



Research Article

Population Dynamics and Fertility Control of Feral Horses

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ABSTRACT The management of free-roaming, feral horse (*Equus caballus*) populations in the western United States is a contentious and challenging issue. Between 2008 and 2014, 1,873 individual horses from a closed population in the northern Great Basin, USA were captured, uniquely marked, and were either removed for private adoption or had permanent fertility control treatments (i.e., vasectomy or ovariectomy) applied prior to release. We derived the annual population size, growth rate, and the number of horses by sex and age by using the horse's estimated age at first capture to infer its age during each year it was part of the population. Estimates of population size from 2 aerial survey techniques averaged within 5.3%–9.6% of derived population estimates. The overall survival (i.e., recapture) rate for individual horses was 88% for individuals released back into the population between 2009 and 2012. Treated horses maintained group associations and there were no differences between survival rates for released females or males that received fertility control treatment, compared to animals released without treatment. The application of combined fertility control efforts resulted in a decline in the population-level annual foaling rate from >20% to <4% within 4 years. Maintaining a proportion of a population as permanently non-reproducing has the potential to safely maintain free-roaming horse herds at desired management levels. © 2016 The Wildlife Society.

KEY WORDS *Equus caballus*, feral horse, fertility control, foaling, ovariectomy, population dynamics, vasectomy.

Management of free-roaming, feral horses (*Equus caballus*) in the western United States is an increasingly controversial and contentious issue. The species is viewed as a symbol of freedom and an icon of the American West, but horses also are a non-native, feral grazer that present significant land management challenges. Unmanaged or poorly managed non-native grazers, including horses, can have substantial impacts on ecosystem integrity, influencing a wide array of native flora (Smith 1986, Levin et al. 2002, Zalba and Cozzani 2004, Beever et al. 2008, Davies et al. 2014), fauna (Beever 2003, Beever and Brussard 2004, Beever and Herrick 2006, Hall et al. 2016, Gooch et al. 2017), and ecosystem processes (Beever and Brussard 2000, Zeigenfuss et al. 2014). On lands managed by the Bureau of Land Management in the western states alone, there are an estimated >67,000 free-roaming horses and burros (*Equus asinus*) occupying 12.8 million ha, more than twice the maximum management level that can exist in balance with other public rangeland resources and uses (Bureau of Land Management 2016a).

Free-roaming female horses typically have their first foals at 2–3 years of age, often produce foals in consecutive years, and remain reproductively active throughout their lives with only a small reduction in foaling rates in the oldest age classes

(Speelman et al. 1944, Berger 1986, Siniff et al. 1986, Wolfe et al. 1989, Garrott et al. 1991). In addition, mortality rates for free-roaming horses are low as or lower than other similarly sized, native mammals (Berger 1986); annual survival estimates for adult horses have ranged from 70–80% (Wolfe 1980) to 95% and higher (National Research Council 1980, Berger 1986, Garrott and Taylor 1990). The result is that free-roaming horse populations can grow at annual rates of 15–20% or more per year (Eberhardt et al. 1982, Berger 1986, Garrott and Taylor 1990) and it is expected that most populations approach this biological potential because current management generally ensures that horses are not resource- or self-limited (National Research Council 2013).

Western land managers have traditionally relied on the practice of capture, removal, and public adoption to manage free-roaming horse abundance. This process is costly and unsustainable because the number of adopted animals represent only a fraction of animals removed, which has resulted in almost as many horses now held for the remainder of their lives in long-term, federally subsidized private pastures as there are on the range (Garrott and Oli 2013, Bureau of Land Management 2016a). Consequently, despite previously aggressive programs to control the number of horses on public rangelands, current management strategies have not been able to reduce free-roaming horse populations to target levels (National Research Council 2013). For a segment of the public, neither capturing and removing horses nor letting horses perish on the range as a result of limited resources is

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acceptable. Methods to control population growth (e.g., fertility control, contraception) may reduce the need for intensive and controversial removals while ensuring that free-roaming horse populations do not become self-limiting (National Research Council 2013). Controlling population growth would also provide significant cost-savings to the American taxpayer (Bartholow 2007, de Seve and Griffin 2013) by affecting the ability to attain free-roaming horse management goals (National Research Council 2013).

