011)
Salt Wells, WY (East)	0.039	0.035	0.047	0.041	0.033	0.029	0.025
Salt Wells, WY (West)	0.035	0.033	0.050	0.049	0.032	0.040	0.033
Stewart Creek, WY	0.057	0.041	0.065	0.055	0.041	0.040	0.039
Stewart Creek, WY (2009)	0.052	0.048	0.064	0.058	0.049	0.052	0.045
White Mountain, WY (2011)	0.042	0.046	0.046	0.049	0.031	0.038	0.024

	Grass Valley, NV	Hall Creek, NV	Jakes Wash, NV	Johnnie, NV	Lahonton Reservoir, NV	Little Fish Lake, NV	Little Highrock Canyon, NV
Grass Valley, NV	0.000						
Hall Creek, NV	0.021	0.000					
Jakes Wash, NV	0.059	0.054	0.000				
Johnnie, NV	0.049	0.052	0.083	0.000			
Lahanton Reservoir, NV	0.062	0.058	0.088	0.090	0.000		
Little Fish Lake, NV	0.033	0.040	0.065	0.077	0.064	0.000	
Little Highrock Canyon, NV	0.051	0.048	0.084	0.066	0.062	0.066	0.000
Little Humboldt, NV	0.046	0.051	0.079	0.072	0.073	0.046	0.068
Little Humboldt, NV (2010)	0.038	0.038	0.064	0.062	0.055	0.043	0.048
Little Owyhee, NV (Fairbanks)	0.034	0.033	0.078	0.061	0.086	0.057	0.062
Little Owyhee, NV (Lake Creek)	0.037	0.045	0.089	0.064	0.078	0.056	0.056
Little Owyhee, NV (Twin Valley)	0.043	0.045	0.077	0.052	0.068	0.068	0.052
Marvel Gap, NV (SWC 2010)	0.029	0.036	0.065	0.052	0.064	0.049	0.051
McGee Mountain, NV	0.034	0.035	0.059	0.049	0.058	0.039	0.052
Miller Mountain, NV (SWC 2010)	0.029	0.026	0.061	0.050	0.063	0.041	0.048
Montezuma Peak, NV	0.050	0.057	0.088	0.094	0.068	0.052	0.046
Nellis, NV	0.022	0.028	0.055	0.045	0.053	0.035	0.051
New Pass-Ravenswood, NV	0.027	0.023	0.049	0.039	0.045	0.045	0.039
North Stillwater, NV	0.044	0.035	0.069	0.068	0.074	0.056	0.047
Paymaster, NV (2006)	0.051	0.052	0.080	0.084	0.070	0.051	0.049
Paymaster, NV (2010)	0.053	0.052	0.079	0.088	0.067	0.053	0.046

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	Grass Valley, NV	Hall Creek, NV	Jakes Wash, NV	Johnnie, NV	Lahonton Reservoir, NV	Little Fish Lake, NV	Little Highrock Canyon, NV
Pine Nut Mountain, NV	0.063	0.051	0.065	0.061	0.087	0.073	0.073
Powell Mountain, NV	0.064	0.039	0.094	0.087	0.086	0.075	0.077
Red Rock, NV	0.040	0.051	0.073	0.046	0.072	0.048	0.054
Reveille, NV	0.044	0.043	0.067	0.065	0.072	0.062	0.070
Roberts Mountain, NV	0.026	0.037	0.070	0.054	0.074	0.052	0.055
Rock Creek, NV (2002)	0.054	0.057	0.078	0.064	0.089	0.073	0.075
Rock Creek, NV (2010)	0.039	0.040	0.064	0.050	0.074	0.052	0.064
Rocky Hills, NV	0.028	0.034	0.067	0.053	0.044	0.045	0.043
Rodeo Creek, NV	0.023	0.023	0.066	0.053	0.058	0.039	0.036
Saulsbury, NV	0.025	0.023	0.057	0.055	0.050	0.032	0.041
Sand Springs East, NV	0.034	0.034	0.059	0.050	0.058	0.039	0.053
Seven Mile, NV	0.037	0.055	0.067	0.062	0.054	0.039	0.055
Shawave Mountains, NV	0.027	0.024	0.068	0.057	0.061	0.045	0.039
Silver Peak, NV	0.043	0.042	0.056	0.072	0.074	0.060	0.059
Snowstorm, NV (Castle Ridge)	0.044	0.039	0.067	0.073	0.056	0.053	0.052
Snowstorm, NV (Dryhill)	0.080	0.081	0.095	0.108	0.095	0.095	0.070
South Shoshone, NV	0.030	0.031	0.052	0.045	0.060	0.033	0.048
Spruce-Pequop, NV (2011)	0.049	0.052	0.080	0.053	0.084	0.073	0.062
Stillwater, NV	0.050	0.045	0.067	0.079	0.074	0.061	0.053
Stone Cabin, NV	0.017	0.026	0.055	0.048	0.059	0.038	0.049
Warm Springs, NV	0.048	0.045	0.078	0.060	0.069	0.064	0.053
Warm Springs Canyon, NV	0.034	0.037	0.063	0.050	0.067	0.052	0.042
Wheeler Pass, NV	0.055	0.067	0.104	0.023	0.103	0.085	0.079
Wheeler Pass, NV (2007)	0.035	0.027	0.069	0.027	0.064	0.045	0.039
Alvord Tule, OR	0.033	0.038	0.068	0.057	0.086	0.068	0.059
Beatys Butte, OR	0.028	0.023	0.055	0.051	0.039	0.042	0.042
Beatys Butte, OR (2010)	0.031	0.027	0.062	0.061	0.056	0.045	0.037
Big Summit, OR (2010)	0.093	0.103	0.149	0.144	0.128	0.117	0.110
Cold Spring, OR	0.031	0.034	0.044	0.049	0.063	0.039	0.046

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	Grass Valley, NV	Hall Creek, NV	Jakes Wash, NV	Johnnie, NV	Lahonton Reservoir, NV	Little Fish Lake, NV	Little Highrock Canyon, NV
Cold Spring, OR (2010)	0.040	0.043	0.056	0.057	0.066	0.044	0.050
Coyote Lake, OR	0.028	0.037	0.060	0.055	0.083	0.055	0.069
Coyote Lake, OR (2011)	0.026	0.027	0.056	0.051	0.066	0.048	0.055
Fishnet, OR	0.044	0.039	0.061	0.068	0.068	0.065	0.054
Hog Creek, OR	0.032	0.034	0.058	0.052	0.065	0.055	0.052
Jackies Butte, OR	0.044	0.040	0.076	0.063	0.067	0.065	0.059
Jackies Butte, OR (2011)	0.038	0.039	0.072	0.051	0.063	0.061	0.043
Kiger, OR (2011)	0.041	0.032	0.063	0.074	0.064	0.056	0.059
Kiger Herd, OR (2009)	0.044	0.039	0.066	0.064	0.079	0.069	0.067
Liggett Table, OR	0.158	0.164	0.204	0.192	0.163	0.182	0.187
Murderers Creek, OR (2001)	0.073	0.080	0.091	0.102	0.089	0.077	0.089
Murderers Creek, OR (2009)	0.055	0.060	0.072	0.095	0.072	0.055	0.070
Paisley Desert, OR	0.024	0.023	0.051	0.039	0.057	0.044	0.041
Riddle Herd, OR (2009)	0.057	0.045	0.077	0.079	0.068	0.072	0.064
Riddle Mountain, OR	0.056	0.042	0.071	0.075	0.064	0.071	0.062
Riddle Mountain, OR (2011)	0.059	0.050	0.080	0.087	0.082	0.079	0.073
Sand Springs, OR (2011)	0.035	0.029	0.059	0.061	0.070	0.053	0.043
Sheepshead, OR	0.026	0.026	0.050	0.047	0.069	0.039	0.050
Sheepshead, OR (2011)	0.031	0.023	0.045	0.043	0.058	0.040	0.040
South Steens, OR	0.024	0.030	0.054	0.039	0.077	0.056	0.045
South Steens, OR (2010)	0.026	0.030	0.058	0.044	0.062	0.053	0.039
Stinkingwater, OR	0.063	0.059	0.089	0.061	0.081	0.082	0.085
Three Fingers, OR	0.045	0.042	0.082	0.078	0.068	0.053	0.067
Three Fingers, OR (2011)	0.037	0.039	0.065	0.060	0.068	0.048	0.064
Warm Springs, OR	0.025	0.030	0.043	0.046	0.055	0.044	0.040
Warm Springs, OR (2010)	0.025	0.030	0.052	0.050	0.052	0.044	0.043
Blawn Wash, UT	0.078	0.066	0.099	0.089	0.088	0.095	0.071
Cedar Mountain, UT	0.040	0.046	0.077	0.059	0.081	0.063	0.064
Cedar Ridge, UT	0.058	0.064	0.103	0.103	0.107	0.074	0.090

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	Grass Valley, NV	Hall Creek, NV	Jakes Wash, NV	Johnnie, NV	Lahonton Reservoir, NV	Little Fish Lake, NV	Little Highrock Canyon, NV
Cedar Ridge, UT (trap)	0.060	0.066	0.112	0.106	0.126	0.088	0.087
Cold Springs, UT (2006)	0.101	0.111	0.136	0.127	0.142	0.118	0.094
Cold Springs, UT (trap)	0.075	0.076	0.093	0.088	0.122	0.089	0.077
Delta, UT	0.025	0.024	0.052	0.040	0.058	0.036	0.047
Hill Creek, UT	0.030	0.032	0.083	0.053	0.077	0.065	0.048
Muddy Creek, UT	0.076	0.084	0.091	0.102	0.109	0.075	0.102
North Hills, UT	0.052	0.069	0.096	0.081	0.094	0.073	0.088
Range Creek, UT	0.045	0.052	0.085	0.080	0.090	0.061	0.059
Sinbad, UT	0.071	0.054	0.084	0.082	0.101	0.078	0.074
Sulphur, UT	0.073	0.087	0.128	0.128	0.119	0.086	0.107
Sulphur Herd, UT (South, 2006)	0.049	0.058	0.078	0.066	0.088	0.071	0.067
Tilley Creek, UT	0.083	0.073	0.103	0.105	0.091	0.086	0.066
Winter Ridge, UT	0.037	0.036	0.082	0.054	0.063	0.051	0.043
Adobe Town, WY	0.028	0.026	0.057	0.052	0.064	0.043	0.054
Adobe Town, WY (2011)	0.027	0.031	0.062	0.054	0.057	0.046	0.035
Antelope Hills, WY	0.048	0.047	0.074	0.063	0.063	0.061	0.056
Conant Creek, WY (Lander)	0.064	0.049	0.084	0.093	0.100	0.069	0.074
Cooper Creek, WY	0.025	0.028	0.053	0.046	0.059	0.043	0.048
Dishpan Butte, WY (Lander)	0.045	0.039	0.069	0.056	0.086	0.044	0.070
Divide Basin, WY	0.025	0.026	0.052	0.041	0.053	0.033	0.037
Divide Basin, WY (2011)	0.022	0.026	0.061	0.046	0.060	0.028	0.039
Eagles Nest, WY	0.051	0.060	0.080	0.073	0.083	0.069	0.075
Happy Creek Springs, WY	0.046	0.050	0.080	0.060	0.083	0.066	0.063
Little Colorado, WY	0.037	0.041	0.076	0.048	0.074	0.057	0.048
Little Colorado, WY (2011)	0.038	0.037	0.068	0.043	0.063	0.054	0.040
Lost Creek, WY	0.023	0.026	0.058	0.045	0.061	0.041	0.045
Lost Creek, WY (combined)	0.026	0.032	0.053	0.042	0.064	0.038	0.041
McCullough Peaks, WY	0.047	0.039	0.069	0.052	0.075	0.068	0.052
Muskrat Basin, WY (Lander)	0.043	0.041	0.065	0.060	0.089	0.048	0.078

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	Grass Valley, NV	Hall Creek, NV	Jakes Wash, NV	Johnnie, NV	Lahonton Reservoir, NV	Little Fish Lake, NV	Little Highrock Canyon, NV
Salt Wells, WY (East)	0.021	0.026	0.058	0.054	0.055	0.040	0.036
Salt Wells, WY (West)	0.031	0.024	0.056	0.054	0.050	0.044	0.047
Stewart Creek, WY	0.032	0.036	0.063	0.052	0.079	0.057	0.056
Stewart Creek, WY (2009)	0.040	0.040	0.067	0.056	0.076	0.052	0.056
White Mountain, WY (2011)	0.051	0.039	0.077	0.071	0.046	0.048	0.032

	Little Humboldt, NV	Little Humboldt, NV (2010)	Little Owyhee, NV (Fairbanks)	Little Owyhee, NV (Lake Creek)	Little Owyhee,NV (Twin Valley)	Marvel Gap, NV (SWC 2010)	McGee Mountain, NV
Little Humboldt, NV	0.000						
Little Humboldt, NV (2010)	0.017	0.000					
Little Owyhee, NV (Fairbanks)	0.071	0.059	0.000				
Little Owyhee, NV (Lake Creek)	0.057	0.047	0.046	0.000			
Little Owyhee, NV (Twin Valley)	0.059	0.048	0.051	0.039	0.000		
Marvel Gap, NV (SWC 2010)	0.042	0.039	0.063	0.046	0.045	0.000	
McGee Mountain, NV	0.043	0.034	0.048	0.046	0.039	0.036	0.000
Miller Mountain, NV (SWC 2010)	0.052	0.040	0.044	0.041	0.041	0.035	0.036
Montezuma Peak, NV	0.080	0.064	0.075	0.061	0.059	0.050	0.054
Nellis, NV	0.048	0.037	0.041	0.047	0.043	0.030	0.023
New Pass-Ravenswood, NV	0.047	0.031	0.047	0.042	0.033	0.034	0.026
North Stillwater, NV	0.071	0.051	0.049	0.051	0.054	0.044	0.044
Paymaster, NV (2006)	0.070	0.063	0.074	0.069	0.065	0.052	0.050
Paymaster, NV (2010)	0.077	0.066	0.075	0.070	0.066	0.055	0.053
Pine Nut Mountain, NV	0.082	0.071	0.075	0.088	0.064	0.070	0.056
Powell Mountain, NV	0.081	0.063	0.061	0.086	0.074	0.071	0.063
Red Rock, NV	0.062	0.057	0.052	0.066	0.050	0.046	0.040
Reveille, NV	0.064	0.049	0.062	0.067	0.058	0.052	0.037
Roberts Mountain, NV	0.060	0.050	0.039	0.054	0.050	0.038	0.035
Rock Creek, NV (2002)	0.063	0.044	0.078	0.072	0.059	0.067	0.052
Rock Creek, NV (2010)	0.041	0.026	0.062	0.055	0.048	0.049	0.034

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	Little Humboldt, NV	Little Humboldt, NV (2010)	Little Owyhee, NV (Fairbanks)	Little Owyhee, NV (Lake Creek)	Little Owyhee,NV (Twin Valley)	Marvel Gap, NV (SWC 2010)	McGee Mountain, NV
Rocky Hills, NV	0.058	0.047	0.062	0.064	0.051	0.034	0.035
Rodeo Creek, NV	0.044	0.030	0.042	0.047	0.043	0.033	0.028
Saulsbury, NV	0.050	0.035	0.046	0.047	0.045	0.044	0.029
Sand Springs East, NV	0.038	0.030	0.046	0.047	0.038	0.034	0.001
Seven Mile, NV	0.053	0.049	0.071	0.062	0.062	0.041	0.036
Shawave Mountains, NV	0.050	0.038	0.038	0.038	0.041	0.035	0.037
Silver Peak, NV	0.053	0.046	0.061	0.052	0.045	0.048	0.053
Snowstorm, NV (Castle Ridge)	0.034	0.019	0.063	0.052	0.052	0.047	0.045
Snowstorm, NV (Dryhill)	0.091	0.079	0.089	0.074	0.069	0.074	0.083
South Shoshone, NV	0.042	0.033	0.056	0.054	0.045	0.027	0.027
Spruce-Pequop, NV (2011)	0.075	0.067	0.052	0.063	0.058	0.055	0.057
Stillwater, NV	0.071	0.051	0.061	0.053	0.058	0.047	0.046
Stone Cabin, NV	0.046	0.037	0.039	0.042	0.039	0.037	0.029
Warm Springs, NV	0.065	0.050	0.065	0.056	0.040	0.044	0.035
Warm Springs Canyon, NV	0.060	0.042	0.051	0.045	0.037	0.037	0.030
Wheeler Pass, NV	0.077	0.067	0.073	0.076	0.071	0.068	0.059
Wheeler Pass, NV (2007)	0.044	0.036	0.046	0.051	0.049	0.034	0.035
Alvord Tule, OR	0.061	0.047	0.056	0.063	0.048	0.036	0.043
Beatys Butte, OR	0.041	0.031	0.049	0.041	0.033	0.034	0.027
Beatys Butte, OR (2010)	0.051	0.036	0.044	0.035	0.038	0.032	0.037
Big Summit, OR (2010)	0.083	0.084	0.131	0.126	0.130	0.111	0.118
Cold Spring, OR	0.052	0.044	0.049	0.051	0.042	0.033	0.042
Cold Spring, OR (2010)	0.056	0.047	0.064	0.060	0.051	0.034	0.051
Coyote Lake, OR	0.059	0.048	0.049	0.057	0.051	0.040	0.041
Coyote Lake, OR (2011)	0.044	0.034	0.042	0.050	0.039	0.029	0.030
Fishnet, OR	0.076	0.056	0.066	0.064	0.054	0.042	0.049
Hog Creek, OR	0.064	0.046	0.050	0.058	0.038	0.039	0.041
Jackies Butte, OR	0.072	0.058	0.062	0.078	0.059	0.051	0.053
Jackies Butte, OR (2011)	0.065	0.050	0.054	0.064	0.045	0.042	0.040

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	Little Humboldt, NV	Little Humboldt, NV (2010)	Little Owyhee, NV (Fairbanks)	Little Owyhee, NV (Lake Creek)	Little Owyhee,NV (Twin Valley)	Marvel Gap, NV (SWC 2010)	McGee Mountain, NV
Kiger, OR (2011)	0.058	0.049	0.065	0.065	0.055	0.051	0.046
Kiger Herd, OR (2009)	0.064	0.055	0.067	0.070	0.057	0.051	0.048
Liggett Table, OR	0.188	0.178	0.198	0.175	0.138	0.148	0.153
Murderers Creek, OR (2001)	0.086	0.071	0.086	0.076	0.092	0.068	0.082
Murderers Creek, OR (2009)	0.073	0.061	0.069	0.067	0.082	0.061	0.066
Paisley Desert, OR	0.039	0.034	0.038	0.046	0.034	0.029	0.027
Riddle Herd, OR (2009)	0.067	0.056	0.081	0.069	0.051	0.063	0.047
Riddle Mountain, OR	0.062	0.053	0.084	0.069	0.050	0.060	0.046
Riddle Mountain, OR (2011)	0.070	0.060	0.087	0.076	0.055	0.069	0.055
Sand Springs, OR (2011)	0.048	0.040	0.047	0.051	0.040	0.036	0.039
Sheepshead, OR	0.050	0.043	0.040	0.051	0.053	0.035	0.038
Sheepshead, OR (2011)	0.046	0.038	0.046	0.053	0.048	0.030	0.034
South Steens, OR	0.052	0.042	0.044	0.037	0.030	0.029	0.036
South Steens, OR (2010)	0.057	0.042	0.041	0.039	0.030	0.039	0.035
Stinkingwater, OR	0.093	0.073	0.079	0.080	0.074	0.052	0.056
Three Fingers, OR	0.053	0.055	0.072	0.069	0.064	0.030	0.045
Three Fingers, OR (2011)	0.049	0.048	0.061	0.063	0.053	0.026	0.034
Warm Springs, OR	0.045	0.036	0.046	0.041	0.031	0.033	0.026
Warm Springs, OR (2010)	0.041	0.035	0.048	0.039	0.027	0.035	0.027
Blawn Wash, UT	0.103	0.080	0.092	0.106	0.075	0.094	0.070
Cedar Mountain, UT	0.064	0.049	0.062	0.050	0.037	0.049	0.051
Cedar Ridge, UT	0.065	0.060	0.097	0.080	0.081	0.060	0.073
Cedar Ridge, UT (trap)	0.080	0.066	0.100	0.086	0.089	0.068	0.090
Cold Springs, UT (2006)	0.128	0.109	0.129	0.114	0.104	0.085	0.083
Cold Springs, UT (trap)	0.095	0.078	0.095	0.092	0.082	0.067	0.057
Delta, UT	0.036	0.027	0.041	0.046	0.035	0.033	0.031
Hill Creek, UT	0.059	0.046	0.047	0.047	0.052	0.040	0.047
Muddy Creek, UT	0.101	0.095	0.097	0.117	0.109	0.086	0.085
North Hills, UT	0.058	0.058	0.089	0.071	0.069	0.058	0.071

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	Little Humboldt, NV	Little Humboldt, NV (2010)	Little Owyhee, NV (Fairbanks)	Little Owyhee, NV (Lake Creek)	Little Owyhee,NV (Twin Valley)	Marvel Gap, NV (SWC 2010)	McGee Mountain, NV
Range Creek, UT	0.061	0.049	0.077	0.063	0.059	0.040	0.045
Sinbad, UT	0.083	0.069	0.076	0.088	0.079	0.086	0.061
Sulphur, UT	0.082	0.079	0.100	0.100	0.115	0.103	0.100
Sulphur Herd, UT (South, 2006)	0.054	0.047	0.067	0.060	0.060	0.050	0.057
Tilley Creek, UT	0.072	0.060	0.112	0.087	0.076	0.074	0.083
Winter Ridge, UT	0.058	0.043	0.051	0.044	0.054	0.032	0.052
Adobe Town, WY	0.043	0.036	0.046	0.045	0.045	0.021	0.037
Adobe Town, WY (2011)	0.046	0.036	0.048	0.038	0.038	0.015	0.037
Antelope Hills, WY	0.056	0.042	0.067	0.063	0.057	0.048	0.039
Conant Creek, WY (Lander)	0.084	0.072	0.062	0.071	0.077	0.077	0.064
Cooper Creek, WY	0.043	0.035	0.040	0.046	0.040	0.040	0.031
Dishpan Butte, WY (Lander)	0.047	0.045	0.057	0.055	0.054	0.042	0.037
Divide Basin, WY	0.032	0.023	0.044	0.033	0.033	0.030	0.028
Divide Basin, WY (2011)	0.031	0.024	0.044	0.033	0.041	0.032	0.029
Eagles Nest, WY	0.048	0.042	0.083	0.071	0.068	0.054	0.056
Happy Creek Springs, WY	0.073	0.061	0.068	0.073	0.076	0.051	0.058
Little Colorado, WY	0.045	0.040	0.063	0.052	0.047	0.033	0.039
Little Colorado, WY (2011)	0.045	0.036	0.059	0.048	0.040	0.032	0.035
Lost Creek, WY	0.040	0.029	0.046	0.045	0.043	0.027	0.032
Lost Creek, WY (combined)	0.041	0.031	0.049	0.044	0.042	0.031	0.032
McCullough Peaks, WY	0.061	0.046	0.056	0.051	0.047	0.051	0.043
Muskrat Basin, WY (Lander)	0.043	0.042	0.056	0.062	0.058	0.043	0.039
Salt Wells, WY (East)	0.046	0.033	0.044	0.043	0.041	0.022	0.036
Salt Wells, WY (West)	0.049	0.037	0.047	0.048	0.048	0.043	0.039
Stewart Creek, WY	0.044	0.035	0.054	0.060	0.047	0.042	0.036
Stewart Creek, WY (2009)	0.055	0.047	0.060	0.051	0.050	0.038	0.044
White Mountain, WY (2011)	0.062	0.041	0.062	0.060	0.054	0.049	0.048