Fertility control has been an attractive alternative to managing wildlife and other animal populations that have become overabundant (Ransom et al. 2014b), including free-roaming horses, white-tailed deer (*Odocoileus virginianus*), and elk (*Cervus canadensis*; Hobbs et al. 2000, Ransom et al. 2010). Contraception that persists for the lifetime of the animal may be the most efficient method for maintaining a population at target densities once an adequate number of animals have been sterilized (Hobbs et al. 2000). However, little empirical data are available on how such efforts affect population-level rates of change (Ransom et al. 2014b) or have demonstrated meaningful reductions in population growth rates in the field (Hobbs et al. 2000). Although a wide variety of fertility control agents have been and are being investigated for free-roaming horses (Bureau of Land Management 2016b), many of the management tools examined thus far are costly or impractical for large-scale use (Ransom et al. 2014a). In addition, managers are generally constrained by a lack of data including scientifically defensible horse population estimates, population growth rates, demographics, and subsequent effects of these proposed management actions (National Research Council 2013). One contraceptive technique, permanent sterilization of males via vasectomy, has had limited field application and previously targeted only socially dominant individuals (Eagle et al. 1993); although it has been recognized that the strategy of targeting only dominant males may not be successful in limiting population growth (Garrott and Siniff 1992, Bowling and Touchberry 2001). A second technique, targeting female horses for contraceptive control via permanent sterilization (i.e., ovariectomy) has not been tested within free-roaming horse populations to date.

We report on an 8-year study of the population dynamics of a free-roaming, feral horse herd in the northern Great Basin, USA. Our objectives were to evaluate the effectiveness of 2 permanent sterilization techniques used to control population growth while targeting individuals of both sexes regardless of social status.

STUDY AREA

Sheldon National Wildlife Refuge (Refuge), managed by the United States Fish and Wildlife Service, consisted of approximately 234,703 ha in northwest Nevada, USA, in the northern Great Basin. The Refuge was established in 1936 for the conservation of American pronghorn (*Antilocapra americana*) and other native sagebrush-obligate species, including greater sage-grouse (*Centrocercus urophasianus*). Elevations ranged from 1,326 m to 2,183 m. Recent summer temperatures ranged from 0°C to 34°C and winter temperatures between -29°C and 14°C; annual precipitation rarely

amounted to more than 30 cm. Dominant vegetation consisted of shrubs, primarily sagebrush (*Artemisia* spp.) and associated sagebrush-steppe habitats. Scattered open woodlands consisting of western juniper (*Juniper occidentalis*) or curl-leaf mountain mahogany (*Cercocarpus ledifolius*) occupied ridgelines and some slopes. Aspen (*Populus* spp.) and willows (*Salix* spp.) were found in dispersed snowpockets and in areas of persistent water.

The feral horse population occupying Sheldon National Wildlife Refuge dated back to prior to the establishment of the Refuge as privately owned animals escaped or were released from ranches and grazing allotments (U.S. Fish and Wildlife Service 2013). During the early 1990s, the horse population averaged 200–300 animals as a result of a proactive population control (removal) program; however, without continued active management, the population substantially increased by the mid-to-late 2000s necessitating management action. Since the early 2000s, feral horses were reported to affect the Refuge's natural resources and native wildlife (Barnett 2002, Davies et al. 2014, Zeigenfuss et al. 2014, Gooch et al. 2017) and were targeted for removal in 2013–2014 (U.S. Fish and Wildlife Service 2013). Small numbers of feral burros also occurred on the Refuge but were not included in this study. The area surrounding the Refuge was predominantly federal land administered by the Bureau of Land Management, and included areas designated as wild horse Herd Management Areas (HMAs) and Herd Areas (HAs); recent surveys estimated over 3,200 horses occupying the surrounding areas (Lubow 2015). A fence along the exterior boundary of the Refuge geographically restricted the movement of livestock, horses, and burros between the Refuge and adjacent lands.

METHODS

Between 2008 and 2014, each fall we used a helicopter to herd feral horses into a trap corral and then transported them by trailer to an on-site facility for handling (U.S. Government Accountability Office 2008). An equine veterinarian estimated the age of each captured horse using teeth characteristics (e.g., eruption date, rate of growth, tooth wear; McMullan 1983). Accurately aging animals by teeth characteristics can be challenging because of individual rates of tooth growth and wear; therefore, the same person aged all horses to ensure consistency in estimates over the duration of the study. We determined the sex of each horse, and paired females with their dependent foals. From 2008 to 2012, we removed approximately 10–20% of the total population each year (predominantly younger horses estimated at <5 yr) from the Refuge and transported them to contractors for private adoption; no removals occurred in 2007. We treated the majority of the remaining captured animals (i.e., those not transported for adoption) with permanent fertility control and released them back at the site of capture. Horses established as previously captured and marked (see below) were identified and recorded, and assessed for removal or re-release back onto the Refuge (prior to 2013). We surgically vasectomized (2008–2009) or chemically epididymectomized (2010–2011; Scully et al. 2015) males and surgically ovariectomized females via colpotomy (2009–2011; McKinnon et al. 1991, Hooper et al.

1993, Auer and Stick 1999). Costs associated with treatments ranged from approximately \$125/horse for vasectomies to \$150/horse for ovariectomies, and included veterinarian time and veterinary supplies (L. G. Pielstick, HCVC, personal communication).

Veterinarians experienced in handling domestic and non-domestic horses performed all procedures. All procedures followed taxon-specific guidelines approved by the American Society of Mammalogists (Sikes et al. 2016), consistent with recommendations for wild taxa (Sikes et al. 2012). In addition, we contracted with an independent veterinarian to provide protocol and program review and animal welfare oversight during all phases and for the duration of the study. We held and observed treated horses in captivity on average 3–8 days before release, as per veterinarian recommendations, and the losses attributed to treatment complications pre-release was 2% ($n = 8$). We implanted all horses with a uniquely identifying microchip in a passive integrated transponder (PIT) tag. We injected the microchip into the nuchal ligament along the base of the horse's mane to reduce the potential for tag migration (Stein et al. 2003); tag retention was 100%. We also marked individuals that received fertility control treatments with a visible freeze-brand signifying treatment type. In 2013 and 2014, all remaining horses in the population were targeted for removal and transportation to contractors for private adoption, including those which had been previously captured and released; approximately half of the animals were removed in 2013 ($n = 415$) and the remainder in 2014 ($n = 397$). As of fall 2015, an estimated <30 horses remained on the Refuge.

We compared 2 aerial survey methods used to monitor temporal trends in the feral horse population. Each July between 2007 and 2014, as part of routine wildlife composition surveys, a pilot and 2 experienced observers made uncorrected direct (i.e., raw) counts of horses from a helicopter flying linear transects at approximately 91 m above ground level (AGL) and 0.4-km spacing, dependent upon visibility, terrain, and habitat. We recorded the global positioning system (GPS) location of and the number of individuals in each group of horses, classified each animal as an adult or foal (<1 yr), and noted the number of freeze-branded individuals present by treatment type. We used the July helicopter survey data to

evaluate differences in group size over time and group association of treated individuals, and to calculate observed foaling rates (foals:100 adults). We used foals:100 adults rather than foals:100 females because the sexes are not distinguishable from a distance (i.e., during aerial surveys), and to be comparable to foaling rates commonly derived from aerial survey estimates for adjacent and other free-ranging horse populations.