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	Miller Mountain, NV (Swc 2010)	Montezuma Peak, NV	Nellis, NV	New Pass-Ravenswood, NV	North Stillwater, NV	Paymaster, NV (2006)	Paymaster, NV (2010)
Miller Mountain, NV (SWC 2010)	0.000						
Montezuma Peak, NV	0.060	0.000					
Nellis, NV	0.026	0.050	0.000				
New Pass-Ravenswood, NV	0.032	0.053	0.021	0.000			
North Stillwater, NV	0.042	0.052	0.043	0.038	0.000		
Paymaster, NV (2006)	0.058	0.018	0.049	0.053	0.058	0.000	
Paymaster, NV (2010)	0.061	0.014	0.048	0.049	0.057	0.004	0.000
Pine Nut Mountain, NV	0.065	0.089	0.054	0.048	0.062	0.085	0.085
Powell Mountain, NV	0.063	0.082	0.062	0.059	0.062	0.083	0.082
Red Rock, NV	0.049	0.054	0.035	0.044	0.058	0.052	0.055
Reveille, NV	0.033	0.077	0.022	0.037	0.058	0.077	0.079
Roberts Mountain, NV	0.038	0.062	0.028	0.036	0.047	0.062	0.065
Rock Creek, NV (2002)	0.066	0.086	0.061	0.050	0.080	0.079	0.083
Rock Creek, NV (2010)	0.048	0.075	0.043	0.036	0.063	0.071	0.074
Rocky Hills, NV	0.034	0.052	0.027	0.030	0.058	0.052	0.052
Rodeo Creek, NV	0.032	0.037	0.027	0.031	0.029	0.041	0.042
Saulsbury, NV	0.032	0.051	0.026	0.020	0.039	0.049	0.049
Sand Springs East, NV	0.035	0.055	0.023	0.027	0.043	0.049	0.052
Seven Mile, NV	0.049	0.059	0.042	0.043	0.061	0.059	0.061
Shawave Mountains, NV	0.036	0.047	0.037	0.033	0.039	0.047	0.047
Silver Peak, NV	0.036	0.067	0.041	0.037	0.042	0.066	0.066
Snowstorm, NV (Castle Ridge)	0.043	0.065	0.042	0.038	0.060	0.060	0.063
Snowstorm, NV (Dryhill)	0.082	0.076	0.066	0.065	0.068	0.091	0.086
South Shoshone, NV	0.034	0.058	0.026	0.023	0.038	0.053	0.054
Spruce-Pequop, NV (2011)	0.059	0.066	0.049	0.042	0.059	0.076	0.074
Stillwater, NV	0.050	0.049	0.047	0.043	0.013	0.054	0.055
Stone Cabin, NV	0.028	0.052	0.015	0.025	0.039	0.051	0.053
Warm Springs, NV	0.036	0.067	0.036	0.035	0.050	0.070	0.070

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	Miller Mountain, NV (Swc 2010)	Montezuma Peak, NV	Nellis, NV	New Pass-Ravenswood, NV	North Stillwater, NV	Paymaster, NV (2006)	Paymaster, NV (2010)
Warm Springs Canyon, NV	0.032	0.056	0.030	0.025	0.039	0.061	0.061
Wheeler Pass, NV	0.063	0.092	0.059	0.058	0.077	0.087	0.094
Wheeler Pass, NV (2007)	0.030	0.062	0.031	0.028	0.040	0.055	0.058
Alvord Tule, OR	0.044	0.065	0.041	0.035	0.042	0.072	0.073
Beatys Butte, OR	0.029	0.053	0.026	0.020	0.040	0.051	0.050
Beatys Butte, OR (2010)	0.031	0.047	0.035	0.031	0.038	0.048	0.047
Big Summit, OR (2010)	0.120	0.125	0.109	0.111	0.126	0.126	0.132
Cold Spring, OR	0.034	0.055	0.029	0.022	0.046	0.050	0.051
Cold Spring, OR (2010)	0.033	0.052	0.035	0.033	0.054	0.049	0.050
Coyote Lake, OR	0.030	0.070	0.034	0.036	0.044	0.075	0.075
Coyote Lake, OR (2011)	0.029	0.058	0.025	0.026	0.033	0.062	0.060
Fishnet, OR	0.032	0.064	0.030	0.037	0.049	0.064	0.063
Hog Creek, OR	0.037	0.054	0.024	0.024	0.050	0.059	0.058
Jackies Butte, OR	0.045	0.075	0.041	0.044	0.054	0.072	0.069
Jackies Butte, OR (2011)	0.038	0.059	0.033	0.035	0.042	0.059	0.056
Kiger, OR (2011)	0.044	0.071	0.038	0.041	0.054	0.064	0.063
Kiger Herd, OR (2009)	0.043	0.084	0.039	0.042	0.059	0.076	0.075
Liggett Table, OR	0.150	0.168	0.165	0.149	0.176	0.162	0.169
Murderers Creek, OR (2001)	0.069	0.094	0.079	0.075	0.093	0.095	0.099
Murderers Creek, OR (2009)	0.059	0.082	0.061	0.059	0.076	0.077	0.077
Paisley Desert, OR	0.028	0.053	0.024	0.024	0.030	0.051	0.051
Riddle Herd, OR (2009)	0.054	0.078	0.054	0.046	0.058	0.067	0.070
Riddle Mountain, OR	0.052	0.078	0.056	0.042	0.064	0.066	0.069
Riddle Mountain, OR (2011)	0.062	0.086	0.061	0.052	0.065	0.074	0.080
Sand Springs, OR (2011)	0.035	0.048	0.034	0.031	0.039	0.047	0.046
Sheepshead, OR	0.034	0.059	0.032	0.031	0.036	0.054	0.056
Sheepshead, OR (2011)	0.032	0.052	0.027	0.024	0.035	0.045	0.047
South Steens, OR	0.035	0.051	0.032	0.025	0.033	0.055	0.054
South Steens, OR (2010)	0.036	0.044	0.029	0.024	0.035	0.048	0.045

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	Miller Mountain, NV (Swc 2010)	Montezuma Peak, NV	Nellis, NV	New Pass-Ravenswood, NV	North Stillwater, NV	Paymaster, NV (2006)	Paymaster, NV (2010)
Stinkingwater, OR	0.053	0.097	0.050	0.049	0.076	0.094	0.095
Three Fingers, OR	0.044	0.063	0.039	0.050	0.059	0.052	0.059
Three Fingers, OR (2011)	0.043	0.062	0.028	0.041	0.057	0.049	0.057
Warm Springs, OR	0.034	0.056	0.026	0.019	0.045	0.050	0.050
Warm Springs, OR (2010)	0.033	0.057	0.025	0.018	0.046	0.054	0.053
Blawn Wash, UT	0.070	0.095	0.069	0.055	0.064	0.089	0.087
Cedar Mountain, UT	0.044	0.069	0.044	0.032	0.047	0.076	0.078
Cedar Ridge, UT	0.073	0.088	0.060	0.068	0.081	0.089	0.092
Cedar Ridge, UT (trap)	0.083	0.085	0.070	0.075	0.079	0.092	0.093
Cold Springs, UT (2006)	0.109	0.112	0.087	0.083	0.092	0.110	0.112
Cold Springs, UT (trap)	0.083	0.093	0.063	0.058	0.064	0.089	0.091
Delta, UT	0.032	0.054	0.026	0.028	0.041	0.051	0.053
Hill Creek, UT	0.040	0.056	0.043	0.045	0.029	0.056	0.060
Muddy Creek, UT	0.083	0.090	0.074	0.080	0.088	0.093	0.093
North Hills, UT	0.072	0.098	0.064	0.065	0.103	0.102	0.102
Range Creek, UT	0.056	0.066	0.040	0.043	0.052	0.065	0.067
Sinbad, UT	0.068	0.096	0.064	0.057	0.074	0.088	0.088
Sulphur, UT	0.091	0.125	0.086	0.093	0.109	0.125	0.122
Sulphur Herd, UT (South, 2006)	0.055	0.088	0.059	0.055	0.063	0.084	0.089
Tilley Creek, UT	0.072	0.085	0.081	0.073	0.082	0.084	0.087
Winter Ridge, UT	0.040	0.050	0.043	0.042	0.040	0.057	0.057
Adobe Town, WY	0.022	0.054	0.033	0.038	0.044	0.047	0.052
Adobe Town, WY (2011)	0.029	0.040	0.028	0.030	0.034	0.041	0.041
Antelope Hills, WY	0.047	0.083	0.039	0.037	0.059	0.084	0.084
Conant Creek, WY (Lander)	0.054	0.084	0.062	0.064	0.044	0.079	0.082
Cooper Creek, WY	0.032	0.060	0.027	0.029	0.045	0.053	0.054
Dishpan Butte, WY (Lander)	0.037	0.063	0.045	0.048	0.050	0.053	0.060
Divide Basin, WY	0.027	0.051	0.025	0.019	0.039	0.048	0.049
Divide Basin, WY (2011)	0.029	0.049	0.022	0.026	0.038	0.046	0.049

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	Miller Mountain, NV (Swc 2010)	Montezuma Peak, NV	Nellis, NV	New Pass-Ravenswood, NV	North Stillwater, NV	Paymaster, NV (2006)	Paymaster, NV (2010)
Eagles Nest, WY	0.052	0.087	0.050	0.046	0.070	0.086	0.087
Happy Creek Springs, WY	0.038	0.092	0.044	0.046	0.063	0.081	0.080
Little Colorado, WY	0.039	0.062	0.040	0.035	0.059	0.059	0.061
Little Colorado, WY (2011)	0.038	0.056	0.038	0.027	0.055	0.053	0.054
Lost Creek, WY	0.029	0.054	0.024	0.021	0.042	0.053	0.054
Lost Creek, WY (combined)	0.029	0.051	0.028	0.023	0.043	0.049	0.050
McCullough Peaks, WY	0.038	0.080	0.040	0.037	0.057	0.080	0.080
Muskrat Basin, WY (Lander)	0.043	0.068	0.040	0.045	0.053	0.058	0.065
Salt Wells, WY (East)	0.024	0.045	0.025	0.029	0.031	0.048	0.047
Salt Wells, WY (West)	0.021	0.057	0.025	0.022	0.045	0.053	0.054
Stewart Creek, WY	0.040	0.076	0.036	0.027	0.049	0.073	0.074
Stewart Creek, WY (2009)	0.032	0.069	0.038	0.035	0.056	0.066	0.066
White Mountain, WY (2011)	0.041	0.044	0.042	0.039	0.050	0.047	0.044

	Pine Nut Moutain, NV	Powell Mountain, NV	Red Rock, NV	Reveille, NV	Roberts Mountain, NV	Rock Creek, NV (2002)	Rock Creek, NV (2010)
Pine Nut Mountain, NV	0.000						
Powell Mountain, NV	0.099	0.000					
Red Rock, NV	0.068	0.081	0.000				
Reveille, NV	0.071	0.073	0.053	0.000			
Roberts Mountain, NV	0.071	0.062	0.040	0.046	0.000		
Rock Creek, NV (2002)	0.072	0.089	0.077	0.089	0.069	0.000	
Rock Creek, NV (2010)	0.062	0.069	0.055	0.066	0.052	0.013	0.000
Rocky Hills, NV	0.063	0.065	0.042	0.051	0.037	0.056	0.042
Rodeo Creek, NV	0.057	0.051	0.038	0.043	0.035	0.057	0.042
Saulsbury, NV	0.054	0.056	0.045	0.040	0.045	0.058	0.039
Sand Springs East, NV	0.058	0.058	0.041	0.033	0.034	0.054	0.035
Seven Mile, NV	0.068	0.081	0.045	0.063	0.056	0.069	0.053
Shawave Mountains, NV	0.065	0.062	0.044	0.056	0.043	0.065	0.049

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	Pine Nut Moutain, NV	Powell Mountain, NV	Red Rock, NV	Reveille, NV	Roberts Mountain, NV	Rock Creek, NV (2002)	Rock Creek, NV (2010)
Silver Peak, NV	0.062	0.088	0.069	0.060	0.053	0.072	0.058
Snowstorm, NV (Castle Ridge)	0.081	0.068	0.067	0.057	0.054	0.048	0.036
Snowstorm, NV (Dryhill)	0.096	0.125	0.082	0.089	0.084	0.118	0.095
South Shoshone, NV	0.057	0.069	0.038	0.049	0.035	0.059	0.038
Spruce-Pequop, NV (2011)	0.081	0.078	0.051	0.065	0.058	0.099	0.074
Stillwater, NV	0.069	0.078	0.060	0.061	0.051	0.083	0.067
Stone Cabin, NV	0.056	0.060	0.038	0.033	0.026	0.055	0.040
Warm Springs, NV	0.072	0.083	0.056	0.054	0.044	0.073	0.059
Warm Springs Canyon, NV	0.063	0.077	0.044	0.042	0.037	0.067	0.051
Wheeler Pass, NV	0.085	0.096	0.051	0.072	0.061	0.077	0.056
Wheeler Pass, NV (2007)	0.054	0.052	0.034	0.047	0.036	0.061	0.043
Alvord Tule, OR	0.069	0.062	0.061	0.057	0.045	0.071	0.056
Beatys Butte, OR	0.057	0.049	0.042	0.042	0.034	0.060	0.043
Beatys Butte, OR (2010)	0.068	0.062	0.049	0.049	0.039	0.069	0.052
Big Summit, OR (2010)	0.144	0.138	0.133	0.130	0.119	0.130	0.109
Cold Spring, OR	0.058	0.070	0.044	0.053	0.039	0.061	0.048
Cold Spring, OR (2010)	0.069	0.079	0.050	0.056	0.052	0.073	0.058
Coyote Lake, OR	0.065	0.068	0.060	0.050	0.044	0.066	0.051
Coyote Lake, OR (2011)	0.054	0.049	0.055	0.043	0.037	0.060	0.043
Fishnet, OR	0.068	0.083	0.060	0.051	0.048	0.076	0.063
Hog Creek, OR	0.055	0.072	0.047	0.035	0.042	0.066	0.055
Jackies Butte, OR	0.068	0.046	0.054	0.055	0.050	0.082	0.058
Jackies Butte, OR (2011)	0.060	0.057	0.039	0.050	0.046	0.069	0.052
Kiger, OR (2011)	0.066	0.072	0.056	0.062	0.059	0.067	0.054
Kiger Herd, OR (2009)	0.067	0.076	0.062	0.057	0.052	0.073	0.060
Liggett Table, OR	0.206	0.236	0.190	0.191	0.170	0.186	0.186
Murderers Creek, OR (2001)	0.127	0.120	0.097	0.107	0.091	0.095	0.088
Murderers Creek, OR (2009)	0.104	0.088	0.084	0.092	0.070	0.090	0.078
Paisley Desert, OR	0.048	0.051	0.033	0.034	0.026	0.062	0.041

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	Pine Nut Moutain, NV	Powell Mountain, NV	Red Rock, NV	Reveille, NV	Roberts Mountain, NV	Rock Creek, NV (2002)	Rock Creek, NV (2010)
Riddle Herd, OR (2009)	0.078	0.090	0.069	0.074	0.072	0.066	0.060
Riddle Mountain, OR	0.076	0.086	0.067	0.075	0.075	0.061	0.054
Riddle Mountain, OR (2011)	0.083	0.098	0.074	0.080	0.076	0.068	0.064
Sand Springs, OR (2011)	0.057	0.060	0.056	0.050	0.043	0.069	0.056
Sheepshead, OR	0.057	0.055	0.042	0.056	0.035	0.062	0.048
Sheepshead, OR (2011)	0.047	0.055	0.039	0.046	0.038	0.055	0.042
South Steens, OR	0.057	0.062	0.043	0.048	0.035	0.056	0.042
South Steens, OR (2010)	0.053	0.058	0.042	0.044	0.038	0.060	0.048
Stinkingwater, OR	0.092	0.090	0.075	0.071	0.059	0.087	0.075
Three Fingers, OR	0.075	0.074	0.062	0.064	0.045	0.081	0.066
Three Fingers, OR (2011)	0.069	0.070	0.048	0.058	0.037	0.066	0.049
Warm Springs, OR	0.054	0.059	0.040	0.047	0.033	0.042	0.029
Warm Springs, OR (2010)	0.055	0.060	0.042	0.045	0.034	0.049	0.032
Blawn Wash, UT	0.087	0.075	0.075	0.082	0.076	0.086	0.077
Cedar Mountain, UT	0.060	0.089	0.056	0.056	0.058	0.078	0.063
Cedar Ridge, UT	0.105	0.100	0.105	0.096	0.091	0.078	0.067
Cedar Ridge, UT (trap)	0.112	0.107	0.107	0.100	0.099	0.085	0.076
Cold Springs, UT (2006)	0.116	0.159	0.112	0.117	0.101	0.130	0.122
Cold Springs, UT (trap)	0.089	0.111	0.077	0.084	0.077	0.101	0.089
Delta, UT	0.047	0.056	0.035	0.044	0.036	0.049	0.035
Hill Creek, UT	0.074	0.071	0.046	0.057	0.040	0.075	0.058
Muddy Creek, UT	0.104	0.123	0.068	0.083	0.091	0.125	0.106
North Hills, UT	0.105	0.108	0.070	0.087	0.075	0.092	0.069
Range Creek, UT	0.077	0.091	0.076	0.072	0.062	0.068	0.059
Sinbad, UT	0.064	0.087	0.085	0.080	0.078	0.093	0.084
Sulphur, UT	0.119	0.105	0.105	0.103	0.085	0.126	0.099
Sulphur Herd, UT (South, 2006)	0.082	0.097	0.069	0.084	0.071	0.072	0.060
Tilley Creek, UT	0.111	0.094	0.086	0.101	0.092	0.073	0.069
Winter Ridge, UT	0.074	0.070	0.052	0.066	0.046	0.073	0.055

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	Pine Nut Moutain, NV	Powell Mountain, NV	Red Rock, NV	Reveille, NV	Roberts Mountain, NV	Rock Creek, NV (2002)	Rock Creek, NV (2010)
Adobe Town, WY	0.064	0.057	0.044	0.040	0.039	0.060	0.043
Adobe Town, WY (2011)	0.068	0.064	0.036	0.042	0.035	0.069	0.050
Antelope Hills, WY	0.058	0.075	0.063	0.047	0.052	0.075	0.058
Conant Creek, WY (Lander)	0.088	0.074	0.082	0.080	0.055	0.082	0.075
Cooper Creek, WY	0.047	0.058	0.040	0.039	0.033	0.058	0.040
Dishpan Butte, WY (Lander)	0.066	0.077	0.061	0.065	0.051	0.056	0.046
Divide Basin, WY	0.053	0.062	0.041	0.045	0.042	0.042	0.028
Divide Basin, WY (2011)	0.052	0.059	0.038	0.045	0.037	0.042	0.026
Eagles Nest, WY	0.089	0.097	0.076	0.067	0.053	0.078	0.060
Happy Creek Springs, WY	0.081	0.091	0.081	0.066	0.051	0.082	0.068
Little Colorado, WY	0.072	0.078	0.049	0.061	0.042	0.050	0.035
Little Colorado, WY (2011)	0.066	0.073	0.047	0.060	0.040	0.042	0.031
Lost Creek, WY	0.061	0.060	0.049	0.045	0.034	0.058	0.042
Lost Creek, WY (combined)	0.059	0.069	0.048	0.049	0.039	0.055	0.042
McCullough Peaks, WY	0.062	0.077	0.072	0.055	0.052	0.063	0.053
Muskrat Basin, WY (Lander)	0.073	0.073	0.059	0.064	0.041	0.059	0.045
Salt Wells, WY (East)	0.064	0.051	0.039	0.037	0.032	0.066	0.047
Salt Wells, WY (West)	0.056	0.062	0.047	0.029	0.039	0.065	0.046
Stewart Creek, WY	0.063	0.068	0.066	0.060	0.039	0.054	0.041
Stewart Creek, WY (2009)	0.077	0.078	0.060	0.053	0.055	0.071	0.054
White Mountain, WY (2011)	0.072	0.058	0.058	0.062	0.054	0.072	0.061

	Rocky Hills, NV	Rodeo Creek, NV	Saulsbury, NV	Sand Springs East, NV	Seven Mile, NV	Shawave Mountains, NV	Silver Peak, NV
Rocky Hills, NV	0.000						
Rodeo Creek, NV	0.033	0.000					
Saulsbury, NV	0.031	0.023	0.000				
Sand Springs East, NV	0.038	0.026	0.031	0.000			
Seven Mile, NV	0.031	0.042	0.038	0.037	0.000		

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	Rocky Hills, NV	Rodeo Creek, NV	Saulsbury, NV	Sand Springs East, NV	Seven Mile, NV	Shawave Mountains, NV	Silver Peak, NV
Shawave Mountains, NV	0.043	0.022	0.031	0.036	0.047	0.000	
Silver Peak, NV	0.055	0.043	0.046	0.051	0.066	0.049	0.000
Snowstorm, NV (Castle Ridge)	0.046	0.041	0.042	0.041	0.054	0.046	0.052
Snowstorm, NV (Dryhill)	0.090	0.076	0.087	0.082	0.098	0.072	0.072
South Shoshone, NV	0.031	0.033	0.034	0.028	0.037	0.043	0.050
Spruce-Pequop, NV (2011)	0.062	0.044	0.056	0.056	0.069	0.049	0.069
Stillwater, NV	0.065	0.035	0.048	0.045	0.067	0.041	0.049
Stone Cabin, NV	0.030	0.024	0.020	0.029	0.038	0.034	0.041
Warm Springs, NV	0.050	0.038	0.044	0.036	0.062	0.045	0.039
Warm Springs Canyon, NV	0.042	0.028	0.030	0.031	0.049	0.032	0.038
Wheeler Pass, NV	0.065	0.055	0.065	0.060	0.077	0.071	0.075
Wheeler Pass, NV (2007)	0.036	0.030	0.033	0.033	0.041	0.036	0.055
Alvord Tule, OR	0.049	0.033	0.039	0.042	0.055	0.045	0.048
Beatys Butte, OR	0.030	0.024	0.027	0.026	0.039	0.025	0.036
Beatys Butte, OR (2010)	0.044	0.029	0.036	0.035	0.049	0.020	0.045
Big Summit, OR (2010)	0.105	0.089	0.102	0.115	0.125	0.099	0.113
Cold Spring, OR	0.034	0.036	0.033	0.043	0.048	0.038	0.035
Cold Spring, OR (2010)	0.038	0.040	0.044	0.051	0.054	0.045	0.038
Coyote Lake, OR	0.047	0.039	0.040	0.041	0.056	0.049	0.043
Coyote Lake, OR (2011)	0.040	0.029	0.034	0.029	0.052	0.037	0.037
Fishnet, OR	0.041	0.048	0.047	0.049	0.065	0.054	0.045
Hog Creek, OR	0.039	0.034	0.037	0.040	0.056	0.043	0.046
Jackies Butte, OR	0.043	0.044	0.043	0.050	0.056	0.053	0.063
Jackies Butte, OR (2011)	0.037	0.035	0.037	0.039	0.045	0.039	0.053
Kiger, OR (2011)	0.047	0.038	0.038	0.045	0.058	0.038	0.042
Kiger Herd, OR (2009)	0.056	0.043	0.046	0.046	0.067	0.044	0.040
Liggett Table, OR	0.163	0.166	0.175	0.156	0.189	0.165	0.142
Murderers Creek, OR (2001)	0.087	0.072	0.075	0.083	0.087	0.074	0.083
Murderers Creek, OR (2009)	0.067	0.058	0.054	0.066	0.068	0.062	0.064

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	Rocky Hills, NV	Rodeo Creek, NV	Saulsbury, NV	Sand Springs East, NV	Seven Mile, NV	Shawave Mountains, NV	Silver Peak, NV
Paisley Desert, OR	0.033	0.019	0.030	0.024	0.042	0.031	0.035
Riddle Herd, OR (2009)	0.060	0.049	0.046	0.049	0.074	0.049	0.051
Riddle Mountain, OR	0.051	0.049	0.043	0.048	0.066	0.048	0.053
Riddle Mountain, OR (2011)	0.067	0.054	0.052	0.056	0.079	0.057	0.056
Sand Springs, OR (2011)	0.043	0.033	0.037	0.036	0.054	0.035	0.037
Sheepshead, OR	0.036	0.029	0.032	0.038	0.036	0.033	0.043
Sheepshead, OR (2011)	0.028	0.026	0.028	0.034	0.038	0.033	0.041
South Steens, OR	0.043	0.030	0.036	0.036	0.043	0.036	0.041
South Steens, OR (2010)	0.042	0.028	0.033	0.034	0.041	0.032	0.046
Stinkingwater, OR	0.058	0.066	0.067	0.056	0.077	0.070	0.086
Three Fingers, OR	0.041	0.043	0.053	0.043	0.054	0.055	0.055
Three Fingers, OR (2011)	0.035	0.044	0.047	0.033	0.047	0.050	0.054
Warm Springs, OR	0.029	0.034	0.025	0.027	0.036	0.035	0.043
Warm Springs, OR (2010)	0.031	0.034	0.025	0.029	0.040	0.038	0.037
Blawn Wash, UT	0.063	0.060	0.057	0.070	0.081	0.085	0.077
Cedar Mountain, UT	0.056	0.041	0.038	0.052	0.056	0.051	0.041
Cedar Ridge, UT	0.071	0.062	0.066	0.073	0.081	0.071	0.072
Cedar Ridge, UT (trap)	0.085	0.061	0.075	0.089	0.096	0.069	0.082
Cold Springs, UT (2006)	0.108	0.099	0.090	0.086	0.111	0.099	0.111
Cold Springs, UT (trap)	0.086	0.066	0.064	0.058	0.087	0.073	0.086
Delta, UT	0.040	0.020	0.028	0.029	0.042	0.024	0.041
Hill Creek, UT	0.053	0.025	0.045	0.044	0.059	0.034	0.051
Muddy Creek, UT	0.088	0.075	0.073	0.083	0.081	0.087	0.101
North Hills, UT	0.062	0.063	0.066	0.070	0.073	0.063	0.080
Range Creek, UT	0.056	0.046	0.045	0.046	0.062	0.051	0.057
Sinbad, UT	0.073	0.061	0.056	0.062	0.076	0.060	0.082
Sulphur, UT	0.093	0.085	0.085	0.096	0.101	0.095	0.104
Sulphur Herd, UT (South, 2006)	0.067	0.053	0.064	0.057	0.068	0.049	0.051
Tilley Creek, UT	0.061	0.068	0.077	0.081	0.078	0.076	0.070

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	Rocky Hills, NV	Rodeo Creek, NV	Saulsbury, NV	Sand Springs East, NV	Seven Mile, NV	Shawave Mountains, NV	Silver Peak, NV
Winter Ridge, UT	0.044	0.030	0.044	0.051	0.055	0.032	0.048
Adobe Town, WY	0.038	0.029	0.042	0.033	0.048	0.031	0.047
Adobe Town, WY (2011)	0.035	0.027	0.038	0.034	0.041	0.024	0.046
Antelope Hills, WY	0.049	0.044	0.044	0.038	0.054	0.046	0.058
Conant Creek, WY (Lander)	0.074	0.052	0.066	0.062	0.090	0.066	0.058
Cooper Creek, WY	0.039	0.029	0.029	0.030	0.047	0.034	0.042
Dishpan Butte, WY (Lander)	0.054	0.039	0.054	0.035	0.063	0.044	0.042
Divide Basin, WY	0.033	0.023	0.021	0.029	0.035	0.024	0.033
Divide Basin, WY (2011)	0.032	0.021	0.022	0.029	0.037	0.026	0.039
Eagles Nest, WY	0.060	0.051	0.062	0.055	0.074	0.062	0.053
Happy Creek Springs, WY	0.048	0.055	0.053	0.059	0.072	0.060	0.055
Little Colorado, WY	0.035	0.036	0.043	0.041	0.051	0.046	0.045
Little Colorado, WY (2011)	0.032	0.035	0.039	0.036	0.048	0.042	0.043
Lost Creek, WY	0.034	0.025	0.029	0.032	0.047	0.033	0.038
Lost Creek, WY (combined)	0.036	0.028	0.032	0.034	0.045	0.035	0.037
McCullough Peaks, WY	0.046	0.047	0.051	0.043	0.066	0.051	0.051
Muskrat Basin, WY (Lander)	0.060	0.041	0.055	0.036	0.066	0.049	0.040
Salt Wells, WY (East)	0.029	0.020	0.026	0.034	0.035	0.032	0.042
Salt Wells, WY (West)	0.030	0.031	0.029	0.037	0.048	0.034	0.037
Stewart Creek, WY	0.046	0.036	0.040	0.037	0.056	0.044	0.045
Stewart Creek, WY (2009)	0.048	0.037	0.036	0.045	0.057	0.040	0.049
White Mountain, WY (2011)	0.044	0.033	0.036	0.047	0.056	0.038	0.054

	Snowstorm, NV (Castle Ridge)	Snowstorm, NV (Dryhill)	South Shoshone, NV	Spruce-Pequop, NV (2011)	Stillwater, NV	Stone Cabin, NV	Warm Springs, NV
Snowstorm, NV (Castle Ridge)	0.000						
Snowstorm, NV (Dryhill)	0.082	0.000					
South Shoshone, NV	0.041	0.075	0.000				
Spruce-Pequop, NV (2011)	0.075	0.094	0.053	0.000			

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	Snowstorm, NV (Castle Ridge)	Snowstorm, NV (Dryhill)	South Shoshone, NV	Spruce-Pequop, NV (2011)	Stillwater, NV	Stone Cabin, NV	Warm Springs, NV
Stillwater, NV	0.065	0.072	0.045	0.059	0.000		
Stone Cabin, NV	0.039	0.079	0.030	0.052	0.044	0.000	
Warm Springs, NV	0.054	0.072	0.043	0.067	0.055	0.038	0.000
Warm Springs Canyon, NV	0.052	0.072	0.037	0.047	0.040	0.029	0.014
Wheeler Pass, NV	0.083	0.125	0.066	0.064	0.082	0.058	0.074
Wheeler Pass, NV (2007)	0.042	0.090	0.028	0.046	0.052	0.032	0.044
Alvord Tule, OR	0.057	0.080	0.042	0.056	0.056	0.041	0.044
Beatys Butte, OR	0.039	0.070	0.032	0.046	0.045	0.025	0.033
Beatys Butte, OR (2010)	0.042	0.064	0.035	0.050	0.042	0.032	0.035
Big Summit, OR (2010)	0.109	0.146	0.118	0.135	0.129	0.109	0.139
Cold Spring, OR	0.050	0.076	0.032	0.045	0.043	0.033	0.050
Cold Spring, OR (2010)	0.057	0.081	0.039	0.054	0.050	0.043	0.056
Coyote Lake, OR	0.057	0.088	0.039	0.058	0.060	0.036	0.053
Coyote Lake, OR (2011)	0.043	0.068	0.030	0.048	0.046	0.031	0.043
Fishnet, OR	0.049	0.073	0.037	0.067	0.057	0.041	0.044
Hog Creek, OR	0.054	0.067	0.035	0.056	0.055	0.031	0.048
Jackies Butte, OR	0.061	0.074	0.049	0.067	0.069	0.048	0.055
Jackies Butte, OR (2011)	0.056	0.060	0.039	0.059	0.054	0.039	0.039
Kiger, OR (2011)	0.055	0.089	0.049	0.082	0.067	0.038	0.044
Kiger Herd, OR (2009)	0.068	0.087	0.053	0.086	0.073	0.043	0.040
Liggett Table, OR	0.184	0.196	0.159	0.194	0.167	0.174	0.129
Murderers Creek, OR (2001)	0.090	0.134	0.077	0.110	0.092	0.076	0.090
Murderers Creek, OR (2009)	0.073	0.126	0.063	0.095	0.079	0.057	0.078
Paisley Desert, OR	0.042	0.062	0.024	0.040	0.038	0.021	0.039
Riddle Herd, OR (2009)	0.063	0.100	0.056	0.097	0.066	0.051	0.041
Riddle Mountain, OR	0.058	0.107	0.052	0.089	0.070	0.050	0.045
Riddle Mountain, OR (2011)	0.069	0.108	0.057	0.103	0.073	0.052	0.050
Sand Springs, OR (2011)	0.041	0.076	0.036	0.058	0.049	0.037	0.049
Sheepshead, OR	0.047	0.084	0.030	0.053	0.047	0.026	0.051

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	Snowstorm, NV (Castle Ridge)	Snowstorm, NV (Dryhill)	South Shoshone, NV	Spruce-Pequop, NV (2011)	Stillwater, NV	Stone Cabin, NV	Warm Springs, NV
Sheepshead, OR (2011)	0.037	0.080	0.026	0.051	0.040	0.026	0.047
South Steens, OR	0.050	0.059	0.029	0.045	0.041	0.028	0.042
South Steens, OR (2010)	0.049	0.055	0.035	0.044	0.041	0.029	0.040
Stinkingwater, OR	0.078	0.098	0.055	0.080	0.085	0.068	0.059
Three Fingers, OR	0.052	0.096	0.043	0.082	0.065	0.045	0.053
Three Fingers, OR (2011)	0.047	0.082	0.030	0.071	0.057	0.034	0.047
Warm Springs, OR	0.041	0.068	0.027	0.046	0.047	0.024	0.038
Warm Springs, OR (2010)	0.042	0.065	0.029	0.048	0.048	0.022	0.034
Blawn Wash, UT	0.076	0.113	0.066	0.089	0.079	0.060	0.065
Cedar Mountain, UT	0.064	0.074	0.043	0.059	0.053	0.040	0.052
Cedar Ridge, UT	0.062	0.113	0.066	0.109	0.093	0.062	0.086
Cedar Ridge, UT (trap)	0.075	0.110	0.078	0.109	0.090	0.071	0.096
Cold Springs, UT (2006)	0.123	0.123	0.088	0.126	0.097	0.096	0.084
Cold Springs, UT (trap)	0.095	0.102	0.059	0.093	0.072	0.067	0.063
Delta, UT	0.042	0.079	0.031	0.049	0.046	0.022	0.045
Hill Creek, UT	0.056	0.079	0.040	0.063	0.040	0.034	0.054
Muddy Creek, UT	0.089	0.117	0.079	0.085	0.104	0.081	0.108
North Hills, UT	0.080	0.115	0.074	0.095	0.107	0.061	0.089
Range Creek, UT	0.057	0.084	0.044	0.083	0.062	0.045	0.052
Sinbad, UT	0.082	0.124	0.069	0.087	0.079	0.060	0.083
Sulphur, UT	0.093	0.145	0.096	0.120	0.117	0.079	0.115
Sulphur Herd, UT (South, 2006)	0.070	0.094	0.058	0.088	0.065	0.060	0.068
Tilley Creek, UT	0.056	0.120	0.070	0.110	0.093	0.074	0.084
Winter Ridge, UT	0.053	0.077	0.040	0.057	0.053	0.045	0.048
Adobe Town, WY	0.043	0.081	0.035	0.050	0.045	0.034	0.053
Adobe Town, WY (2011)	0.040	0.055	0.029	0.042	0.036	0.031	0.043
Antelope Hills, WY	0.058	0.084	0.051	0.076	0.070	0.044	0.054
Conant Creek, WY (Lander)	0.065	0.105	0.061	0.094	0.057	0.056	0.062
Cooper Creek, WY	0.042	0.079	0.035	0.060	0.053	0.026	0.047

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	Snowstorm, NV (Castle Ridge)	Snowstorm, NV (Dryhill)	South Shoshone, NV	Spruce-Pequop, NV (2011)	Stillwater, NV	Stone Cabin, NV	Warm Springs, NV
Dishpan Butte, WY (Lander)	0.048	0.098	0.043	0.074	0.054	0.048	0.051
Divide Basin, WY	0.030	0.067	0.026	0.044	0.048	0.024	0.036
Divide Basin, WY (2011)	0.031	0.071	0.030	0.048	0.046	0.020	0.042
Eagles Nest, WY	0.056	0.098	0.047	0.080	0.072	0.056	0.063
Happy Creek Springs, WY	0.068	0.113	0.051	0.086	0.080	0.050	0.063
Little Colorado, WY	0.049	0.089	0.037	0.064	0.064	0.038	0.042
Little Colorado, WY (2011)	0.044	0.080	0.032	0.060	0.061	0.038	0.037
Lost Creek, WY	0.042	0.074	0.028	0.050	0.048	0.027	0.037
Lost Creek, WY (combined)	0.045	0.070	0.027	0.053	0.050	0.030	0.039
McCullough Peaks, WY	0.046	0.082	0.041	0.077	0.069	0.040	0.039
Muskrat Basin, WY (Lander)	0.045	0.100	0.043	0.068	0.051	0.042	0.049
Salt Wells, WY (East)	0.038	0.070	0.028	0.041	0.036	0.022	0.041
Salt Wells, WY (West)	0.036	0.074	0.035	0.052	0.051	0.027	0.047
Stewart Creek, WY	0.050	0.081	0.036	0.068	0.058	0.037	0.045
Stewart Creek, WY (2009)	0.058	0.091	0.039	0.062	0.067	0.038	0.045
White Mountain, WY (2011)	0.046	0.076	0.041	0.063	0.060	0.047	0.042

	Warm Springs Canyon, NV	Wheeler Pass, NV	Wheeler Pass, NV (2007)	Alvord Tule, OR	Beatys Butte, OR	Beatys Butte, OR (2010)	Big Summit, OR (2010)
Warm Springs Canyon, NV	0.000						
Wheeler Pass, NV	0.061	0.000					
Wheeler Pass, NV (2007)	0.036	0.040	0.000				
Alvord Tule, OR	0.037	0.073	0.043	0.000			
Beatys Butte, OR	0.029	0.063	0.027	0.040	0.000		
Beatys Butte, OR (2010)	0.029	0.074	0.036	0.046	0.018	0.000	
Big Summit, OR (2010)	0.123	0.130	0.109	0.115	0.099	0.107	0.000
Cold Spring, OR	0.032	0.067	0.036	0.045	0.030	0.039	0.115
Cold Spring, OR (2010)	0.040	0.071	0.041	0.055	0.038	0.044	0.112
Coyote Lake, OR	0.043	0.068	0.042	0.021	0.039	0.047	0.124

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	Warm Springs Canyon, NV	Wheeler Pass, NV	Wheeler Pass, NV (2007)	Alvord Tule, OR	Beatys Butte, OR	Beatys Butte, OR (2010)	Big Summit, OR (2010)
Coyote Lake, OR (2011)	0.036	0.067	0.033	0.018	0.028	0.035	0.107
Fishnet, OR	0.043	0.088	0.051	0.052	0.041	0.047	0.148
Hog Creek, OR	0.039	0.071	0.045	0.039	0.036	0.038	0.115
Jackies Butte, OR	0.049	0.073	0.044	0.044	0.039	0.051	0.117
Jackies Butte, OR (2011)	0.033	0.062	0.036	0.038	0.034	0.040	0.111
Kiger, OR (2011)	0.048	0.091	0.049	0.054	0.028	0.039	0.125
Kiger Herd, OR (2009)	0.047	0.082	0.050	0.047	0.031	0.044	0.128
Liggett Table, OR	0.131	0.199	0.178	0.171	0.143	0.151	0.275
Murderers Creek, OR (2001)	0.078	0.114	0.089	0.100	0.078	0.073	0.160
Murderers Creek, OR (2009)	0.065	0.105	0.074	0.084	0.060	0.062	0.151
Paisley Desert, OR	0.029	0.048	0.024	0.031	0.018	0.028	0.098
Riddle Herd, OR (2009)	0.049	0.096	0.059	0.065	0.039	0.048	0.143
Riddle Mountain, OR	0.048	0.094	0.055	0.063	0.036	0.045	0.137
Riddle Mountain, OR (2011)	0.057	0.105	0.066	0.067	0.046	0.055	0.147
Sand Springs, OR (2011)	0.038	0.075	0.035	0.033	0.035	0.031	0.104
Sheepshead, OR	0.035	0.061	0.029	0.034	0.030	0.032	0.115
Sheepshead, OR (2011)	0.034	0.058	0.023	0.036	0.031	0.035	0.111
South Steens, OR	0.028	0.058	0.034	0.022	0.033	0.032	0.118
South Steens, OR (2010)	0.030	0.063	0.035	0.030	0.027	0.027	0.121
Stinkingwater, OR	0.054	0.092	0.057	0.056	0.052	0.060	0.162
Three Fingers, OR	0.053	0.089	0.046	0.059	0.042	0.050	0.130
Three Fingers, OR (2011)	0.046	0.073	0.039	0.052	0.041	0.048	0.127
Warm Springs, OR	0.028	0.064	0.035	0.042	0.023	0.032	0.106
Warm Springs, OR (2010)	0.027	0.067	0.037	0.043	0.022	0.032	0.107
Blawn Wash, UT	0.066	0.096	0.065	0.077	0.053	0.069	0.167
Cedar Mountain, UT	0.041	0.065	0.050	0.045	0.037	0.046	0.122
Cedar Ridge, UT	0.078	0.120	0.073	0.067	0.069	0.073	0.125
Cedar Ridge, UT (trap)	0.084	0.116	0.077	0.069	0.078	0.076	0.109
Cold Springs, UT (2006)	0.075	0.153	0.105	0.100	0.099	0.093	0.207

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	Warm Springs Canyon, NV	Wheeler Pass, NV	Wheeler Pass, NV (2007)	Alvord Tule, OR	Beatys Butte, OR	Beatys Butte, OR (2010)	Big Summit, OR (2010)
Cold Springs, UT (trap)	0.053	0.111	0.073	0.069	0.073	0.070	0.166
Delta, UT	0.036	0.055	0.025	0.034	0.022	0.032	0.090
Hill Creek, UT	0.043	0.054	0.034	0.046	0.037	0.035	0.110
Muddy Creek, UT	0.086	0.111	0.079	0.083	0.084	0.093	0.156
North Hills, UT	0.075	0.088	0.071	0.083	0.052	0.064	0.109
Range Creek, UT	0.044	0.101	0.055	0.049	0.050	0.049	0.126
Sinbad, UT	0.065	0.107	0.061	0.076	0.064	0.065	0.133
Sulphur, UT	0.107	0.129	0.089	0.107	0.076	0.090	0.138
Sulphur Herd, UT (South, 2006)	0.061	0.071	0.061	0.059	0.056	0.061	0.119
Tilley Creek, UT	0.085	0.110	0.069	0.098	0.057	0.071	0.134
Winter Ridge, UT	0.044	0.058	0.035	0.054	0.036	0.028	0.103
Adobe Town, WY	0.040	0.062	0.033	0.046	0.030	0.028	0.107
Adobe Town, WY (2011)	0.031	0.067	0.032	0.043	0.026	0.020	0.106
Antelope Hills, WY	0.042	0.080	0.050	0.048	0.036	0.044	0.120
Conant Creek, WY (Lander)	0.064	0.100	0.061	0.080	0.057	0.062	0.137
Cooper Creek, WY	0.039	0.056	0.031	0.043	0.027	0.035	0.100
Dishpan Butte, WY (Lander)	0.047	0.066	0.039	0.050	0.045	0.046	0.123
Divide Basin, WY	0.025	0.055	0.026	0.036	0.020	0.025	0.095
Divide Basin, WY (2011)	0.029	0.056	0.026	0.042	0.022	0.028	0.087
Eagles Nest, WY	0.057	0.086	0.059	0.056	0.055	0.060	0.118
Happy Creek Springs, WY	0.051	0.077	0.051	0.064	0.056	0.053	0.120
Little Colorado, WY	0.034	0.056	0.033	0.047	0.035	0.037	0.111
Little Colorado, WY (2011)	0.032	0.054	0.031	0.046	0.029	0.031	0.114
Lost Creek, WY	0.031	0.052	0.031	0.031	0.030	0.031	0.093
Lost Creek, WY (combined)	0.032	0.055	0.032	0.036	0.035	0.035	0.097
McCullough Peaks, WY	0.040	0.079	0.043	0.048	0.043	0.038	0.132
Muskrat Basin, WY (Lander)	0.047	0.065	0.038	0.049	0.044	0.051	0.126
Salt Wells, WY (East)	0.025	0.060	0.027	0.031	0.025	0.024	0.101
Salt Wells, WY (West)	0.038	0.068	0.031	0.051	0.027	0.035	0.106

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	Warm Springs Canyon, NV	Wheeler Pass, NV	Wheeler Pass, NV (2007)	Alvord Tule, OR	Beatys Butte, OR	Beatys Butte, OR (2010)	Big Summit, OR (2010)
Stewart Creek, WY	0.042	0.069	0.041	0.029	0.038	0.043	0.111
Stewart Creek, WY (2009)	0.039	0.077	0.045	0.046	0.045	0.037	0.113
White Mountain, WY (2011)	0.042	0.086	0.040	0.051	0.032	0.029	0.112

	Cold Spring, OR	Cold Spring, OR (2010)	Coyote Lake, OR	Coyote Lake, OR (2011)	Fishnet, OR	Hog Creek, OR	Jackies Butte, OR
Cold Spring, OR	0.000						
Cold Spring, OR (2010)	0.011	0.000					
Coyote Lake, OR	0.036	0.048	0.000				
Coyote Lake, OR (2011)	0.032	0.040	0.010	0.000			
Fishnet, OR	0.047	0.054	0.047	0.040	0.000		
Hog Creek, OR	0.034	0.035	0.042	0.033	0.041	0.000	
Jackies Butte, OR	0.050	0.058	0.055	0.039	0.060	0.051	0.000
Jackies Butte, OR (2011)	0.044	0.052	0.048	0.034	0.047	0.041	0.011
Kiger, OR (2011)	0.055	0.062	0.059	0.048	0.040	0.047	0.063
Kiger Herd, OR (2009)	0.054	0.060	0.051	0.043	0.047	0.045	0.059
Liggett Table, OR	0.145	0.150	0.162	0.154	0.165	0.165	0.183
Murderers Creek, OR (2001)	0.068	0.069	0.088	0.085	0.084	0.078	0.115
Murderers Creek, OR (2009)	0.052	0.060	0.073	0.067	0.069	0.071	0.087
Paisley Desert, OR	0.029	0.036	0.028	0.018	0.037	0.031	0.032
Riddle Herd, OR (2009)	0.064	0.074	0.070	0.056	0.055	0.058	0.082
Riddle Mountain, OR	0.058	0.068	0.069	0.056	0.056	0.059	0.078
Riddle Mountain, OR (2011)	0.070	0.081	0.073	0.063	0.059	0.061	0.091
Sand Springs, OR (2011)	0.038	0.042	0.035	0.024	0.041	0.031	0.056
Sheepshead, OR	0.027	0.040	0.030	0.027	0.050	0.038	0.049
Sheepshead, OR (2011)	0.019	0.028	0.033	0.027	0.044	0.035	0.050
South Steens, OR	0.033	0.045	0.027	0.023	0.044	0.031	0.044
South Steens, OR (2010)	0.039	0.050	0.037	0.029	0.043	0.027	0.038
Stinkingwater, OR	0.054	0.065	0.056	0.054	0.053	0.059	0.057
Three Fingers, OR	0.050	0.056	0.059	0.045	0.046	0.062	0.058