In addition to annual helicopter surveys, we also surveyed horses on the Refuge in June 2008, 2010–2012, and 2014 as part of a larger, interagency landscape-level effort, which included surveying 14 surrounding wild horse HMAs and HAs administered by the Bureau of Land Management. This double-observer count technique, detailed by Ransom (2012) and which includes an analysis of detection probabilities, used a fixed-wing aircraft (Cessna 185, 206, or 210) to fly parallel transects spaced 2.4 km apart at approximately 152 m AGL at approximately 100–140 knots. A pilot and 3 observers independently recorded GPS locations of horse groups when sighted, number of horses in each group, and age classification (foal vs. adult; 2010, 2011, and 2014 only). We used the observed June foaling rate (i.e., foals:100 adults) obtained from fixed-wing surveys to compare annual rates across populations within the larger landscape.

Because the recapture rate for individuals was 88% for the entire study period (i.e., 88% of individual horses captured, marked, and released back onto the study area were physically recaptured ≥ 1 yr later), we assumed this to be an essentially closed population, with minimal exchange of horses moving between the fenced study area and surrounding lands in any given year. This was further corroborated by data collected between 2009 and 2012 from horses marked with collars outfitted with GPS receivers (Collins et al. 2014), all of whom remained entirely within the study area (G. H. Collins, U.S. Fish and Wildlife Service, unpublished data). We derived the annual population size and number of horses by sex (sex ratio) and age class (foal [<1 yr], 1-yr-old, 2-yr-old, adult [≥ 3 yr]) each year by using the horse's estimated age at first capture to infer its age during each year it was part of the population (Table 1). We assumed all horses ≥ 3 years

Table 1. Number of feral horses by year and reproductive status (treated vs. untreated) derived by using the horse's estimated age at first capture to infer its age during each year it was part of the population, Sheldon National Wildlife Refuge, Nevada, USA, 2007–2014.

Age/sex class	2007	2008	2009	2010	2011	2012	2013	2014
Foal (<1 yr)	169	185	155	115	85	48	23	33
1-yr-old	141	169	127	96	67	56	27	7
2-yr-old	123	141	126	95	59	39	47	18
Adult F (≥ 3 yr)	353	428	402	402	347	320	253	113
Treated adult F	0	0	0	32	70	97	73	28
Untreated adult F	353	428	402	370	277	223	180	85
Adult M (≥ 3 yr)	424	471	512	501	461	474	426	226
Treated adult M	5 ^a	5 ^a	99	117	165	225	202	108
Untreated adult M	419	467	413	384	296	249	224	118
Other ^b	6	7	7	7	7	7	4	0

^a Includes surgically castrated males (i.e., geldings), which were treated and released prior to this study.

^b Horse/burro hybrids (i.e., mule or hinny), which are sterile. Not included in reproductive calculations, only in population estimates.

Table 2. Estimates of feral horse annual population sizes and growth rates, Sheldon National Wildlife Refuge, Nevada, USA, 2007–2014.

Year	Double observer estimate ^a (95% CI)	Direct count estimate ^b	Derived estimate ^c	Derived annual growth rate (λ) ^d
2007		786	1,216	—
2008	1,341 (1,215–2,043)	1,148	1,402	15.3% (1.15)
2009		1,210	1,329	–5.2% (0.95)
2010	1,236 (1,215–1,263)	1,053	1,216	–8.5% (0.91)
2011	1,070 (998–1,118)	1,104	1,026	–15.6% (0.84)
2012	908 (865–934)	973	944	–8.0% (0.92)
2013		831	780	–17.4% (0.83)
2014	452 (394–505)	411	397	–49.1% (0.51)

^a Fixed-wing survey with corrected population estimate using sighting probabilities; no fixed-wing surveys conducted in 2007, 2009, or 2013. Individual survey results can be found in Lubow (2009), Lubow et al. (2010), Lubow (2011), Manning (2013), and Lubow (2015).

^b Helicopter survey with uncorrected direct (i.e., raw) count.

^c Derived by using the horse's estimated age at first capture to infer its age during each year it was part of the population.

^d From derived population estimate. Declining values for 2008–2014 represent the combined result of removals and fertility control treatments.

old to be capable of reproducing (Garrott and Taylor 1990) unless treated with fertility control.