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	Cold Spring, OR	Cold Spring, OR (2010)	Coyote Lake, OR	Coyote Lake, OR (2011)	Fishnet, OR	Hog Creek, OR	Jackies Butte, OR
Three Fingers, OR (2011)	0.037	0.044	0.052	0.037	0.041	0.051	0.052
Warm Springs, OR	0.023	0.037	0.042	0.031	0.039	0.036	0.034
Warm Springs, OR (2010)	0.025	0.037	0.042	0.030	0.038	0.034	0.036
Blawn Wash, UT	0.074	0.088	0.079	0.073	0.073	0.069	0.061
Cedar Mountain, UT	0.042	0.050	0.044	0.039	0.053	0.041	0.064
Cedar Ridge, UT	0.067	0.068	0.068	0.051	0.079	0.070	0.090
Cedar Ridge, UT (trap)	0.076	0.074	0.078	0.061	0.087	0.069	0.099
Cold Springs, UT (2006)	0.090	0.107	0.106	0.096	0.094	0.105	0.120
Cold Springs, UT (trap)	0.065	0.080	0.075	0.065	0.073	0.067	0.089
Delta, UT	0.030	0.035	0.037	0.027	0.049	0.029	0.050
Hill Creek, UT	0.055	0.059	0.046	0.040	0.054	0.046	0.060
Muddy Creek, UT	0.075	0.082	0.078	0.082	0.101	0.081	0.080
North Hills, UT	0.062	0.069	0.073	0.069	0.089	0.066	0.091
Range Creek, UT	0.045	0.053	0.052	0.039	0.053	0.053	0.070
Sinbad, UT	0.074	0.078	0.080	0.064	0.090	0.068	0.089
Sulphur, UT	0.096	0.112	0.091	0.084	0.119	0.109	0.098
Sulphur Herd, UT (South, 2006)	0.054	0.063	0.050	0.050	0.078	0.072	0.076
Tilley Creek, UT	0.074	0.075	0.091	0.083	0.078	0.086	0.096
Winter Ridge, UT	0.045	0.043	0.051	0.041	0.057	0.046	0.057
Adobe Town, WY	0.034	0.034	0.039	0.031	0.047	0.036	0.043
Adobe Town, WY (2011)	0.034	0.035	0.048	0.034	0.042	0.032	0.038
Antelope Hills, WY	0.056	0.066	0.053	0.038	0.061	0.049	0.053
Conant Creek, WY (Lander)	0.068	0.084	0.074	0.064	0.067	0.078	0.082
Cooper Creek, WY	0.037	0.047	0.034	0.026	0.051	0.037	0.043
Dishpan Butte, WY (Lander)	0.041	0.044	0.046	0.038	0.061	0.056	0.069
Divide Basin, WY	0.025	0.031	0.034	0.027	0.044	0.036	0.045
Divide Basin, WY (2011)	0.029	0.035	0.039	0.031	0.046	0.040	0.046
Eagles Nest, WY	0.053	0.056	0.055	0.045	0.074	0.059	0.076
Happy Creek Springs, WY	0.051	0.054	0.047	0.045	0.051	0.061	0.067

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	Cold Spring, OR	Cold Spring, OR (2010)	Coyote Lake, OR	Coyote Lake, OR (2011)	Fishnet, OR	Hog Creek, OR	Jackies Butte, OR
Little Colorado, WY	0.033	0.037	0.046	0.040	0.055	0.045	0.057
Little Colorado, WY (2011)	0.030	0.037	0.043	0.036	0.046	0.038	0.054
Lost Creek, WY	0.031	0.036	0.033	0.025	0.048	0.032	0.045
Lost Creek, WY (combined)	0.031	0.032	0.036	0.028	0.051	0.034	0.050
McCullough Peaks, WY	0.053	0.062	0.046	0.039	0.040	0.044	0.066
Muskrat Basin, WY (Lander)	0.038	0.043	0.042	0.034	0.061	0.058	0.075
Salt Wells, WY (East)	0.028	0.034	0.035	0.028	0.042	0.030	0.030
Salt Wells, WY (West)	0.031	0.032	0.043	0.035	0.039	0.034	0.050
Stewart Creek, WY	0.042	0.053	0.031	0.025	0.054	0.046	0.057
Stewart Creek, WY (2009)	0.042	0.041	0.041	0.038	0.059	0.047	0.062
White Mountain, WY (2011)	0.049	0.050	0.054	0.043	0.047	0.041	0.053

	Jackies Butte, OR (2011)	Kiger, OR (2011)	Kiger Herd, OR (2009)	Liggett Table, OR	Murderers Creek, OR (2001)	Murderers Creek, OR (2009)	Paisley Desert, OR
Jackies Butte, OR (2011)	0.000						
Kiger, OR (2011)	0.050	0.000					
Kiger Herd, OR (2009)	0.046	0.012	0.000				
Liggett Table, OR	0.160	0.176	0.177	0.000			
Murderers Creek, OR (2001)	0.097	0.081	0.086	0.192	0.000		
Murderers Creek, OR (2009)	0.078	0.063	0.070	0.187	0.018	0.000	
Paisley Desert, OR	0.027	0.039	0.037	0.157	0.078	0.060	0.000
Riddle Herd, OR (2009)	0.060	0.017	0.027	0.146	0.086	0.075	0.053
Riddle Mountain, OR	0.057	0.019	0.034	0.148	0.084	0.073	0.053
Riddle Mountain, OR (2011)	0.068	0.021	0.030	0.161	0.091	0.082	0.056
Sand Springs, OR (2011)	0.044	0.046	0.049	0.171	0.080	0.063	0.027
Sheepshead, OR	0.040	0.042	0.046	0.169	0.067	0.049	0.023
Sheepshead, OR (2011)	0.040	0.044	0.049	0.167	0.070	0.054	0.023
South Steens, OR	0.033	0.047	0.046	0.159	0.087	0.072	0.020
South Steens, OR (2010)	0.029	0.043	0.044	0.157	0.092	0.074	0.024

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	Jackies Butte, OR (2011)	Kiger, OR (2011)	Kiger Herd, OR (2009)	Liggett Table, OR	Murderers Creek, OR (2001)	Murderers Creek, OR (2009)	Paisley Desert, OR
Stinkingwater, OR	0.052	0.082	0.072	0.157	0.100	0.094	0.055
Three Fingers, OR	0.053	0.053	0.063	0.155	0.081	0.065	0.042
Three Fingers, OR (2011)	0.045	0.055	0.061	0.149	0.079	0.065	0.035
Warm Springs, OR	0.028	0.044	0.045	0.152	0.073	0.055	0.024
Warm Springs, OR (2010)	0.031	0.043	0.044	0.148	0.074	0.056	0.023
Blawn Wash, UT	0.054	0.076	0.084	0.200	0.142	0.120	0.061
Cedar Mountain, UT	0.050	0.060	0.059	0.151	0.092	0.082	0.034
Cedar Ridge, UT	0.076	0.070	0.078	0.199	0.089	0.082	0.068
Cedar Ridge, UT (trap)	0.082	0.078	0.083	0.220	0.101	0.102	0.073
Cold Springs, UT (2006)	0.093	0.117	0.111	0.199	0.144	0.126	0.103
Cold Springs, UT (trap)	0.064	0.082	0.077	0.194	0.107	0.094	0.066
Delta, UT	0.043	0.033	0.034	0.172	0.067	0.056	0.019
Hill Creek, UT	0.044	0.049	0.047	0.175	0.090	0.079	0.024
Muddy Creek, UT	0.074	0.107	0.110	0.233	0.144	0.120	0.072
North Hills, UT	0.080	0.066	0.070	0.205	0.078	0.073	0.057
Range Creek, UT	0.051	0.058	0.059	0.162	0.079	0.068	0.051
Sinbad, UT	0.075	0.076	0.081	0.222	0.129	0.107	0.065
Sulphur, UT	0.105	0.104	0.108	0.276	0.154	0.121	0.079
Sulphur Herd, UT (South, 2006)	0.060	0.066	0.065	0.175	0.079	0.068	0.049
Tilley Creek, UT	0.084	0.069	0.091	0.201	0.125	0.108	0.068
Winter Ridge, UT	0.048	0.054	0.053	0.169	0.067	0.060	0.034
Adobe Town, WY	0.040	0.053	0.055	0.153	0.075	0.064	0.024
Adobe Town, WY (2011)	0.029	0.047	0.052	0.154	0.075	0.064	0.025
Antelope Hills, WY	0.045	0.051	0.051	0.176	0.092	0.070	0.035
Conant Creek, WY (Lander)	0.068	0.059	0.068	0.195	0.104	0.083	0.054
Cooper Creek, WY	0.037	0.041	0.040	0.174	0.079	0.060	0.021
Dishpan Butte, WY (Lander)	0.056	0.053	0.055	0.148	0.087	0.077	0.039
Divide Basin, WY	0.034	0.035	0.040	0.153	0.065	0.051	0.023
Divide Basin, WY (2011)	0.038	0.036	0.044	0.172	0.076	0.059	0.026

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	Jackies Butte, OR (2011)	Kiger, OR (2011)	Kiger Herd, OR (2009)	Liggett Table, OR	Murderers Creek, OR (2001)	Murderers Creek, OR (2009)	Paisley Desert, OR
Eagles Nest, WY	0.069	0.078	0.069	0.170	0.097	0.079	0.052
Happy Creek Springs, WY	0.058	0.066	0.062	0.173	0.080	0.063	0.048
Little Colorado, WY	0.045	0.055	0.053	0.150	0.072	0.065	0.033
Little Colorado, WY (2011)	0.042	0.048	0.048	0.141	0.064	0.057	0.030
Lost Creek, WY	0.038	0.046	0.043	0.140	0.065	0.048	0.028
Lost Creek, WY (combined)	0.039	0.050	0.048	0.142	0.066	0.052	0.030
McCullough Peaks, WY	0.051	0.047	0.047	0.181	0.086	0.071	0.037
Muskrat Basin, WY (Lander)	0.066	0.059	0.058	0.159	0.092	0.078	0.039
Salt Wells, WY (East)	0.025	0.049	0.053	0.156	0.073	0.055	0.021
Salt Wells, WY (West)	0.044	0.042	0.046	0.176	0.081	0.068	0.026
Stewart Creek, WY	0.049	0.051	0.044	0.156	0.087	0.068	0.036
Stewart Creek, WY (2009)	0.051	0.053	0.049	0.170	0.072	0.064	0.041
White Mountain, WY (2011)	0.044	0.044	0.053	0.170	0.081	0.067	0.040

	Riddle Herd, OR (2009)	Riddle Mountain, OR	Riddle Mountain, OR (2011)	Sand Springs, OR (2011)	Sheepshead, OR	Sheepshead, OR (2011)	South Steens, OR
Riddle Herd, OR (2009)	0.000						
Riddle Mountain, OR	0.007	0.000					
Riddle Mountain, OR (2011)	0.006	0.011	0.000				
Sand Springs, OR (2011)	0.056	0.051	0.061	0.000			
Sheepshead, OR	0.058	0.052	0.061	0.025	0.000		
Sheepshead, OR (2011)	0.054	0.047	0.058	0.025	0.009	0.000	
South Steens, OR	0.057	0.055	0.058	0.030	0.026	0.028	0.000
South Steens, OR (2010)	0.054	0.053	0.057	0.034	0.033	0.035	0.010
Stinkingwater, OR	0.094	0.084	0.104	0.068	0.062	0.061	0.056
Three Fingers, OR	0.062	0.058	0.067	0.043	0.043	0.038	0.056
Three Fingers, OR (2011)	0.063	0.060	0.067	0.045	0.038	0.031	0.045
Warm Springs, OR	0.051	0.045	0.054	0.041	0.034	0.031	0.025
Warm Springs, OR (2010)	0.049	0.044	0.052	0.040	0.037	0.035	0.026

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	Riddle Herd, OR (2009)	Riddle Mountain, OR	Riddle Mountain, OR (2011)	Sand Springs, OR (2011)	Sheepshead, OR	Sheepshead, OR (2011)	South Steens, OR
Blawn Wash, UT	0.080	0.074	0.081	0.074	0.066	0.063	0.075
Cedar Mountain, UT	0.062	0.064	0.063	0.048	0.046	0.047	0.039
Cedar Ridge, UT	0.077	0.075	0.077	0.065	0.064	0.060	0.069
Cedar Ridge, UT (trap)	0.085	0.088	0.085	0.070	0.075	0.071	0.070
Cold Springs, UT (2006)	0.109	0.114	0.116	0.103	0.113	0.106	0.098
Cold Springs, UT (trap)	0.077	0.082	0.081	0.071	0.073	0.069	0.065
Delta, UT	0.045	0.046	0.048	0.031	0.028	0.027	0.028
Hill Creek, UT	0.055	0.063	0.058	0.040	0.036	0.039	0.030
Muddy Creek, UT	0.129	0.121	0.135	0.079	0.074	0.073	0.085
North Hills, UT	0.085	0.074	0.087	0.075	0.061	0.069	0.064
Range Creek, UT	0.058	0.060	0.061	0.049	0.054	0.048	0.050
Sinbad, UT	0.085	0.079	0.093	0.058	0.056	0.053	0.069
Sulphur, UT	0.130	0.126	0.135	0.101	0.088	0.098	0.092
Sulphur Herd, UT (South, 2006)	0.072	0.070	0.076	0.058	0.048	0.048	0.048
Tilley Creek, UT	0.076	0.069	0.075	0.077	0.077	0.067	0.079
Winter Ridge, UT	0.065	0.070	0.075	0.044	0.037	0.037	0.043
Adobe Town, WY	0.067	0.063	0.075	0.035	0.034	0.031	0.031
Adobe Town, WY (2011)	0.058	0.056	0.065	0.034	0.034	0.032	0.026
Antelope Hills, WY	0.059	0.058	0.072	0.046	0.044	0.044	0.046
Conant Creek, WY (Lander)	0.062	0.066	0.067	0.063	0.053	0.053	0.063
Cooper Creek, WY	0.051	0.050	0.057	0.034	0.029	0.031	0.029
Dishpan Butte, WY (Lander)	0.056	0.053	0.061	0.038	0.039	0.032	0.044
Divide Basin, WY	0.044	0.040	0.052	0.031	0.024	0.022	0.025
Divide Basin, WY (2011)	0.051	0.046	0.056	0.035	0.027	0.025	0.030
Eagles Nest, WY	0.083	0.079	0.090	0.053	0.060	0.052	0.055
Happy Creek Springs, WY	0.081	0.076	0.091	0.047	0.048	0.046	0.058
Little Colorado, WY	0.058	0.050	0.063	0.041	0.038	0.034	0.040
Little Colorado, WY (2011)	0.050	0.043	0.056	0.038	0.036	0.031	0.036
Lost Creek, WY	0.055	0.053	0.062	0.032	0.030	0.026	0.030

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	Riddle Herd, OR (2009)	Riddle Mountain, OR	Riddle Mountain, OR (2011)	Sand Springs, OR (2011)	Sheepshead, OR	Sheepshead, OR (2011)	South Steens, OR
Lost Creek, WY (combined)	0.054	0.052	0.062	0.033	0.032	0.027	0.029
McCullough Peaks, WY	0.055	0.049	0.057	0.035	0.041	0.034	0.037
Muskrat Basin, WY (Lander)	0.064	0.064	0.069	0.041	0.040	0.033	0.048
Salt Wells, WY (East)	0.061	0.057	0.066	0.033	0.027	0.025	0.024
Salt Wells, WY (West)	0.054	0.051	0.061	0.033	0.033	0.026	0.040
Stewart Creek, WY	0.057	0.056	0.061	0.040	0.039	0.035	0.032
Stewart Creek, WY (2009)	0.061	0.055	0.068	0.043	0.041	0.035	0.040
White Mountain, WY (2011)	0.055	0.056	0.065	0.037	0.043	0.038	0.048

	South Steens, OR (2010)	Stinkingwater, OR	Three Fingers, OR	Three Fingers, OR (2011)	Warm Springs, OR	Warm Springs, OR (2010)	Blawn Wash, UT
South Steens, OR (2010)	0.000						
Stinkingwater, OR	0.058	0.000					
Three Fingers, OR	0.058	0.069	0.000				
Three Fingers, OR (2011)	0.049	0.058	0.016	0.000			
Warm Springs, OR	0.024	0.051	0.047	0.031	0.000		
Warm Springs, OR (2010)	0.026	0.055	0.044	0.030	0.004	0.000	
Blawn Wash, UT	0.063	0.097	0.086	0.087	0.061	0.062	0.000
Cedar Mountain, UT	0.041	0.082	0.066	0.055	0.044	0.039	0.071
Cedar Ridge, UT	0.080	0.111	0.065	0.058	0.069	0.064	0.125
Cedar Ridge, UT (trap)	0.079	0.126	0.087	0.077	0.079	0.076	0.136
Cold Springs, UT (2006)	0.097	0.104	0.098	0.091	0.083	0.085	0.128
Cold Springs, UT (trap)	0.068	0.088	0.086	0.072	0.061	0.064	0.091
Delta, UT	0.030	0.065	0.049	0.043	0.030	0.030	0.077
Hill Creek, UT	0.037	0.082	0.061	0.056	0.050	0.050	0.081
Muddy Creek, UT	0.086	0.093	0.102	0.099	0.088	0.096	0.113
North Hills, UT	0.073	0.087	0.084	0.077	0.058	0.053	0.129
Range Creek, UT	0.055	0.073	0.047	0.040	0.043	0.042	0.093
Sinbad, UT	0.062	0.107	0.094	0.087	0.064	0.069	0.102

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	South Steens, OR (2010)	Stinkingwater, OR	Three Fingers, OR	Three Fingers, OR (2011)	Warm Springs, OR	Warm Springs, OR (2010)	Blawn Wash, UT
Sulphur, UT	0.087	0.138	0.112	0.112	0.085	0.081	0.131
Sulphur Herd, UT (South, 2006)	0.058	0.091	0.071	0.062	0.054	0.055	0.116
Tilley Creek, UT	0.081	0.127	0.078	0.080	0.069	0.070	0.076
Winter Ridge, UT	0.044	0.079	0.058	0.055	0.046	0.048	0.088
Adobe Town, WY	0.034	0.056	0.042	0.038	0.034	0.037	0.086
Adobe Town, WY (2011)	0.026	0.061	0.039	0.036	0.029	0.031	0.074
Antelope Hills, WY	0.045	0.064	0.052	0.057	0.046	0.044	0.096
Conant Creek, WY (Lander)	0.064	0.102	0.063	0.072	0.066	0.068	0.071
Cooper Creek, WY	0.028	0.066	0.050	0.044	0.028	0.027	0.072
Dishpan Butte, WY (Lander)	0.053	0.068	0.048	0.046	0.052	0.055	0.093
Divide Basin, WY	0.029	0.053	0.047	0.040	0.022	0.022	0.071
Divide Basin, WY (2011)	0.032	0.058	0.043	0.038	0.025	0.024	0.070
Eagles Nest, WY	0.061	0.078	0.071	0.065	0.055	0.055	0.112
Happy Creek Springs, WY	0.065	0.063	0.056	0.058	0.051	0.054	0.097
Little Colorado, WY	0.048	0.058	0.045	0.041	0.033	0.033	0.068
Little Colorado, WY (2011)	0.039	0.051	0.047	0.041	0.026	0.027	0.064
Lost Creek, WY	0.033	0.053	0.044	0.038	0.030	0.032	0.077
Lost Creek, WY (combined)	0.032	0.061	0.051	0.041	0.029	0.032	0.080
McCullough Peaks, WY	0.040	0.056	0.059	0.055	0.045	0.045	0.076
Muskrat Basin, WY (Lander)	0.058	0.076	0.047	0.038	0.051	0.050	0.090
Salt Wells, WY (East)	0.024	0.054	0.042	0.038	0.026	0.027	0.059
Salt Wells, WY (West)	0.038	0.068	0.044	0.044	0.035	0.033	0.063
Stewart Creek, WY	0.036	0.063	0.053	0.045	0.035	0.037	0.082
Stewart Creek, WY (2009)	0.047	0.068	0.060	0.055	0.037	0.040	0.091
White Mountain, WY (2011)	0.038	0.070	0.059	0.061	0.048	0.048	0.065

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	Cedar Mountain, UT	Cedar Ridge, UT	Cedar Ridge, UT (Trap)	Cold Springs, UT (2006)	Cold Springs, UT (Trap)	Delta, UT	Hill Creek, UT
Cedar Mountain, UT	0.000						
Cedar Ridge, UT	0.077	0.000					
Cedar Ridge, UT (trap)	0.075	0.018	0.000				
Cold Springs, UT (2006)	0.101	0.133	0.144	0.000			
Cold Springs, UT (trap)	0.074	0.099	0.103	0.030	0.000		
Delta, UT	0.040	0.063	0.062	0.106	0.068	0.000	
Hill Creek, UT	0.049	0.081	0.073	0.107	0.071	0.033	0.000
Muddy Creek, UT	0.096	0.142	0.145	0.144	0.112	0.079	0.094
North Hills, UT	0.070	0.086	0.096	0.148	0.110	0.048	0.081
Range Creek, UT	0.056	0.029	0.042	0.041	0.034	0.050	0.059
Sinbad, UT	0.085	0.119	0.125	0.140	0.101	0.058	0.076
Sulphur, UT	0.112	0.145	0.152	0.192	0.162	0.075	0.106
Sulphur Herd, UT (South, 2006)	0.063	0.100	0.107	0.132	0.103	0.049	0.055
Tilley Creek, UT	0.082	0.096	0.104	0.150	0.115	0.067	0.082
Winter Ridge, UT	0.052	0.078	0.075	0.113	0.083	0.035	0.028
Adobe Town, WY	0.054	0.074	0.077	0.116	0.087	0.028	0.037
Adobe Town, WY (2011)	0.044	0.067	0.068	0.091	0.070	0.031	0.032
Antelope Hills, WY	0.057	0.079	0.091	0.103	0.083	0.038	0.062
Conant Creek, WY (Lander)	0.078	0.099	0.107	0.141	0.100	0.059	0.063
Cooper Creek, WY	0.047	0.076	0.083	0.114	0.079	0.021	0.041
Dishpan Butte, WY (Lander)	0.064	0.068	0.083	0.124	0.087	0.036	0.052
Divide Basin, WY	0.036	0.051	0.061	0.090	0.067	0.021	0.037
Divide Basin, WY (2011)	0.043	0.051	0.059	0.089	0.067	0.022	0.038
Eagles Nest, WY	0.071	0.080	0.093	0.128	0.102	0.049	0.071
Happy Creek Springs, WY	0.076	0.085	0.103	0.112	0.094	0.057	0.065
Little Colorado, WY	0.053	0.055	0.066	0.097	0.069	0.036	0.052
Little Colorado, WY (2011)	0.049	0.060	0.070	0.091	0.065	0.033	0.049
Lost Creek, WY	0.040	0.065	0.070	0.092	0.066	0.026	0.040
Lost Creek, WY (combined)	0.044	0.064	0.069	0.098	0.067	0.027	0.044