Foal mortality in free-roaming horse populations is highest during the first 1–2 months of life (Welsh 1975, Boyd 1979, Berger 1986, Turner and Morrison 2001). As such, we defined foal recruitment as foals that survived to October each year. We derived the actual number of foals and actual foaling rate (foals/adults) for each year. We calculated estimated annual foal recruitment as the difference between observed (Jul) and actual (Oct) foaling rates. In 2007 and 2008, prior to fertility control treatments, the derived ratio of recruited foals to adult females averaged 45% (47.9% and 43.2%, respectively), that is, an average of 45% of all potentially reproductive adult females (≥ 3 yr) recruited foals each year. Using that average, for each year, we estimated the number of recruited foals that would have been expected had no fertility control treatments been applied (adult females $\times 0.45$) and the expected foaling rate without treatment (expected foals/adults).

To infer the relative effectiveness of each treatment type, we calculated the expected number of recruited foals if only females were treated ($[\text{adult F} \times 0.45] - [\text{treated F} \times 0.45]$) and divided by the number of adults to calculate the foaling rate considering treated females only for each year. We calculated the fecundity of reproductive females exposed to treated males present in the population as the derived ratio of number of foals to untreated adult females. We performed statistical analyses following Wilkinson (1990). We used Pearson's chi-square to test for differences in survival rates (i.e., recapture rates) between treated and untreated horses. We used multiple regression analysis of variance to determine whether 1) the number of treated males or females was correlated with group size as observed during aerial surveys; and 2) the number of foals was correlated with group size, the number of treated males, or number of treated females; $P \leq 0.05$ was considered statistically significant.

RESULTS

Between 2008 and 2014, we captured 1,873 individual feral horses. The population occupying the Refuge was estimated to have reached a high of around 1,400 animals in 2008 and, with the exception of 2007, both aerial survey techniques

used to estimate the size of the feral horse population were in close agreement with derived estimates of population size (Table 2). The population's adult sex ratio averaged from 127.2 males:100 females (2007–2012) to 172.2 males:100 females (2013–2014; Table 1). For recruited foals, the sex ratio averaged 90.2 males:100 females for 2007–2014 (range = 68.2–120.0 M:100 F).

Estimated ages of captured horses ranged from dependent foals at 2–3 months old to 30 years old for males and 26 years old for females. Estimated ages of untreated females with dependent foals ranged from 2–22 years old, with foal recruitment peaking for females at 3–11 years old (79.1%; Fig. 1). Estimated ages of fertility control treated males ranged from 1–27 years old (83% were ≥ 7 yr old) and for fertility control treated females 2–26 years old (84% were ≥ 7 yr old). Recapture rates (i.e., survival rates) for individual horses were 85.3% for released females ($n = 150$) and 89.2% ($n = 278$) for released males across the period of study. Survival rates for released females that received fertility control treatment (85.1%, $n = 114$) did not differ from females that were released without treatment (86.1%, $n = 36$; $\chi^2 = 0.023$, $P = 0.880$). Also, survival rates for released males that received fertility control treatment (89.2%, $n = 268$) did

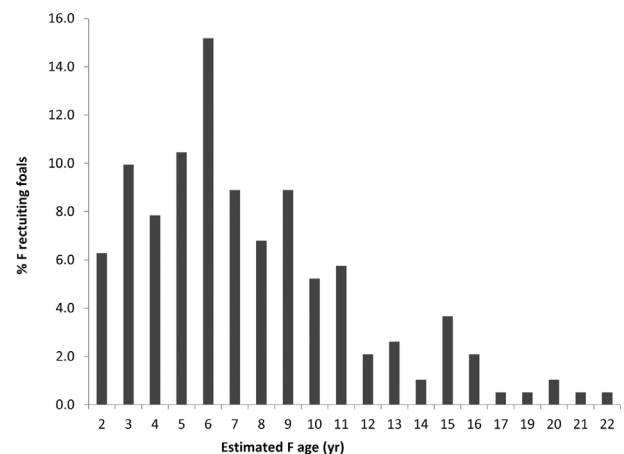


Figure 1. Estimated ages of untreated female feral horses recruiting foals (accompanied by dependent foals in the fall each year), Sheldon National Wildlife Refuge, Nevada, USA, 2008–2014.