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	Cedar Mountain, UT	Cedar Ridge, UT	Cedar Ridge, UT (Trap)	Cold Springs, UT (2006)	Cold Springs, UT (Trap)	Delta, UT	Hill Creek, UT
McCullough Peaks, WY	0.063	0.078	0.092	0.113	0.083	0.046	0.053
Muskrat Basin, WY (Lander)	0.062	0.066	0.079	0.121	0.084	0.035	0.053
Salt Wells, WY (East)	0.039	0.064	0.068	0.093	0.066	0.029	0.030
Salt Wells, WY (West)	0.047	0.067	0.075	0.116	0.085	0.029	0.046
Stewart Creek, WY	0.050	0.068	0.077	0.098	0.076	0.037	0.050
Stewart Creek, WY (2009)	0.058	0.075	0.083	0.115	0.084	0.038	0.057
White Mountain, WY (2011)	0.065	0.087	0.091	0.110	0.082	0.037	0.053

	Muddy Creek, UT	North Hills, UT	Range Creek, UT	Sinbad, UT	Sulphur, UT	Sulphur Herd, UT (South, 2006)	Tilley Creek, UT
Muddy Creek, UT	0.000						
North Hills, UT	0.129	0.000					
Range Creek, UT	0.109	0.082	0.000				
Sinbad, UT	0.122	0.118	0.094	0.000			
Sulphur, UT	0.162	0.086	0.130	0.128	0.000		
Sulphur Herd, UT (South, 2006)	0.114	0.070	0.081	0.092	0.103	0.000	
Tilley Creek, UT	0.140	0.095	0.086	0.122	0.128	0.089	0.000
Winter Ridge, UT	0.097	0.076	0.061	0.080	0.097	0.056	0.072
Adobe Town, WY	0.079	0.067	0.061	0.072	0.094	0.055	0.073
Adobe Town, WY (2011)	0.074	0.066	0.046	0.075	0.098	0.056	0.066
Antelope Hills, WY	0.094	0.070	0.057	0.066	0.104	0.064	0.098
Conant Creek, WY (Lander)	0.117	0.117	0.083	0.094	0.113	0.085	0.081
Cooper Creek, WY	0.086	0.049	0.060	0.062	0.043	0.043	0.078
Dishpan Butte, WY (Lander)	0.088	0.082	0.060	0.076	0.115	0.057	0.077
Divide Basin, WY	0.073	0.051	0.037	0.057	0.090	0.045	0.061
Divide Basin, WY (2011)	0.072	0.053	0.036	0.058	0.080	0.054	0.061
Eagles Nest, WY	0.102	0.088	0.069	0.092	0.119	0.071	0.102
Happy Creek Springs, WY	0.105	0.087	0.064	0.077	0.115	0.072	0.103
Little Colorado, WY	0.097	0.057	0.042	0.094	0.106	0.068	0.068

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	Muddy Creek, UT	North Hills, UT	Range Creek, UT	Sinbad, UT	Sulphur, UT	Sulphur Herd, UT (South, 2006)	Tilley Creek, UT
Little Colorado, WY (2011)	0.097	0.053	0.041	0.084	0.104	0.063	0.060
Lost Creek, WY	0.076	0.062	0.045	0.059	0.092	0.043	0.081
Lost Creek, WY (combined)	0.076	0.068	0.047	0.058	0.099	0.041	0.080
McCullough Peaks, WY	0.115	0.080	0.060	0.070	0.111	0.063	0.082
Muskrat Basin, WY (Lander)	0.093	0.087	0.058	0.083	0.112	0.064	0.084
Salt Wells, WY (East)	0.068	0.063	0.046	0.066	0.081	0.057	0.069
Salt Wells, WY (West)	0.082	0.075	0.057	0.064	0.090	0.069	0.069
Stewart Creek, WY	0.098	0.079	0.049	0.065	0.101	0.045	0.094
Stewart Creek, WY (2009)	0.092	0.075	0.060	0.068	0.112	0.057	0.087
White Mountain, WY (2011)	0.086	0.090	0.064	0.067	0.104	0.073	0.063

	Winter Ridge, UT	Adobe Town, WY	Adobe Town, WY (2011)	Antelope Hills, WY	Conant Creek, WY (Lander)	Cooper Creek, WY	Dishpan Butte, WY (Lander)
Winter Ridge, UT	0.000						
Adobe Town, WY	0.034	0.000					
Adobe Town, WY (2011)	0.028	0.013	0.000				
Antelope Hills, WY	0.061	0.046	0.044	0.000			
Conant Creek, WY (Lander)	0.071	0.066	0.063	0.080	0.000		
Cooper Creek, WY	0.041	0.033	0.036	0.040	0.056	0.000	
Dishpan Butte, WY (Lander)	0.054	0.036	0.047	0.062	0.047	0.042	0.000
Divide Basin, WY	0.032	0.027	0.024	0.028	0.060	0.027	0.034
Divide Basin, WY (2011)	0.036	0.027	0.026	0.033	0.056	0.030	0.036
Eagles Nest, WY	0.065	0.053	0.054	0.050	0.090	0.058	0.054
Happy Creek Springs, WY	0.053	0.051	0.056	0.053	0.079	0.048	0.055
Little Colorado, WY	0.044	0.041	0.038	0.054	0.072	0.045	0.039
Little Colorado, WY (2011)	0.038	0.039	0.035	0.048	0.070	0.040	0.039
Lost Creek, WY	0.033	0.031	0.028	0.033	0.063	0.032	0.040
Lost Creek, WY (combined)	0.036	0.033	0.030	0.038	0.062	0.031	0.035
McCullough Peaks, WY	0.056	0.052	0.051	0.049	0.061	0.044	0.046

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	Winter Ridge, UT	Adobe Town, WY	Adobe Town, WY (2011)	Antelope Hills, WY	Conant Creek, WY (Lander)	Cooper Creek, WY	Dishpan Butte, WY (Lander)
Muskrat Basin, WY (Lander)	0.057	0.041	0.051	0.070	0.056	0.045	0.014
Salt Wells, WY (East)	0.031	0.018	0.013	0.042	0.057	0.032	0.045
Salt Wells, WY (West)	0.044	0.032	0.033	0.047	0.053	0.031	0.046
Stewart Creek, WY	0.053	0.047	0.046	0.039	0.070	0.040	0.047
Stewart Creek, WY (2009)	0.040	0.039	0.039	0.051	0.077	0.039	0.048
White Mountain, WY (2011)	0.035	0.044	0.037	0.053	0.065	0.044	0.055

	Divide Basin, WY	Divide Basin, WY (2011)	Eagles Nest, WY	Happy Creek Springs, WY	Little Colorado, WY	Little Colorado, WY (2011)	Lost Creek, WY
Divide Basin, WY	0.000						
Divide Basin, WY (2011)	0.007	0.000					
Eagles Nest, WY	0.039	0.045	0.000				
Happy Creek Springs, WY	0.040	0.044	0.053	0.000			
Little Colorado, WY	0.030	0.030	0.045	0.050	0.000		
Little Colorado, WY (2011)	0.024	0.029	0.044	0.046	0.005	0.000	
Lost Creek, WY	0.019	0.024	0.026	0.033	0.034	0.029	0.000
Lost Creek, WY (combined)	0.019	0.025	0.024	0.033	0.033	0.029	0.006
McCullough Peaks, WY	0.037	0.041	0.061	0.048	0.043	0.036	0.039
Muskrat Basin, WY (Lander)	0.038	0.037	0.049	0.062	0.039	0.040	0.038
Salt Wells, WY (East)	0.023	0.023	0.051	0.048	0.035	0.032	0.022
Salt Wells, WY (West)	0.028	0.027	0.057	0.053	0.038	0.039	0.038
Stewart Creek, WY	0.030	0.034	0.029	0.041	0.042	0.036	0.014
Stewart Creek, WY (2009)	0.024	0.033	0.041	0.033	0.042	0.039	0.022
White Mountain, WY (2011)	0.033	0.037	0.068	0.060	0.051	0.040	0.040

	Lost Creek, WY (Combined)	McCullough Peaks, WY	Muskrat Basin, WY (Lander)	Salt Wells, WY (East)	Salt Wells, WY (West)	Stewart Creek, WY	Stewart Creek, WY (2009)	White Mountain, WY (2011)
Lost Creek, WY (combined)	0.000							
McCullough Peaks, WY	0.040	0.000						

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	Lost Creek, WY (Combined)	McCullough Peaks, WY	Muskrat Basin, WY (Lander)	Salt Wells, WY (East)	Salt Wells, WY (West)	Stewart Creek, WY	Stewart Creek, WY (2009)	White Mountain, WY (2011)
Muskrat Basin, WY (Lander)	0.037	0.057	0.000					
Salt Wells, WY (East)	0.028	0.045	0.047	0.000				
Salt Wells, WY (West)	0.037	0.041	0.045	0.035	0.000			
Stewart Creek, WY	0.017	0.040	0.040	0.039	0.050	0.000		
Stewart Creek, WY (2009)	0.018	0.046	0.053	0.039	0.041	0.032	0.000	
White Mountain, WY (2011)	0.041	0.046	0.063	0.037	0.039	0.054	0.045	0.000

SOURCE: Data provided by E. Gus Cothran. To access the data, contact the National Research Council's Public Access Records Office at paro@nas.edu.

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6

Wild and Feral Equid Population Dynamics

JASON I. RANSOM, LAURA LAGOS, HALSZKA HRABAR, HANIYEH NOWZARI, DORJ USUKHJARGAL, AND NATALIA SPASSKAYA

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Wild equid populations are shaped by births, deaths, emigration, and immigration, each of which is subject to a suite of biological and ecological inputs across space and time. How these inputs influence population dynamics varies between populations as well as among species. In our rapidly changing world, human actions also increasingly affect wildlife populations (Sanderson *et al.* 2002). Fragmented landscapes, hunting of predators, reintroduction of species, invasive species, competition with humans and their livestock for resources, direct killing, and climate change all can influence population dynamics (see chap. 12). Most wild equids occupy arid or semiarid steppe, grassland, and desert environments, but some feral populations also thrive in forests, montane, and coastal environments, and across hot and cold, xeric and mesic, conditions. The array of factors potentially influencing these populations is great, but some fundamental elements influencing birth, survival, and movement are common to all.

Food can be one of the most important natural factors limiting populations of large herbivores (Fowler 1987; Gaillard *et al.* 1998, 2000; Gaidet and Gaillard 2008). As such, some populations may exhibit density dependence and be limited because of their own impact on forage resources, or because population density itself influences age-specific natality, behavior, or survival (Choquenot 1991; Gaillard *et al.* 1998, 2000; Flux 2001; Linklater *et al.* 2004; Bonenfant *et al.* 2009). When such populations lack resources, body condition of individuals can diminish and disease and parasitism can increase, all with the cumulative effect of reducing fecundity and survival, and ultimately limiting population growth (Eberhardt 1977). Some populations may persist without exhibiting density dependence, changing through time without realized self-imposed resource limitation. Those populations may still be limited by predation or climate events (Ellis and Swift 1988; Georgiadis *et al.* 2003). Over time, any given population may move between exhibiting density dependence and apparent density independence as the influencing factors change. Regardless of the specific paradigm, both deterministic and stochastic mechanisms play important roles in shaping populations (Björnstad and Grenfell 2001).

Attempting to draw broad inferences across equid population states, processes, and inputs is a challenging task, but the wild and feral members of family Equidae are perhaps more similar than not in their equation of life on earth. Some species, notably African wild ass (*Equus africanus*) and kiang (*E. kiang*), are vastly understudied, and considerable gaps persist in our knowledge of even their basic ecology. Other species, such as the feral horse (*E. caballus*), provide rich data sets that can inform us with in-depth ecological perspectives. In this chapter, we have synthesized data from studies on equids across the globe toward understanding the common and diverging natural influences acting to shape their populations. The populations in these studies ranged on 6 continents across >91 degrees of latitude, from savannah to mountains and deserts to islands, and thus were influenced by a diversity of biotic and abiotic factors. We focus here on natality, survival, and population growth. We briefly discuss movement into and out of populations, but largely defer that topic to chapter 13. The influence of humans on these populations is a broad topic that can profoundly affect survival, and we must defer that topic to chapter 12.

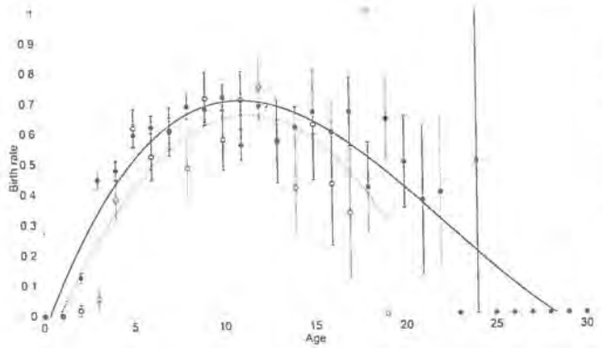


Fig. 6.1 Mean age-specific birth rates of horses ± standard error, as derived from *E. caballus* (feral) in the western United States (solid dots and solid trend line, n = 1,013 births, excluding females that received fertility control treatments) (Ransom *et al.* 2011; J. Ransom, unpublished data), and *E. f. przewalskii* (open dots and dashed trend line, n = 217 births, excluding females in the year of their introduction) (Great Gobi B Strictly Protected Area, Mongolia, unpublished data).

Natality

All species of wild equid appear to follow the same general distribution of age-specific natality that is observed in horses, with primiparous births most typically occurring from females age 2–5 years, and peak birth rates occurring roughly for females age 6–17 (fig. 6.1). There is some evidence that when forage is abundant, female equids are more likely to give birth at an earlier age (Berger 1986; Saltz and Rubenstein 1995; Tatin *et al.* 2009). When forage and water becomes exhausted, age of primiparous birth can increase and birth rates for all females can decline quickly (Ginsberg 1989). The majority of feral asses (*E. asinus*) in Death Valley, USA, for example, were observed giving primiparous birth at age ≥4 years while persisting in an extremely harsh environment (Moehlman 1974). (Note that sexual maturity is reached at 1.5 years; Grinder *et al.* 2006.) In the wild, female plains zebra (*E. quagga*) have been documented giving birth as old as age 18 (Klingel 1969), mountain zebra (*E. zebra*) at age >21 (Joubert 1974*a*), Przewalski's horses (*E. ferus przewalskii*) at age 20 (O. Ganbaatar, unpublished data), and feral horses as old as age 24 (fig. 6.1).

Horses and zebras typically give birth to one offspring annually, though extraordinarily rare cases of twins have been reported (Roelle *et al.* 2010; Vodička 2010). Feral asses have been observed giving birth to either one or two offspring (Grinder *et al.* 2006), as have Asiatic wild asses (*E. hemionus*) (Schook *et al.* 2013). The cases of twins born to Asiatic wild asses all resulted in early mortality of at least one sibling, and it is unknown how frequently twin births occur in the wild. Wild females of all asses are most typically observed with only one offspring of the year. The mean birth rate for equid females ≥2 years old across all species and studies we reviewed ranged from 0.20 in mountain zebras to 0.68 in feral asses, with a mean across species of 0.47 (95% confidence interval, or CI = 0.35–0.59) (table 6.1). Note that the lowest value from individual studies in this range arose from Przewalski's horses in the Gobi Desert following a catastrophic winter climate event (birth rate = 0.04) (Kaczensky *et al.* 2011), and the maximum value occurred in a small Asiatic wild ass (onager) population that started to increase rapidly six years after reintroduction (birth rate = 1.00) (Saltz and Rubenstein 1995). Despite these extremes, however, birth rates among wild equid species are remarkably similar when put in context of the pressures selecting for fitness.

Birth rates in wild populations reflect offspring born and observed, rather than pregnancy rate, which is presumably higher in most cases. Pregnancy rates



Table 6.1. Mean birth, survival, and population growth rates of wild and feral equids

Species	Populations	Mean Adult Birth Rate	Mean Foal Survival Rate	Mean Adult Survival Rate	Mean Population Growth Rate (λ)
E. caballus (feral)[1]	Tornquist Park, Argentina; Garden Station, Australia; Alberta, Canada; Sable Island, Canada; La Camargue, France; Namib Desert, Namibia; Kaimanawa Ranges, New Zealand; Peneda-Gerês, Portugal; Vodnyi Island, Russia; Galicia, Spain; Exmoor, UK; New Forest, UK; Snowdonia National Park, UK; Assateague Island, USA; Garfield Flat, USA; Granite Range, USA; Great Basin, USA; Jicarilla Wild Horse Territory, USA; Little Book Cliffs, USA; McCullough Peaks, USA; Montgomery Pass, USA; Pine Nut and Pah Rah, USA; Pryor Mountain, USA; Red Desert, USA; Salmon, USA; multiple locations across western USA	0.56 ± 0.001 (0.23–0.92)	0.84 ± 0.002 (0.09–0.97)	0.90 ± 0.001 (0.79–0.98)	1.18 ± 0.001 (0.84–1.39)
E. f. przewalskii[2]	Xinjiang, China; Le Villaret, France; Great Gobi B, Mongolia; Hustai National Park, Mongolia	0.36 ± 0.011 (0.27–0.75)	0.61 ± 0.003 (0.59–0.83)	0.86 ± 0.003 (0.83–0.98)	1.13 ± 0.001 (1.12–1.18)
E. asinus (feral)[3]	Dorisvale, Australia; Victoria River, Australia; Bandelier National Monument, USA; Death Valley, USA; Grand Canyon, USA; Mojave Desert, USA	0.68 ± 0.003 (0.41–0.89)	—	—	1.19 (—)
E. africanus[4]	Denkelia Desert, Eritrea	0.30 ± 0.066 (0.00–0.71)	—	—	—
E. hemionus[5]	Qatrouyeh National Park, Iran, Makhtesh Ramon, Israel; Great Gobi B, Mongolia; Badghyz Nature Reserve, Turkmenistan	0.48 ± 0.004 (0.15–0.76)	0.57 ± 0.001 (0.40–0.64)	0.86 (0.85–0.86)	1.04 ± 0.001 (0.95–1.15)
E. kiang[6]	Tibetan Plateau	0.50 (—)	—	—	—
E. zebra[7]	Ai-Ais / Fish River Canyon National Park, Namibia; BüllsPort Guest Farm, Namibia; Gondwana Cañon Park, Namibia; NamibRand Nature Reserve, Namibia; Camdeboo National Park, South Africa; De Hoop Nature Reserve, South Africa; Karoo National Park, South Africa; Mountain Zebra National Park, South Africa	0.20 ± 0.002 (0.16–0.45)	0.98 ± 0.001 (0.87–0.98)	0.92 ± 0.001 (0.91–0.93)	1.13 ± 0.002 (0.85–1.23)
E. grevyi[8]	Barsalinga, Kenya; Dvur Kralove Zoological Garden (translocated from Kenya); Laikipia, Kenya; Lewa, Kenya; Ngare Ndare, Kenya; Samburu Buffalo Springs Game Reserve, Kenya	0.64 (—)	0.57 ± 0.084 (0.27–0.90)	0.85 ± 0.002 (0.77–0.88)	1.02 —

Table 6.1. continued

Species	Populations	Mean Adult Birth Rate	Mean Foal Survival Rate	Mean Adult Survival Rate	Mean Population Growth Rate (λ)
E. quagga[9]	Laikipia, Kenya; Athi-Kapiti Plains, Kenya; Serengeti, Tanzania; Ngorongoro, Tanzania; Hwange National Park, Zimbabwe; iMfolozi-Hluhluwe, South Africa; multiple private reserves, South Africa; Kruger National Park, South Africa; Boland Lanbou, South Africa; Elandsberg Private Reserve, South Africa	0.48 ± 0.056 (0.23–0.75)	0.67 ± 0.120 (0.13–0.96)	0.84 ± 0.025 (0.79–0.88)	0.98 ± 0.028 (0.92–1.01)

Sources:

[1]Pellegrini 1971, Tyler 1972, Feist and McCullough 1975, Nelson 1978, Perkins *et al.* 1979, Boyd 1980, Wolfe 1980, Eberhardt *et al.* 1982, Salter and Hudson 1982, Seal and Plotka 1983, Keiper and Houpt 1984, Berger 1986 Sniff *et al.* 1986, Wolfe *et al.* 1989, Garrott and Taylor 1990, Berman 1991, Turner *et al.* 1992, Baker 1993, Monard *et al.* 1997, Gregor and Romney 1999, Ashley 2000, Gomes and Oom 2000, Goodloe *et al.* 2000, Ashley and Holcombe 2001, Turner and Morrison 2001, Linklater *et al.* 2004, Greyling 2005, Grange *et al.* 2009, Scorolli and Lopez Cazorla 2010, Contasti *et al.* 2012, Dawson and Hone 2012, Ransom 2012, Spasskaya *et al.* 2012, Stanley and Shultz 2012, Lagos 2013.

[2]Chen *et al.* 2008, Tatin *et al.* 2009, Kaczensky *et al.* 2011, Usukhjargal and Bandi 2013.

[3]Moehlman 1974, Norment and Douglas 1977, Mogart 1978, White 1980, Ruffner and Carothers 1982, Johnson *et al.* 1987, Perryman and Muchlinski 1987, Choquenot 1990, 1991.

[4]P. Moehlman, unpublished data.

[5]Solomatin 1973, 1977, Wolfe 1979, Zhirnov and Ilyinsky 1986, Saltz and Rubenstein 1995, Feh *et al.* 2001, Ziaee 2008, Nowzari 2011, Hemami and Momeni 2013, Lkhagvasuren *et al.* in review.

[6]Schaller 1998.

[7]Joubert 1971, Penzhorn 1985, Lloyd and Rasa 1989, Novelle *et al.* 1992, 1996, Smith *et al.* 2007, Gosling 2013, Eastern Cape Parks, unpublished data, H. Hrabar, unpublished data, South African National Parks, unpublished data.

[8]Dobroruka *et al.* 1987, Rubenstein 1989, 2010, Rowen 1992, Williams 1998.

[9]Klingel 1965, 1969, Petersen and Casebeer 1972, Spinage 1972, Smuts 1976*a*,*b*, Ohsawa 1982, Rubenstein 1989, Hack *et al.* 2002, Georgiadis *et al.* 2003, Grange *et al.* 2004, Barnier *et al.* 2012, Grange *et al.* 2012, 2015, H. Hrabar and G. Kerley, unpublished data.

Note: Table includes some semiwild populations in managed reserves. Mean rates from each source study were weighted by sample size (number of individuals sampled) and length of study (years) to generate the mean values shown for each species ± standard error. The range of individual study means is given in parentheses after the point estimate. Birth rate is total number of foals divided by all females at least 2 years of age, and survival rate for adults represents individuals ≥2 years of age. Foal survival represents individuals surviving from birth to age 1.

have not been rigorously measured across equid species in the wild, but the feral horses of Kaimanawa, New Zealand, exhibited pregnancy rates of 0.79–0.94, with an average birth rate observed at only 0.49 (Linklater *et al.* 2004). Similarly, feral horses in Idaho, USA, exhibited an average pregnancy rate (across all ages) of 0.68, with only 8% of 1- to 3-year-olds becoming pregnant, increasing to 93% of 10- to 12-year-olds becoming pregnant (Seal and Plotka 1983). Plains zebra pregnancy rates in the Serengeti were reported ranging from 0.69 in 3- to 5-year-olds to 0.88 in 13- to 16-year-olds (Grange *et al.* 2004), but birth rates in similar systems of east Africa were reported as only 0.26–0.51 (Klingel 1969; Georgiadis *et al.* 2003). It is possible that in many studies the reported birth rates may be negatively biased because offspring aborted, stillborn, or depredated immediately after birth were undetected by observers. Abortion is extraordinarily unlikely after three months of gestation in horses, which implies that the environmental conditions early in pregnancy are perhaps most influential in the successful birth of a foal (Roberts 1986).

Interbirth interval (the time between subsequent offspring) among equids can vary depending on individual-level reproductive history and resource availability. Primiparous feral horses, for example, were less likely to foal in the year following their first foal, whereas multiparous females were more likely to foal if they had foaled the previous year (Roelle *et al.* 2010). The interbirth interval among plains zebra, on the other hand, appeared to be longer if the first foal was male (Barnier *et al.* 2012). Feral horses also demonstrated a protracted interbirth interval after producing a male foal under stressed resource conditions (Monard *et al.* 1997).

Both strong physiological and environmental inputs influence the rate and phenology of conception

and subsequent year births in most wild equid populations. Hormones associated with reproduction (such as estradiol, progesterone, and testosterone) fluctuate cyclically through time in both males and females (Kirkpatrick *et al.* 1977; Nuñez *et al.* 2011; Schook *et al.* 2013), reaching an annual apex of reproductive potential when enough sunlight and warm temperatures have stimulated the hormonal cascade (Ransom *et al.* 2013). This mechanism can help regulate birth cycles, and ultimately produces birth pulses that are often synchronized with forage availability. Estrus, birth rates, and birth phenology have been correlated with rainfall in some populations of zebras (Klingel 1969; Joubert 1974*b*; Williams 1998; Sinclair *et al.* 2000; Rubenstein 2010), feral horses (Siniff *et al.* 1986; Berman 1991; Scorolli and Lopez Cazorla 2010; Ransom *et al.* 2013), and Asiatic wild asses (Saltz *et al.* 2006). This synchrony with forage resources may increase female and neonate survival, especially because nutritional requirements of lactating females are elevated and higher-quality forage can result in increased body condition and nutritional support for neonates (Ginsberg 1989; National Research Council 2007). In a study of three temperate populations of feral horses where birth phenology was perturbed, estimated survival of foals decreased 1.4% for every 10 days after peak forage that parturition occurred (Ransom *et al.* 2013).

Environmental pressures can contribute greatly to birth phenology, and in some cases can truncate the birth season to a short, synchronized pulse. Predation, for example, has been posited to influence the timing of births under the premise that neonates are most vulnerable in their first hours or days of life, and as such predators can only harvest a finite number of young in a short period of time; consequently, if all young are born together, more should survive (Darling 1938; Sinclair *et al.* 2000). Parturition season for Asiatic wild asses in the Mongolian Gobi (where wolves prey on them), for example, typically begins mid-June and concludes around mid-July (P. Kaczensky, personal communication), and similarly the same species in Badghyz State Reserve, Turkmenistan (13° latitude farther south), was reported to foal primarily between 14 April and 14 May, but some foals were recorded as early as late as 28 July (Wolfe 1979). In contrast, a Sri Lanka feral ass population located almost on the equator and with no predators present exhibited no birth seasonality, and offspring were born uniformly across every month of the year (Santiapillai *et al.* 1999). Predation pressure may not be the primary driver of length of birthing season, however; length of gestation, birth interval, and duration of resource availability can all be important factors (Williams 1998). Wildebeest (*Connochaetes taurinus*) sympatric with Grevy's zebra (*E. grevyi*) in Kenya, for example, exhibited a birth season constrained to only two weeks, whereas the Grevy's zebra present in the same environmental conditions gave birth over the course of months (Williams 1998). In that system, rainfall was highly stochastic, and thus seasonal forage availability did not exhibit a pronounced peak.

Gestation period is similar among equid species, though environmental inputs can create plasticity (Howell and Rollins 1951). Average gestation length ranges from 327 to 357 days in horses (Howell and Rollins 1951; Card and Hillman 1993; Monfort *et al.* 1994), 321 to 404 days in asses (Grinder *et al.* 2006; Pagan *et al.* 2009; Schook *et al.* 2013), and 364 to 390 days in zebras (Grubb 1981; Penzhorn 1988; Churcher 1993). Gestation period in kiang is the least quantified, with reports ranging from 210 to 365 days (St-Louis and Côté 2009). Given the nearly yearlong gestation across all equid species, we could expect estrus, reproductive behavior, and conception to peak between the spring equinox and the summer solstice, waning thereafter with subsequent parturition occurring roughly at the same time the following year. Where such empirical data were present in the literature, this pattern was evident across equid species, though it is more variable in populations near the equator (fig. 6.2).

While body condition, resource availability, and biological inputs all contribute to conception and birth success, these factors may also influence sex ratio of young born into the population. Female feral horses in poor body condition at the time of conception have been observed producing more female foals (Cameron *et al.* 1999), for example, aligning with the much-debated Trivers-Willard hypothesis, which posits that when populations are experiencing more stress (and thus individuals have decreased body condition), more female offspring will be produced because they can increase fitness more quickly than inputs of male offspring (Trivers and Willard 1973). Sex ratio of foals across all equid species and populations we reviewed is of course quite variable, precisely because of these environmental inputs, but on average we found that the ratio of males to females born did not differ from parity (1.1 males to 1 female; 95% CI = 0.93–1.29:1). The extreme situations were 2.2 males to 1 female in a population of mountain zebra (n = 16 foals; H. Hrabar, unpublished data), and 2.2 males to 1 female in an Asiatic wild ass population that was experiencing a high growth rate (n = 53 foals; Saltz and Rubenstein 1995). In the latter case, it is interesting that while more males were being produced in a density-independent environment

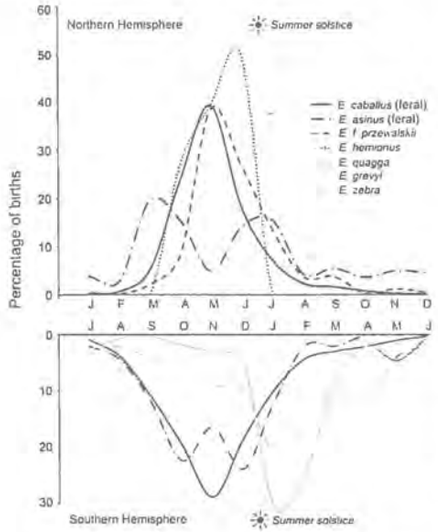


Fig 6.2 Percentage of births by month across equid species. Data are smoothed and shown as the mean across populations. Data for *E. caballus* derived from Tyler 1972, Boyd 1980, Keiper and Houpt 1984, Berger 1986, Berman 1991, Lucas *et al.* 1991, Ashley 2000, Gomes and Oom 2000, Linklater *et al.* 2004, Greyling 2005, Nuñez *et al.* 2010, Scorolli and Lopez Cazorla 2010, Lagos 2013, Ransom *et al.* 2013, and N. Spasskaya, unpublished data; data for *E. asinus* derived from Moehlman 1974, McCool *et al.* 1981, Ruffner and Carothers 1982, and Santiapillai *et al.* 1999; data for *E. f. przewalskii* derived from Chen *et al.* 2008, Prague Zoo 2010 (wild and semiwild populations only), and Usukhjargal and Bandi 2013; data for *E. hemionus* derived from Wolfe 1979 and O. Ganbaatar, unpublished data; data for *E. quagga* derived from Klingel 1965, Smuts 1976*b*, and Sinclair *et al.* 2000, data for *E. grevyi* derived from Dobroruka *et al.* 1987 and Rowen 1992, data for *E. zebra* derived from Joubert 1974*b*, Penzhorn 1985, Westlin-van Aarde *et al.* 1988, and H. Hrabar, unpublished data.

(in concurrence with Cameron and Linklater 2007), the investigators noted that more female foals were being produced by primiparous mothers of age 2 or 3 years as compared to multiparous mothers of age 4 or 5 years. This may reflect an evolutionary disparity in effective maternal investment, but that hypothesis was not specifically tested. The opposite extreme was observed in a resource-stressed population of plains zebra where the sex ratio was 0.27 males to 1 female (n = 19 foals; Hrabar and Kerley 2013) and a feral horse population where the sex ratio of 0.47 males to 1 female was observed (n = 25 foals; Stanley and Shultz 2012).

Survival

Most feral horses, feral asses, and some Przewalski's horses and mountain zebra live in environments without significant predation pressure and exhibit relatively high survival rates across all age classes. Most other wild equid populations are subject to predation from a variety of large predators, and thus experience locally reduced survival rates. Despite this dichotomy of population paradigms, age-specific survival is surprisingly comparable among equid species, with some elevated mortality in foals, relative security in the adult cohort, and then a gradual decrease as senescence prevails (fig. 6.3). The resulting age structure of wild populations is also relatively consistent among species and populations, with foals typically comprising 8–15% of a population, juveniles 13–28% of a population, and adults 71–78% of a population (Berman 1991; Tatin *et al.* 2003; Grange *et al.* 2004; Smith *et al.* 2007). Equids are long-lived animals, and where individuals were followed from birth, known ages for individual wild Przewalski's horses exceeded 25 years old (Prague Zoo 2010) and for feral horses exceeded 29 years old (Ransom 2012). Equids generally live longer in captivity owing to more controlled environmental conditions and applied veterinary care; as such, captive Asiatic wild asses >27 years old have been reported (Volf 2010), as have Przewalski's horses >30 years old (Ballou 1994). Mortalities in wild equid populations arise from a variety of causes. Deaths of adult Przewalski's horses (n = 145) at Hustai National Park, Mongolia, for example, were attributed to blood parasites (2.1%), endoparasites (1.4%), disease (7.6%), stillbirth (9.7%), injury (12.4%), predation (22.1%), starvation (31.1%), and other/unknown reasons (13.8%) (Usukhjargal and Bandi 2013). Nine percent of foal deaths (25 of 278 foals) in the same study were attributed to infanticide by stallions (box 6.1).

Annual foal survival rates reported across the studies we reviewed averaged 0.71 (95% CI = 0.53–0.88), and adult survival rates averaged 0.88 (95% CI = 0.85–0.90) (table 6.1). Much of the variation in annual survival rates of both foals and adults by population may be attributed to localized predation. A large number of predators have been documented killing both young and adult equids, including African lion (*Panthera leo*), leopard (*P. pardus*), cheetah (*Acinonyx jubatus*), and spotted hyena (*Crocuta crocuta*) for feral horses, zebras, and asses in Africa; wolf (*Canis lupus*) and snow leopard (*Uncia uncia*) for Asiatic asses, Przewalski's horses, and kiang in the Middle East and Asia; wolf and brown bear (*Ursus arctos*) for feral horses in Europe; and puma

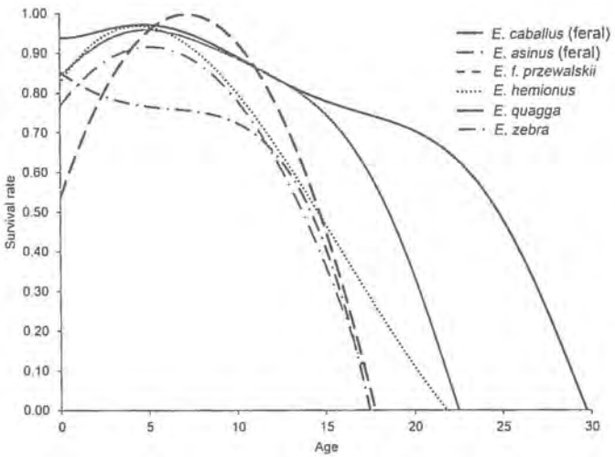


Fig. 6.3 Trend in age-specific survival rates for equid species. Data for *E. caballus* derived from Ransom 2012; data for *E. asinus* derived from McCool *et al.* 1981; data for *E. f. przewalskii* derived from Hustai National Park, unpublished data; data for *E. hemionus* derived from Saltz and Rubenstein 1995 and Lkhagvasuren *et al.* in review; data for *E. quagga* derived from Spinage 1972; data for *E. zebra* derived from Joubert 1974*a*

(*Puma concolor*) and jaguar (*P. onca*) for feral horses and feral asses in the Americas. In one feral horse population in the western United States, foal survival was reported to be only 27%, and 82% of foal carcasses found showed evidence of being killed by puma (Turner *et al.* 1992); however, most feral horse populations coexist with pumas and experience limited depredation. In the Gobi Desert of Mongolia, 23% of wolf scats analyzed contained remains of Asiatic ass (Feh *et al.* 2001), but it is unknown how many of those samples arose from predation as opposed to scavenging.

Analysis of predator diets has provided some evidence of selection for equids, with a wide range of selection to nonselection across species and seasons. Wolves in northwest Spain clearly selected for feral horses (Ivlev index = 0.99–1.00) (Lagos 2013), but a similarly pack-organized canine, African wild dog (*Lycaon pictus*), specifically avoided hunting zebra even when they were relatively abundant (Hayward *et al.* 2006). In Lewa, Kenya, African lions strongly selected Grevy's zebra over plains zebra, even though plains zebra outnumbered Grevy's zebra four to one (Rubenstein 2010). In the Serengeti, Tanzania, 90% of all spotted hyena kills were adult zebra when the available ungulate assemblage was quite diverse (Kruuk 1972). In systems where feral horses and predators most typically coexist, a high percentage of all mortality is attributed to a sole predator as opposed to disease, accident, or other natural causes. Wolves in Peneda-Gerês National Park, Portugal, for example, have been responsible for 89% of horse mortalities, and in nearby Galicia, Spain, that figure rises to 96% (Gomes and Oom 2000; Lagos 2013). In systems with multiple predators or sympatric prey species, the percentage of equid mortality attributed to depredation can be somewhat ameliorated, such as plains zebras in the Serengeti, Tanzania, where 59–74% of all mortality was attributed to African lion and spotted hyena (Schaller 1972), or Przewalski's horses in Hustai National Park, where 13–50% of horse mortalities were attributed to wolves (Van Duyne *et al.* 2009).

At a finer scale, predator species may also select for one sex of prey over the other; thus they may affect prey populations differently at long timescales. Spotted hyenas at Ngorongoro, Tanzania, killed 2.25 female plains zebra for every one male, but lions at Serengeti, Tanzania, killed only 0.83 female plains zebra for every one male (Kruuk 1972). Longitudinal studies indicate that shifts in diet can also occur over time, as in the Serengeti, Tanzania, where 19–20% of spotted hyena diet was composed of plains zebra before the 1970s, but after that time it diminished to <9% (Kruuk 1972). The zebra population remained relatively stable over that time period (Hack *et al.* 2002), but changes in other prey populations or competing predator populations could have contributed to the apparent dietary shift.

Some behavioral traits may also influence survival. Group formation in ungulates has been posited to be a function of open environments where foraging can be optimized because groups of animals are more vigilant for predators than isolated individuals can be (Kie 1999). Equids form groups of various sizes and composition, which may influence predation risk (see chap. 2). Schaller (1972) reported that lions were 13% more successful when plains zebras were alone rather than

BOX 6.1 INFANTICIDE AMONG EQUIDS

Infanticide is not common in equids but has been reported in both captive and wild populations. This unique source of mortality arises when a stallion intentionally kills a foal, an action hypothesized to be a fitness-driven evolutionary behavior (Hrdy 1979). The concept posits that if a novel stallion kills an unrelated foal, then the foal's mother may more quickly return to estrus and be fertilized by the assailant male, thus increasing his fitness faster through reduction of interbirth interval. This concept has been discussed most broadly in the classic case of the African lion (Packer and Pusy 1982), but it has drawn the attention of equine ethologists because of their polyandrous mating systems.

Infanticide among the equids appears to be most prevalent in the harem-forming species and has been reported most frequently in captive conditions where artificial social constructs may elevate frequency (Pluháček *et al.* 2006). In the wild, infanticide has been documented at the highest rates in Przewalski's horses, where 9% (25 of 278 foals born 1993–2011) of all foal mortality in Hustai National Park, Mongolia, was attributed to this phenomenon (Usukhjargal and Bandi 2013). It was also reported in the same species at Kalamaili Ungulate Protected Area, China, where 83.3% of all foal mortalities (7 mortalities out of 24 births) was attributed to infanticide in the 5-year period following reintroduction (Chen *et al.* 2008). Nearly half of those deaths occurred in the first year, lending support to the proximate social stresses presented when novel stallions suddenly become available to social groups.

Infanticide was reported in domestic horses (Duncan 1982) and New Forest ponies (Tyler 1972), and attempted infanticide among feral horses has been documented across populations (Tyler 1972; Berger 1986; Gray 2009). When more than one adult male has been present in a band of feral horses, extraordinary maternal protection has also been reported, potentially minimizing the incidents of infanticide (Cameron *et al.* 2003). While the sample size is limited, there is some evidence that intruding stallions may selectively target male foals (all cases reported by Duncan 1982, with additional cases reported by Berger 1986), which could reflect the potential for reducing future competition from unrelated males, but that hypothesis has never been explicitly tested. Induced abortion has also been documented when novel stallions forcibly copulate with a pregnant female. At the Granite Range, USA, such feticide was reported for 78% of forced copulations by novel feral horse males (Berger 1986).

Harem-forming zebra have also demonstrated infanticide, with three cases being reported in wild mountain zebra (Penzhorn 1975), and multiple cases reported in captive plains zebra (of which several individuals originated from wild populations) (Pluháček *et al.* 2006). In a captive mountain zebra enclosure in Namibia, Joubert (1971) reported an attempted infanticide that failed when the female actively defended her foal, but the stallion then proceeded to kill two sympatric antelope instead. This event illustrates the uncertainties underlying our understanding of mechanisms and motivations related to infanticide (Pluháček *et al.* 2006). It is possible that some cases of infanticide are motivated by a more immediate need: survival. At Hluhluwe Reserve, South Africa, a severely injured plains zebra foal was observed in the center of a band vocalizing continuously and loudly after escaping from a predator attack. All adult members of the band were expressing elevated vigilance behaviors and nervousness, and the band stallion eventually approached and killed the foal with strikes to the head. While the genetic relationship of the stallion and foal was unknown, the silencing of the foal instantly reduced the exposure of the band to local predators (J. Ransom, unpublished data). Infanticide has not been reported for Grevy's zebra, but the territorial organization of this species can result in females not remaining with specific males long enough for the males to benefit from such behavior.



Photo by J. Ransom

in a group. Unlike most equids, where foals closely accompany their dams most or all of the time, Grevy's zebra sometimes leave their foals in aggregated juvenile groups or "kindergartens" (Williams 1998). The source of this behavior may arise from energetic constraints of young, but ultimately it may also place foals at risk of depredation, especially during nocturnal aggregations (Klingel 1974).

Because most equids inhabit arid environments, considerable interannual variance in precipitation and related productivity may also influence survival (Archer *et al.* 1999). One model simulation of zebra populations suggested that survival decreases more rapidly during dry seasons than reproduction increases during wet seasons, which would constrain population growth over time (Georgiadis *et al.* 2003). In contrast, neither wet season nor dry season rainfall at Kruger National Park, South Africa, influenced plains zebra survival in a longitudinal empirical study, though it did affect other ungulates in the system (Owen-Smith *et al.* 2005). Across ungulate species, it appears that interannual variance in precipitation influences juvenile survival more profoundly than it does adult survival (Gaillard *et al.* 1998, 2000). In feral horses, each centimeter of spring rainfall increased foal survival by 1.5%, did not measurably influence survival for animals up to age 19, and then significantly increased survival rates for animals ≥20 years old (Ransom 2012).

Population Growth

Quantifying population dynamics is generally not as simple as adding births and subtracting deaths. Understanding population growth and decline is further complicated by movement into and out of populations, and by catastrophic stochastic events that change rates both instantaneously and longitudinally. In addition to that volume of uncertainty, the size of most wild equid populations is not absolutely known or even estimated robustly (Moehlman 2002). We have reviewed studies where some measure of population growth was reported or could be reasonably derived. To discuss this more clearly, we refer to the theta-logistic model because it accommodates the nonlinear density dependence more indicative of equid populations (Gilpin and Ayala 1973):

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)^{\theta}$$

In this model, r is the intrinsic rate of increase, N is the population size, K is the carrying capacity, t is time, and θ is the nonlinear modifying parameter for the ratio of

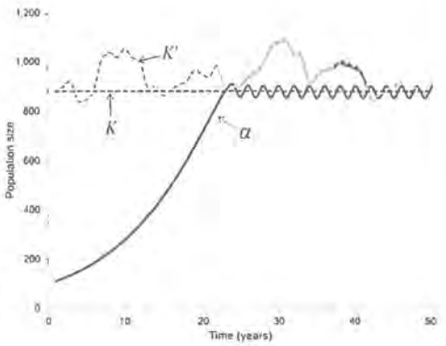


Fig. 6.4 An example of theta-logistic population growth for a simulated equid population over time (black line), where growth rate (r) is fixed and reaches the fixed carrying capacity of K. The same population is simulated with a randomized carrying capacity (K') in gray, illustrating the stochastic effects of resource availability on a single parameter. Point α represents the inflection point where population growth begins to moderate as the population approaches K.

N:K. Conceptually, when $\theta < 1$, r decreases rapidly with population size; likewise, the population will quickly approach K when $\theta > 1$. For equids, this is a steeper curve than the classic logistic sigmoid curve, and the inflection point is much closer to K (fig. 6.4). In this example, a simplified deterministic population trajectory is used to illustrate growth of hypothetical equid population. To add a degree of reality, K is randomized (K') to illustrate how carrying capacity can vary annually with the amount and quality of resources available over time, which in turn can influence the maximum number of individuals that could survive at a given time (fig. 6.4, gray lines). Conceptually, when rapid growth is reported for a population, the theta-logistic model suggests that the population is most likely below α (the inflection point) on the sigmoid curve, and when slow growth is observed, the population might be closer to K at that point in time. Many studies report an instantaneous rate of increase (λ) rather than r. This simply reflects the growth rate of a population from one year to the next as if it had instantly occurred, or $\lambda_t = (N_t / N_{t-1})$ where t represents one year. For synthesis and discussion purposes, we have converted r values from individual studies to λ, using $\lambda = e^r$.

Mean annual population growth (λ) in the studies we reviewed averaged 1.12 (95% CI = 1.04–1.19) across all species (table 6.1). While the reported range of growth rates was similar between species, the average

growth rates for Asiatic wild ass, Grevy's zebra, and plains zebra were notably lower than the other species (1.04, 1.02, and 0.98, respectively). It is unknown whether this finding simply reflects the paucity of data for these species, is an artifact of their different life history strategies, or is indicative of a more complex set of factors. Robust population dynamics metrics for African wild ass and kiang are completely missing from the literature, illustrating critical science needs for better understanding equid ecology.

Some variability in population growth rates over time and between studies and species may be explained by the relationship between abundance and resources. Equids are generally well equipped to persist near K because their longevity and high survival rates, low recruitment rates, and low sensitivity to moderate environmental stressors result in relatively durable populations, barring catastrophic mortality events (Saltz 2002). When mass mortality events occur, equids are quite slow to recover because of their inherently low recruitment rates, but at the longitudinal scale, this is when equids should be most productive. For example, a small, reintroduced Asiatic wild ass (onager) population exhibited its maximum growth rate as abundance expanded to the resources available (Saltz and Rubenstein 1995). In feral horses, heavily managed populations that have persisted near K but then experience a large culling event can be suddenly reduced far below α, prompting a compensatory response in increased growth rate (Choquenot 1990; National Research Council 2013).

Focused predation can impart nonrandom influence on population growth, such as at Pryor Mountain, USA, where predation from specific pumas was increasingly limiting the horse population from 1993 to 2004 to a nadir of $\lambda = 0.97$ before the pumas were killed and the predation pressure was dramatically released (Ransom 2012). In a plains zebra population in South Africa, models of population growth including lion predation were far more supported than models of climate factors, though population growth of only one of the two populations was affected by number of lions present (Grange *et al.* 2012). While food, water, and predation have been widely investigated as agents of population constraint, behavior has also been posited to limit equid populations by reduced fecundity arising from social stress (Linklater 2000; Tatin *et al.* 2009).

Perhaps the most unpredictable natural influence on population growth of equids also carries the greatest magnitude of effect: catastrophic climate events such as extreme drought and storms. Such events can have lasting influence on population dynamics and in some cases can threaten extirpation of populations. The dzud winter (extreme cold with heavy snow) of 2009/2010 in the Mongolian Gobi, for example, suddenly reduced the Przewalski's horse population by 60% in a single season (Kaczensky *et al.* 2011). The population effect from direct mortality was compounded by a severe reduction in per capita births the following year, with only one female foaling. Though not well quantified, the extirpation of Asiatic wild asses from Kazakhstan at the end of the nineteenth century was documented following a similar dzud winter, though hunting by humans and competition with their livestock certainly contributed to the decline (Zhirnov and Ilyinsky 1986). Winter mass mortalities of feral horses in the American West have been documented with a 51% decline in a single winter at Pryor Mountain (Garrott and Taylor 1990) and 12% in a winter at the Granite Range (Berger 1983). The latter study indicated that severe snowstorm mortality might be more common than assumed and also referenced an earlier unpublished event in the Granite Range when 300 horses died (roughly 50% of the population).

Despite the extraordinary capacity of equids to persist in harsh arid environments, drought can still promulgate catastrophe. One severe mass mortality event related to drought was reported for plains zebra at the Tuli Game Reserve in southern Africa in 1983, where 199 carcasses and only 58 live zebra were detected following two years of drought (Walker *et al.* 1987). Hundreds of mountain zebra were reported dead in the Namibian Khomas Hochland during the 1968/1969 drought, with mortalities attributed to starvation, entrapment in mud at waterholes, and behavioral disorientation leading to increased human depredation (Joubert 1971). Large-scale drought-related mortalities are relatively common in the Australian outback, where tens of thousands of feral horses perish during extended drought. Similar events are generally precluded in the United States only by artificial water supplementation.

Severe thunderstorms have also had population-level effects on small equid populations. For example, a thunderstorm overtook Tornquist Provincial Park in Argentina, killing 193 feral horses in 48 hours (28% of the population) (Scorolli *et al.* 2006). Likewise, electrical storms at the high-altitude area of Pryor Mountain have produced fatal lightning strikes to individuals and entire feral horse bands, with an event in 1999 killing 4% of the population with a single lightning strike (US Bureau of Land Management, unpublished data).

Little has been quantified regarding movement of individuals into and out of equid populations in the



context of population growth rate. But one only need consider the migrant case of the plains zebra to understand the ramifications of how migration can quickly influence access to resources and changes in body condition that may influence birth rates, or how such migrations attract predators that might influence survival rates (Naidoo *et al.* 2014). Localized movements of plains zebra in Kruger National Park, South Africa, required travel of 10–15 km every 1–2 days during the dry season for individuals to drink, thus reducing time available for foraging and resting (Cain *et al.* 2012). Feral horses in central Australia also traveled up to 15 km during drought in order to access water, and one population declined 51% in density during a severe drought; it is unknown how many of those animals died as opposed to emigrated from the area (Berman 1991). In a similar xeric environment, feral asses of Death Valley became more prevalent within 1.6 km of a water source in summer (Moehlman 1974). Anthropogenic disturbance at water holes has been implicated in movement of Grevy's zebra, with the energetic costs arising from long-distance movement to and from water being reflected in reduced foal survival (Williams 1998). Whether any of these traveling individuals truly moved from one population to another, affecting population demography, is unknown, but the catalysts for such movement clearly provide an opportunity for immigration and emigration, which ultimately can influence both population dynamics and genetic flow.

Conclusion

The wild and feral equid populations of the world share many common features, and they function similarly for a variety of reasons. Equids can be quite long-lived ungulates and demonstrate relatively low fecundity, meaning that, in the absence of extreme stressors, their populations should be rather stable over time. Unfortunately, this is seldom realized in a changing world where anthropogenic influence permeates nearly all populations (see chap. 12) and climate events can impart severe catastrophes. Recovering from such population decimations requires long timescales for equids. Ultimately, most wild equids persist in a state where extensive conservation measures are needed to prevent extirpation and most feral equids persist at the other end of the curve, where extensive management is necessary to mitigate resource damage.

We aimed in this synthesis to gain a better understanding of equid ecology and what naturally shapes their populations, but such findings are not functionally separate from the effects that humans have on these populations. Direct killing, encroachment, and resource competition remain the largest threats to wild equids and profoundly influence the dynamics of most populations. The scale of human impacts thus confounds attempts to understand the natural influences on these species. What we can conclude, however, is that precipitation and phenological rhythms can strongly influence births, whereas survival is more strongly influenced by predation and mass catastrophe. Equids also exhibit complex social behavior that may drive population dynamics in ways we simply have not quantified or fully understand (see chap. 3). Such uncertainties in both the changing environment and our shortfalls in understanding the depth of equid societies demand forward thinking conservation and careful management for a group of species that nearly all persist on the world's threatened and endangered list.

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Original Research

Mortality and Operational Attributes Relative to Feral Horse and Burro Capture Techniques Based on Publicly Available Data From 2010-2019

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ABSTRACT

Management of excessive feral horse (*Equus ferus caballus*) and burro (*Equus asinus*) populations in the United States and globally has been a controversial subject for decades. I reviewed all available US federal feral horse and burro daily gather reports from 2010 to 2019 to extract equine species, technique (bait trapping or helicopter gathering), reason (emergency or other), number gathered, number of mortalities, and mortality attributes (acute or chronic/pre-existing condition, specific cause). I found 70 reports (bait trapping burros n = 10, bait trapping horses n = 24, helicopter gathering horses n = 21) from 9 states (AZ, CA, CO, ID, MT, NV, OR, UT, WY) representing 28,821 horses and 2,005 burros. For bait trapping, 100 animals died (4 burros, 96 horses) with 16 acute causes (1 burro, 15 horses) and 84 chronic/pre-existing causes (3 burros, 81 horses). For helicopter gathering, 268 horses died with 62 acute causes and 206 chronic/pre-existing causes. Mortality ratios did not differ by capture technique ($P > .05$) for broken necks, emaciation, acute causes, or chronic/pre-existing causes. The most common mortality-causing problems were structural deformations, club foot, blindness, and emaciation. The more horses gathered per day resulted in a greater proportion of chronic/pre-existing mortalities for both trapping techniques, but only an increase of acute mortalities for helicopter gathering. The slope suggests 1 acute mortality for every 300 horses gathered. The capture mortality rate across all gathers [1.1% (368 mortalities out of 30,826 horses and burros captured)] is below a general threshold of 2% suggested for wildlife studies.

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1. Introduction

Management of excessive feral horses (*Equus ferus caballus*) and burros (*Equus asinus*) in the United States has been a controversial and costly subject for many decades [1]. Population growth of these two equine species has been increasing dramatically over the last ten years with the current on-range population estimates of 88,090 animals (71,892 horses and 16,198 burros) which is greater than the federally mandated appropriate management level of 26,690 total horses and burros by a factor of >3× [2,3]. A common approach to feral horse and burro population management is gathering and removing horses from rangelands which is guided by the 1971 Wild Free-Roaming Horse and Burro Act (WFRHBA) [4] and subsequent amendments including in the 1976 Federal Land and Policy Management Act [5] and 1978 Public Rangelands Improvement Act [6]. Many of the feral horses and burros in the United States reside on public rangelands administered by the Bureau of Land Management (BLM) within the Department of the Interior; however, >46,000 horses and burros reside in "off-range" temporary holding and >90,000 free-roaming horses and burros also occur on Native American reservations [2,3].

The associated authority for equine gathering procedures are established for BLM Wild Horse and Burro Specialists and contracting partners by the 1971 WFRHBA as amended and are used regularly [4–6]. The standard operating procedures (SOPs) for gathering equids have been refined to optimize animal safety and include the use of helicopters and bait/water trapping [7]. In

Animal welfare/ethical statement: This is a third-party assessment of federally approved horse and burro gathers which are under the purview of the Bureau of Land Management (BLM).

Conflict of interest statement: The author has not received any funding for this particular mortality analyses and all research, analyses, and writing were conducted independent of BLM input. However, the author has received funding from BLM for unrelated research using GPS/VHF collars on feral horses and has been an observer of bait trapping and helicopter gathering in Wyoming, USA, only for the purposes of being on-site to place collars on horses.

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addition, reporting requirements for BLM Wild Horse and Burro Specialists are mandated [8]. Bait and water trapping techniques (henceforth "bait trapping") have been around for millennia and use discrete water (in the summer) and feed (both in the summer or winter if forage is limiting) placed in a corral with a gate that can be closed remotely (Fig. 1A). In other countries, bait trapping horses is a common population management technique, such as Australia's Kosciuszko National Park (Fig. 1B) [9].

Helicopter gathering ("helicopter drive trapping" in some BLM documents; mustering in other regions of the world) is commonly used in extensive landscapes for gathering livestock and for capturing wildlife species [7,10,11] (Fig. 1C). Helicopter gathers use a helicopter to locate and then herd animals toward a set of corrals. For horses specifically, a ground crew is often used along with a domestic horse that leads horses into the corrals. Corrals often have wings comprised of light-weight material that is visible to animals to help funnel them to the corrals. In other countries, helicopter gathering is regularly used, such as for New Zealand's Kaimanawa horses (Fig. 1D) [12]. For both bait trapping and helicopter gathering, traps and temporary holding sites are placed as close to animal locations as possible to reduce the likelihood of injury and stress to the animals [7].

Regardless of technique, the physical handling of any large animal, including wildlife and livestock, brings certain risks for both the animals and their handlers [13]. For animals, such risks include acute injuries incurred during the gathering process or chronic and/or pre-existing conditions that either manifest during the gathering process or that are a welfare concern to supervising veterinarians, agency staff, contractors, and the public [14]. However, stationary bait trapping techniques differ from helicopter gathering techniques in terms of relative labor demands, time constraints, weather limitations, and physical stimulation and stress imposed on ungulates [15]. There is some evidence that helicopter gathering may affect feral horse reproduction [16] although other studies have shown no effect [17]. In addition, because horses and burros may incur new injuries or exacerbate old injuries or conditions during the gathering process, veterinary oversight beyond the mandate for helicopter gathers only may be necessary to optimize animal safety and welfare [7].

Thus, there exists many complex questions attributed to (1) the increase of feral horse and burro populations over the last decade, (2) the need to optimize animal safety during gather procedures, and (3) the need for a more in-depth understanding of daily capture rates of different capture techniques. I therefore analyzed publicly available data for US BLM–authorized horse and burro gathers nationally. I specifically addressed explicit research questions about mortalities relative to gather type, equine species, and operational attributes, specifically the number of animals gathered per day. This information will be of use to other countries seeking to adopt or revise capture techniques, will enhance US BLM horse and burro gathers for BLM staff planning and conducting gathers, and will inform veterinarians overseeing horse and burro health during gathers.

2. Materials and Techniques

2.1. Source of Data

From September 1 to November 25 of 2019, I reviewed all publicly available BLM feral horse and burro gather reports for all the western US states using daily gather reports [18]. These reports are the result of a 2010 mandated reporting requirement for BLM Horse and Burro Specialists [8]. Reports were reviewed and data were systematically extracted and organized into a database that included the equine species of focus for a gather (horse or burro), type of capture technique (bait trapping or helicopter gathering), reason for the gather (emergency or other), number of animals gathered, number of daily mortalities, and mortality attributes (acute or chronic/pre-existing condition, specific cause). By assessing daily gather reports, I then calculated proportions of mortality relative to the total number of animals gathered and relative to type of capture technique and the proportion of mortality attributes. These calculations were stratified for three capture technique and equine species combinations available in the data: bait trapping burros, bait trapping horses, and helicopter gathering horses. In addition, I calculated the number of animals gathered per successful gather day relative to capture technique and species.

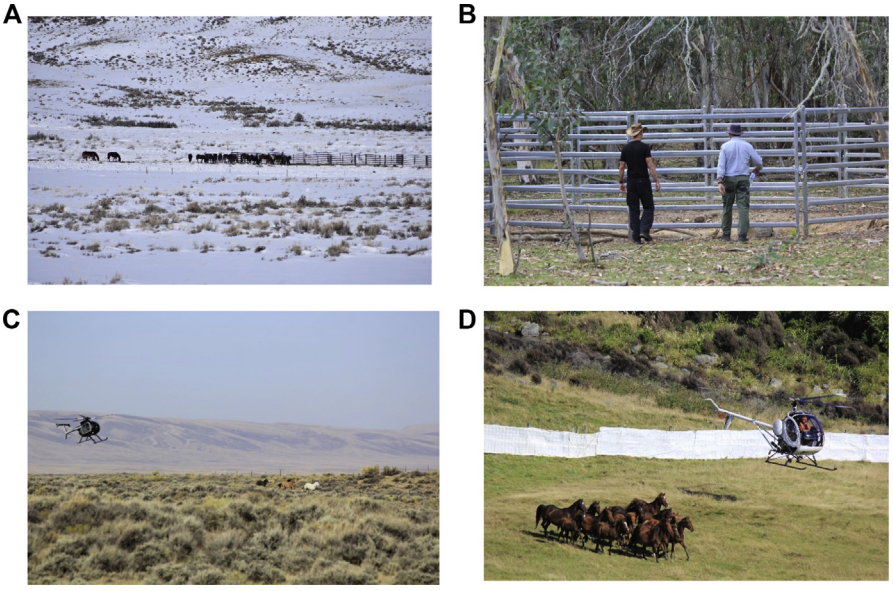


Fig. 1. Demonstration of international use of equine capture techniques. (A) Bait trapping in Wyoming, USA, during the winter, (B) bait traps in Australia's Kosciuszko National Park, (C) helicopter gather in Wyoming, USA, and (D) helicopter gather (muster) of Kaimanawa horses in New Zealand. Photo credit for all photos to J.D. Scasta.

2.2. Statistical Analyses

I examined three explicit research questions. First, is bait trapping or helicopter gathering safer for horses and burros in terms of acute and/or chronic—pre-existing mortality causes? To accomplish this and for the appropriate analysis, I stratified equine mortalities at the individual gather level by equine species and cause (acute or chronic/pre-existing), calculated the proportion of equine mortalities relative to the total numbers of animals gathered, and transformed the proportions using an arcsine transformation to meet assumptions of normality. I then ran analysis of variance models with either acute mortality or chronic/pre-existing mortality as a response variable and capture technique (bait trapping or helicopter gather) and then equine species as main fixed effects. I then conducted pairwise comparisons between the three capture techniques and equine species combinations.

The second research questions was, is bait trapping or helicopter gather more effective in terms of daily capture success? For the number of animals gathered per successful gather day, I analyzed the mean number of animals gathered per day as the response variable and capture technique as the main fixed effect, and then similar to the aforementioned analyses, I conducted pairwise comparisons between the three capture techniques and equine species combinations [19]. Because ~92% of mortalities (337 of 367) occurred on days equines were gathered, as opposed to days when they were only shipped or unsuccessful trap days, I then calculated the mean daily acute and chronic/pre-existing mortalities and plotted those relative to the mean number of equines gathered per day (only for days with at least 1 equine gathered) and used linear least squares regression stratified by capture technique to determine strength and significance of relationships.

The third research question was, what are the most frequent medical conditions leading to equine mortalities? I thus summarized reported medical condition and cause of mortality or need for euthanasia for horses and burros relative to capture technique (bait trapping or helicopter) and acute or chronic/pre-existing status of the condition for 32 different identified medical conditions. Given the variability in detail and medical records provided, some of the reported categories are not mutually exclusive, and thus the presentation here reflects that level of variability rather than inclusivity or exclusivity. Finally, I also calculated mortality ratios for broken necks (a specific acute cause of mortality), emaciation (a specific chronic cause of mortality), acute mortalities, and chronic/pre-existing mortalities for horses relative to capture technique and then compared relative risk and mortality ratios between techniques using an independent samples *t*-test, effect size (Cohen's d), and 95% confidence intervals [19,20].

3. Results

3.1. Horse and Burro Gather Report Summary

I found 70 reports (bait trapping burros n = 10, bait trapping horses n = 24, helicopter gathering horses n = 21) from 9 states (AZ, CA, CO, ID, MT, NV, OR, UT, WY) representing 28,821 horses and 2,005 burros (Tables 1 and 2). Reports represented 1,006 unique daily gather activity summaries with 760 of the daily reports being successful gather days, where at least one horse or burro was gathered. No gather reports were available for New Mexico. In a few instances, gather reports were omitted because of confounding factors making it difficult to interpret data, particularly those gathers that were explicitly for administering contraception treatments for research purposes. The 70 gather reports with suitable data in total represented 30,826 total equids (2,005 burros captured with bait trapping, 5,564 horses captured with bait trapping, and 23,257 horses captured with helicopter gathering) (Table 3). Of those reports, 34 used bait trapping (Table 1) and 36 used helicopter gathering (Table 2). For burros, bait trapping techniques were the only technique used (never helicopter gathers of burros), but both bait/water trapping and helicopter gathering procedures were used for horses (Tables 1 and 2).

Table 1
Details about the bait trapping studies with publicly available gather reports including state, equine species, year, and name of gather.

State	Species	Year	Name of Gather
AZ	Burro	2017	Planet Ranch *Nuisance*
	Burro	2019	Big Sandy *Nuisance*
	Burro	2019	Black Mountain *Nuisance*
CA	Burro	2018	Outside Chemehuevi
	Burro	2018	Piute Mountain
NV	Burro	2017	Johnnie
	Burro	2017	Marietta
	Burro	2018	Bullfrog
	Burro	2019	Bullfrog
	Burro	2019	Seven Troughs
CO	Horse	2016	Sand Wash Basin
	Horse	2018	Little Books
MT	Horse	2015	Pryor Mountain
NV	Horse	2016	Goshute *Emergency*
	Horse	2016	Maverick-Medicine *Emergency*
	Horse	2016	Pancake *Emergency*
	Horse	2016	Stone Cabin
	Horse	2016	Wood Hills *Emergency*
	Horse	2017	Antelope Valley Private Land
	Horse	2018	Antelope Valley and Goshute *Emergency*
	Horse	2018	Antelope Valley Deer Spring *Emergency*
	Horse	2018	Outside Goshute
	Horse	2018	Pancake
	Horse	2018	Spruce-Pequop *Emergency*
	Horse	2018	Wild Horse Range *Emergency*
	Horse	2019	Antelope Valley
	Horse	2019	Caliente Complex *Nuisance*
	Horse	2019	Red Rock *Emergency*
OR	Horse	2016	South Steens
	Horse	2018	South Steens
UT	Horse	2018	Cedar Mountain *Emergency*
	Horse	2018	Range Creek
WY	Horse	2013	McCullough Peaks
	Horse	2017	Adobe Town

3.2. Total Mortalities Reported

Across all gather reports, 368 mortalities were reported, 364 horses and 4 burros, representing 1.26% of horses and <1% of burros (Table 3). Acute causes of mortality were noted for 77 horse mortalities and 1 burro mortality. Chronic/pre-existing causes of mortality were noted for 287 horse mortalities and 3 burro mortalities (Table 3).

3.3. Trap Techniques and Mortalities

Relative to capture technique, there were 148 daily gather reports for bait trapping burros, 402 daily gather reports for bait trapping horses, and 456 daily gather reports for helicopter gathering horses (Table 1). This accounted for 2,005 burros and 5,564 horses gathered with bait trapping and 23,257 horses gathered with helicopters. A total of 100 animals died during bait trapping (4 burros, 96 horses) with 16 acute mortality causes (1 burro, 15 horses) and 84 chronic/pre-existing causes (3 burros, 81 horses) (Table 3). A total of 268 horses died during helicopter trapping with 62 acute mortality causes and 206 chronic/pre-existing mortality causes (Table 3). The proportion of mortalities relative to the total number of animals gathered for acute mortality causes was 0.0005

Table 2
Details about the horse helicopter gathers with publicly available gather reports including state, year, and name of gather.

State	Year	Name of Gather
CO	2015	West Douglas
	2017	Cathedral Creek
ID	2015	Soda Fire *Emergency*
	2019	Challis
NV	2015	Fish Creek
	2015	Humboldt
	2015	Little Fish Lake
	2016	Eagle and Silver King
	2016	Owyhee
	2017	Fox and Lake Range *Emergency*
	2017	Reveille
	2018	Eagle *Emergency*
	2018	Owyhee Complex *Emergency*
	2018	Silver King
	2018	Triple B Complex
	2019	Fish Creek
	2019	Triple B Complex
OR	2015	Kiger and Riddle Mountain
	2018	Cold Springs
	2018	Warm Springs
UT	2017	Cedar Mountain
	2017	Frisco
	2018	Bible Springs
	2018	Muddy Creek
	2019	Onaqui
	2019	Range Creek
WY	2010	Adobe Town, Salt Wells
	2011	Antelope Hills—Great Divide Basin
	2011	Antelope Hills—Red Desert Complex
	2011	Little Colorado and White Mountain
	2012	North Lander Complex Conant Creek
	2013	Adobe Town, Salt Wells
	2014	Checkerboard
	2017	Adobe Town, Salt Wells, Great Divide Basin
	2018	Red Desert Complex
	2019	Fifteen Mile

(±0.0005, standard error) for bait trapped burros, 0.0041 (±0.0015) for bait trapped horses, and 0.0028 (±0.0005) for helicopter gathered horses and did not differ for capture technique ($F = 1.181$, $P = .281$) but did differ for equine species ($F = 5.437$, $P = .023$; Fig. 2). The proportion of mortalities relative to the total number of animals gathered for chronic mortality causes was 0.0019 (±0.0012, standard error) for bait trapped burros, 0.0127 (±0.0050) for bait trapped horses, and 0.0073 (±0.0013) for helicopter gathered horses and did not differ for capture technique ($F = 0.340$, $P = .562$) but did differ for equine species ($F = 4.956$, $P = .029$; Fig. 2).

3.4. Horse Medical Conditions and Need for Euthanasia

Table 4 shows all reported medical conditions and causes of mortality (both natural and euthanasia) for horses and burros

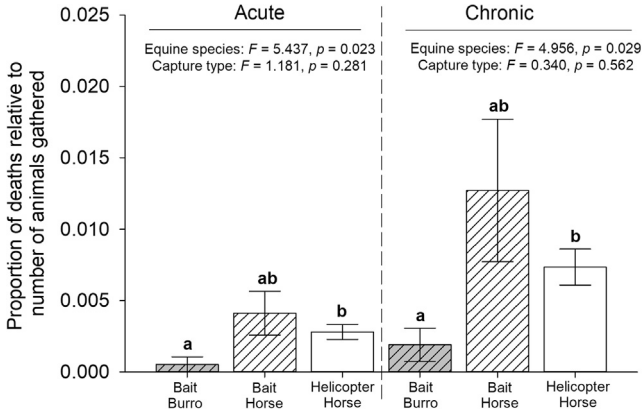


Fig. 2. Proportion of equine mortalities relative to equine capture technique and acute or chronic/pre-existing medical condition. Proportion data were transformed using an arcsine transformation to meet assumptions of normality and analyzed with analysis of variance (ANOVA) models with either acute mortality or chronic/pre-existing mortality as a response variable and capture technique type (bait trapping or helicopter gather) and then equine species as main fixed effects. Pairwise comparisons between the three technique and equine species combinations were assessed and are considered significantly different with different letters (a, b) at $P < .05$. Data from 70 publicly available gather reports (bait trapping burros n = 10, bait trapping horses n = 24, helicopter gathering horses n = 21) from 9 US states (AZ, CA, CO, ID, MT, NV, OR, UT, WY) representing 28,821 horses and 2,005 burros from 2010 to 2019.

relative to capture technique (bait trapping or helicopter) and acute or chronic/pre-existing status of the condition. Regardless of gathering procedure, the most common health problems and mortality cause identified was structural deformations for 58 horses which in our assessment, included developmental abnormalities and improperly healed bone breaks that resulted in deformed limbs, joints, or other features. The second-most common, which is a more specified form of structural deformation, was club foot for 42 horses. The third-most common was blindness for 44 horses. In some cases, specific details about a missing eye or eye injury were provided. The fourth-most common was emaciation and poor body condition for 33 horses and 1 burro. Horses identified as being emaciated often also had other noted problems including being old and tooth wear (although these were not always mentioned). When emaciation was assessed relative to total animals caught per capture technique, mortality ratios were 0.0033 (±0.0025) and 0.0009 (±.0004) for bait and helicopter, respectively, but did not significantly differ [$P = .254$, Cohen's d = 0.304, 95% CI (−0.217, 0.822)] (Table 5). The fifth-most common was broken legs for 29 horses and 2 burros. The sixth-most common was unknown for 28 horses. Broken necks were noted for 21 horses and 1 burro. Broken neck mortality ratios were 0.0026 (±0.0014) and 0.0006 (±0.0003) for bait and helicopter respectively, but did not differ significantly [$P = .112$, Cohen's d = 0.425, 95% CI (−0.099, 0.945)] (Table 5). Broken legs and broken backs occurred in both capture

Table 3
Summary data for 70 horse and burro gathers in the United States from 2010 to 2019 based on capture technique, equid species gathered, total gather days reported, total animals gathered, and total animals mortalities relative to acute or chronic/pre-existing conditions.

Capture Technique Equine Species	Gather Days	Total Animals Gathered	Total Animal Mortalities	[a]Acute Mortalities	[b]Chronic/Pre-Existing Mortalities
Bait trapping					
Burro	148	2,005	4	1	3
Horse	402	5,564	96	15	81
Helicopter gathering					
Horse	456	23,257	268	62	206
Total	1,006	30,826	368	78	290

[a] Acute mortality considered when an animal dies or is euthanized due to acute injuries or medical conditions brought about by the gather and removal process including associated activities of capturing, sorting, and holding; includes undiagnosed mortalities.
[b] Chronic/pre-existing mortality considered when an animal dies or is euthanized for reasons related to chronic or pre-existing conditions such as poor body condition, lameness, serious physical defects, etc. Includes animals euthanized for conditions not brought about by the gather activity.

Table 4
Reported medical condition and cause of mortality or need for euthanasia for horses and burros relative to capture technique (bait trapping or helicopter) and acute or chronic/pre-existing status of the condition.

Diagnoses/Condition/Cause	Bait Trapping		Helicopter		Total
	Acute	Chronic	Acute	Chronic	
Aortic aneurysm			1		1
Blind		15		29	44
Broken back		2		6	8
Broken leg	4	11	11	5	31
Broken neck	10		12		22
Burn injuries				2	2
Capture myopathy			2		2
Cardiac arrest			1		1
Club foot		23		19	42
Colic		1	1		2
Dehydration		2			2
Emaciated		15		19	34
Head injury/fractured skull			4	1	5
Hernia				3	3
Hip dislocation				1	1
Infection				1	1
Laceration			3		3
Lameness		3		21	24
Neurologic disorder	1				1
New fatal injuries			11		11
Parasite infestation				6	6
Pneumonia		1		5	6
Pre-existing condition		1		7	8
Pre-existing wounds				7	7
Seizure			1		1
Strain			5		5
Structural deformation		7		51	58
Tooth loss		1		4	5
Toxicity			1		1
Tumors				2	2
Unknown	1	2	9	16	28
Weak				1	1
Total	**16**	**84**	**62**	**206**	**368**
Euthanasia	6	81	30	187	304
Natural	7	1	27	4	39
Unknown	3	2	5	15	25

Data derived from 70 horse and burro gathers in the United States from 2010 to 2019 using publicly available gather data as administered by the Bureau of Land Management.

technique with broken backs only noted as chronic/pre-existing. Other less-frequent health conditions included aortic aneurysm (1), burn injuries (2), capture myopathy (2), cardiac arrest (1), colic (2), dehydration (2), head injury/fractured skull (5), hernia (3), hip dislocation (1), infection (1), laceration (3), lameness (24 horses [no burros] reported and details include arthritis, fetlocks, laminitis, etc., [21]), neurologic disorder (1), new fatal injuries undefined (11), parasite infestation (6), pneumonia (6), pre-existing condition (8), pre-existing wounds (7), seizure (1), strain (5), tooth loss and wear (5), toxicity (1), tumors (2), and weakness (1) (Table 4).

Acute mortalities occurred in 10 of 24 bait trap gathers of horses and 23 of 36 helicopter gathers of horses (Table 5). Acute mortalities occurred in 15 of 5,564 horses caught with bait trapping and 62 of 23,257 horses caught with helicopter trapping (Table 5). For horse acute mortalities, the bait mortality ratio was 0.0041 (±0.0015) and the helicopter mortality ratio was 0.0028 (±0.0013), with a relative risk of 1.5. When analyzed, horse acute mortality ratios did not differ significantly [$P = .388$, Cohen's d = 0.229, 95% CI (−0.290 to 0.746)] (Table 5).

Chronic mortalities occurred in 13 of 24 bait trap gathers of horses and 26 of 36 helicopter gathers of horses (Table 5). Acute mortalities occurred in 81 of 5,564 horses caught with bait trapping and 206 of 23,257 horses caught with helicopter trapping (Table 5). For horse chronic mortalities, the bait mortality ratio was 0.0127 (±0.0050) and the helicopter mortality ratio was 0.0073 (±0.0013), with a relative risk of 1.7. When analyzed, horse acute mortality ratios did not differ significantly [$P = .220$, Cohen's d = 0.326, 95% CI (−0.195 to 0.845)] (Table 5).

3.5. Number Gathered Daily Relative to Capture Technique

For capture technique, the mean number of animals gathered per successful gather day was 20 (±6) for bait trapping burros, 19 (±3) for bait trapping horses, and 58 (±5) for helicopter gathering horses; significantly higher for helicopter gathering ($P < .001$; Fig. 3). The range of mean number of animals gathered per successful gather day was 7–63 for bait trapping burros, 4 to 67 for bait trapping horses, and 15 to 131 for helicopter gathering horses.

3.6. Mortalities Relative to Number Gathered per Day

When the average number of equids gathered per day was used to predict the mean daily mortalities only for days equids were actually gathered, relationships differed by equine species and capture technique. For bait trapping burros, the more burros trapped in a day had no significant or correlative effect on acute ($r^2 = 0.03$, $P = .656$) or chronic mortalities ($r^2 = 0.11$, $P = .341$) (Fig. 4A). For bait trapping horses, the more horses gathered per day had no significant or correlative effect on acute mortalities ($r^2 = 0.13$, $P = .083$); however, chronic mortalities increased ($r^2 = 0.36$, $P = .002$) (Fig. 4B). For helicopter gathering horses, the more horses gathered per day resulted in increased acute ($r^2 = 0.24$, $P = .003$) and chronic mortalities ($r^2 = 0.22$, $P = .004$) (Fig. 4C). When the slope ($m = 0.0035$) for the linear equation predicting increasing acute mortalities is examined, the increase of 1 additional acute mortality

Table 5
Mortality ratios for both capture techniques and relative risk for horse bait trapping relative to horse helicopter trapping for broken necks, emaciated condition, acute mortalities, chronic/pre-existing mortalities, and total mortalities.

Metric	Broken Neck	Emaciated	Acute Mortalities	Chronic Mortalities
Bait gather occurrence (of 24 gathers)	7 of 24	4 of 24	10 of 24	13 of 24
Helicopter gather occurrence (of 36 gathers)	8 of 36	8 of 36	23 of 36	26 of 36
Bait horse occurrence (of 5,564 horses)	9 of 5,564	14 of 5,564	15 of 5,564	81 of 5,564
Helicopter horse occurrence (of 23,257 horses)	12 of 23,257	19 of 23,257	62 of 23,257	206 of 23,257
Bait mortality ratio (± standard error)	0.0026 (±0.0014)	0.0033 (±0.0025)	0.0041 (±0.0015)	0.0127 (±0.0050)
Helicopter mortality ratio (± standard error)	0.0006 (±0.0003)	0.0009 (±0.0004)	0.0028 (±0.0013)	0.0073 (±0.0013)
Relative risk (bait/helicopter)	4.2	3.6	1.5	1.7
P-value (α = 0.05)	.112	.254	.388	.220
Effect size (Cohen's d)	0.425	0.304	0.229	0.326
95% Confidence intervals (lower, upper)	−0.099, 0.945	−0.217, 0.822	−0.290, 0.746	−0.195, 0.845

Data from 60 publicly available gather reports (bait trapping horses n = 24, helicopter gathering horses n = 21) from 9 US states (AZ, CA, CO, ID, MT, NV, OR, UT, WY) representing 28,821 horses from 2010 to 2019.

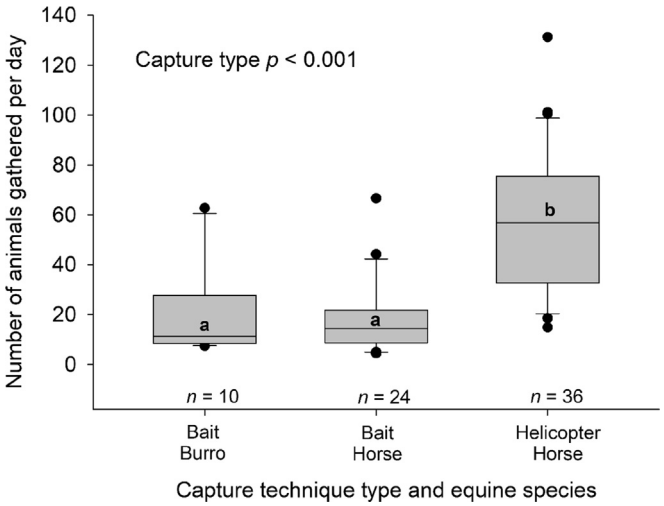


Fig. 3. Number of horses and burros gathered per day across 10 burro bait trap gathers, 24 horse bait trap gathers, and 36 horse helicopter gathers from 2010 to 2019 as administered by the Bureau of Land Management. Numbers are derived for days reporting at least 1 animal gathered as some daily reports were days where trapping efforts were made but no animals were caught. Pairwise comparisons between the three technique and equine species combinations were assessed and are considered significantly different with different letters (a, b) at $P < .05$. Data from 70 publicly available gather reports (bait trapping burros n = 10, bait trapping horses n = 24, helicopter gathering horses n = 21) from 9 US states (AZ, CA, CO, ID, MT, NV, OR, UT, WY) representing 28,821 horses and 2,005 burros from 2010 to 2019.

daily could be expected with gathering an additional 300 horses per day.

4. Discussion

4.1. Gathering Equids Reveals Many Chronic/Pre-existing Medical Conditions

The process of gathering equids, regardless of capture technique, reveals many chronic and pre-existing medical conditions from which feral horses and burros may be suffering. Structural deformities were the most common medical condition and included a wide range of conditions including deformities from developmental origins, improperly healed broken bones, etc. Specific structural deformities were diagnosed in some cases such as club foot which was the second-most prevalent issue. A limitation of this study is that often there were very limited details regarding the diagnoses of mortality making it difficult to understand more specific death causes. Regardless, research on feet of wild horses in New Zealand also revealed a frequent occurrence of foot abnormalities and undesirable foot morphometric traits [22]. Such feet problems can lead to subchondral bone sclerosis particularly in horses with severe articular cartilage damage with severity increasing as horses aged in the same population of New Zealand wild horses [23]. Reintroduction of Przewalski's horses (*Equus ferus przewalskii*) includes a selection criterion of captive breeding stock that addresses horse hooves [21]. Furthermore, lameness was noted in more than ten horses, and while causality for lameness was difficult to ascertain from the reports, it was often associated with feet and lower legs (i.e., fetlocks). Problems of the eyes, particularly blindness in one or both eyes, were the third-most common medical condition. Although blindness has not been studied much in wild horses, trauma can be a cause of blindness in horses generally and can be attributed to both perforation injury and blunt trauma injury leading to optic nerve atrophy [24].

4.2. Emergency Gathers Have Greater Frequency of Chronic/Pre-existing Medical Conditions

The greater relative occurrence for associated chronic/pre-existing mortalities may likely be skewed as a function of the greater proportion of emergency gathers. Specifically in this data set, emergency gathers of horses represented 42% of the bait trap gathers (10 of 24) but only 11% (4 of 36) of helicopter gathers. A plausible argument could be made that the prompt for emergency gathers is often inadequate forage and/or water and thus horses and burros that subsequently have lower body condition and other problems such as reduced immunity, etc. This notion is supported by relative proportion of emaciated horses for the different capture techniques (Table 5). Thus, prudence in capturing and shipping emaciated animals should be part of the welfare consideration integrated into wild horse and burro management similar to other wild herbivore management programs [25].

4.3. Helicopter Gathering Does Not Present Any Greater Risk of Mortalities

Helicopter gathering may be as safe, if not safer than bait trapping—a conclusion that seems counterintuitive given the perception that helicopter gathering may be perceived as a more dangerous and physically demanding technique particularly given the agitated escape behavior wild equids display in response to helicopters [12,26]. The notion of no greater risk for helicopter gathering may be supported by the proportionally lower incidence of broken necks and lack of statistical differences specifically and the similar proportion of acute mortalities generally when compared with bait trapping. Greater emphasis on SOPs for (1) gather operations generally [7], (2) daily gather reporting specifically [8], and (3) for helicopter pilots certification [27] may all have collectively enhanced gather implementation. In addition, in 2010, a private horse protection group worked with BLM to develop an Independent Designated Observer Pilot Program with independent observers (IOs), where equine specialists not affiliated with BLM observed 3 gathers in 3 states of a total of 352 horses [28]. The IOs observed four mortalities and multiple injuries and concluded that contractors and BLM staff were skilled at avoiding excessive stress on captured animals but also gave recommendations to improve facility design, handling of the horses, sorting techniques, transport practices, etc. [28]. Specifically, a focused emphasis on the design of gathers to optimize the care and welfare of horses and the precision with which pilots are handling horses and burros from the air may be outcomes of such high-level administrative direction and participatory involvement. In addition, helicopter gathering has a greater daily capture rate and may optimize animal handling times.

4.4. Need to Better Understand Unknown Mortality Causes and Capture Myopathy of Horses

Interestingly, capture myopathy was only noted for the death of 2 horses. The unknown causes of death in horses, coupled with the documented deaths attributed to strain/stress, seizure, and cardiac arrest (Table 4), in this study could be attributed to capture myopathy [13]. Capture myopathy is a noninfectious metabolic disease that is most commonly associated with pursuit, capture, restraint, and transportation of animals and the induced stress that can lead to death either during or after capture efforts [29]. Unfortunately, capture myopathy has been persistently difficult to diagnose and includes several different clinical syndromes including capture shock syndrome, ataxic myoglobinuric syndrome, ruptured muscle syndrome, and delayed peracute syndrome [13]. Owing to the absence of more detailed medical data

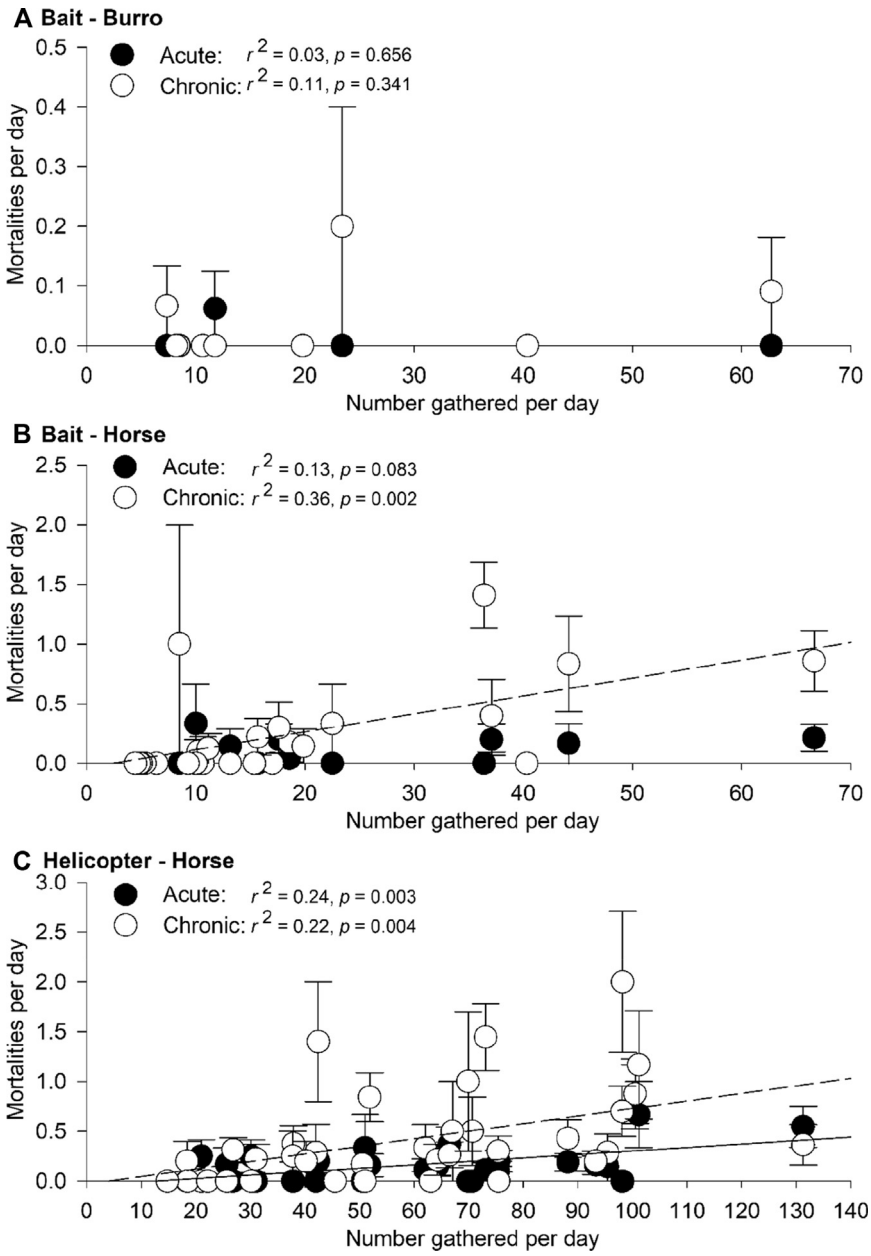


Fig. 4. Comparison of mean daily mortalities relative to mean number of equines gathered per day for (A) bait trapping burros, (B) bait trapping horses, and (C) helicopter gathering horses. Data from 70 publicly available gather reports (bait trapping burros n = 10, bait trapping horses n = 24, helicopter gathering horses n = 21) from 9 US states (AZ, CA, CO, ID, MT, NV, OR, UT, WY) representing 28,821 horses and 2,005 burros from 2010 to 2019. Significant trendlines graphed as solid lines for acute mortalities and dashed lines for chronic mortalities.

necessary to confirm diagnoses, more thorough investigations of unknown death causes are needed, particularly for helicopter gathers [30].

4.5. Comparison of Equid Mortality Rates to Other Wildlife Species and Capture Techniques

The total capture mortality rate across all gathers in this study [1.1% (368 mortalities of 30,826 horses and burros captured)], or for specific horse capture techniques (bait mean = 1.7% ± 0.5% SE; helicopter mean = 1.0% ± 0.1% SE), can be compared with capture-related mortality rates published for other wildlife species. For 5 wildlife species chemically immobilized in Scandinavia, the mean mortality rate was 2.3% and ranged from 0.7% to 3.9% [31]. For white-tailed deer caught with 4 different physical trapping techniques, capture-related mortality rates ranged from 2.0% to 20.7% [32]. For caribou calves darted from a helicopter, capture-related mortality rates ranged from 0.5% to 4.1% [33]. Thus, given the capture-related mortality rates from these studies, and the recommendation that >2% capture mortality is unacceptable [31], it seems that BLM horse and burro welfare is generally being optimized to a level acceptable across other animal handling disciplines [31]. It is important to note however that for several individual gathers, mortality rates exceeded 2% mortality. Two gathers were emergency gathers that had mortality rates >3.5% and >10.5% (2018 Wild Horse Range Emergency gather and 2016 Goshute Emergency gather, both in Nevada). In addition, one helicopter gather had a mortality rate >3.5% due to a prevalence of genetically related

structural deformations and lameness (2018 Warm Springs gather in Oregon, specifically "*angular limb deformities (ALD), conditions were indicated by club feet, severely overgrown hoof walls, collapsed heals, limb deformity, arthritic joints, toes pointed out at the fetlock, and lameness*"). Thus, a distinguishing feature of the US federal horse and burro management is the intervention when forage and water is limiting and/or when horses are suffering from other health problems, which is fundamentally different than capturing healthy animals for wildlife research. This emphasizes the continued need for quality equine veterinary care and the importance of having detailed medical history and veterinarian diagnoses and/or necropsies to move beyond lay terms and general attributions of mortalities.

5. Conclusions

This study assesses feral equine capture techniques in the United States, which is an important tool for when horse and burro overpopulation threatens the "thriving natural ecological balance" of rangelands [32,33]. My objective analyses of publicly available BLM equine gather data over 70 gathers, 9 states, 30,826 horses and burros, and a 10-year period has allowed for quantitative analyses that suggests helicopter gathering presents no additional risk for acute mortalities than bait trapping. Moreover, helicopter trapping can capture more horses per day. I also have provided details that both veterinarians and federal horse managers can use proactively when preparing for and supervising gathers; specifically, being aware of structural deformities, feet problems, blindness, and a greater prevalence of emaciated horses or acute mortality manifestations relative to capture technique and reason for a gather. In addition, emergency gathers may have a greater risk of mortalities attributed to handling weaker and sicker horses. My results should be considered in the context of repeatedly gathering mares for other treatments and could also guide animal welfare frameworks for US horses and burros [34–37].

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