not differ from those that were released untreated (90.0%, $n = 10$; $\chi^2 = 0.007$, $P = 0.935$). Of the treatments applied to released males, 51% received surgical vasectomies ($n = 137$) and 47% were chemically epididymectomized ($n = 126$); we also recaptured 5 males that were surgically castrated and released prior to this study (~ 2005). The percent of treated individuals in the population ranged from 7.4–35.3% each year, with 8.0–30.3% for females and 19.3–47.8% for males (Table 1).

Based on helicopter surveys, horse group sizes in July did not differ for 2008–2011, averaging 9.9 individuals/group (range = 1–115 $\pm$ 13.9 [SD], $n = 446$ groups). Group sizes were smaller in 2012–2013 ($\bar{x} = 6.2$ horses/group, range = 1–63 $\pm$ 7.6, $n = 291$ groups). We were able to determine the sex composition for 61% of the groups we observed during helicopter survey efforts ($n = 737$ groups) using the combined presence of foals and marked individuals. Of those, 48.4% were mixed-sex groups (≥ 1 M and ≥ 1 F; $n = 357$) and 13.1% were solitary animals ($n = 97$); the sex composition of the remaining groups ($n = 283$) could not be determined (i.e., no foals present or combination of marked individuals). Of the solitary animals documented, 23.7% were treated males ($n = 23$ observations); there were no observations of solitary treated females. Because they were not visibly marked, it is unknown how many of the remaining solitary individuals were untreated males versus untreated females. However, during captures in 2013 and 2014, the number of horses captured alone was predominantly untreated males; therefore, it is reasonable to assume that the majority of the remaining solitary animals observed during helicopter surveys were also untreated males.

The number of treated males in a group was positively correlated to group size based on helicopter surveys (i.e., larger groups had more treated M; $R^2 = 0.765$, $F_2 = 1,197.785$, $P < 0.001$), although the number of treated females was not ($R^2 = 0.000$, $F_2 = 0.348$, $P = 0.706$). Of groups containing multiple treated males (≥ 2 treated males; $n = 106$ groups), 70.0% were mixed-sex groups ($n = 71$) and 33.0% ($n = 35$) were groups of undetermined sex composition. As an example, 1 mixed-sex group of 34 horses observed in 2013 comprised 16 treated males, 4 treated females, 13 untreated (i.e., sex unknown) individuals, and 1 foal.

Overall, each horse group (>1 horse) averaged 1.5 ± 2.7 foals/group ($n = 396$ groups) for 2008–2011 and 0.50 ± 0.81 foals/group ($n = 244$ groups) for 2012–2013 based on helicopter surveys. For groups with no fertility control treated horses, the average number of foals/group was 1.2 ± 2.3 ($n = 402$ groups). Not surprisingly, the number of foals in a group was positively correlated to group size; larger groups had more foals ($R^2 = 0.702$, $F_1 = 1,731.924$, $P < 0.001$). For groups with ≥ 1 treated males, the average number of foals/group decreased as the number of treated males within the group increased (1.05, 0.68, and 0.65 foals/group for 1, 2, or 3 treated males, respectively). A similar pattern was observed for groups with ≥ 1 treated females (0.67 and 0.56 foals/group for 1 or 2 treated females, respectively). However, the best predictor for the number of foals within a group was the interaction between group size and both treatments (group size $\times$ no. treated females $\times$ no. treated males; $R^2 = 0.769$,

$F_3 = 816.733$, $P < 0.001$). Larger groups had more foals ($\beta = 0.921$, $t_3 = 49.469$, $P < 0.001$), but the number of foals decreased correspondingly with increasing numbers of treated females ($\beta = -0.071$, $t_3 = -3.685$, $P < 0.001$) and treated males ($\beta = -0.238$, $t_3 = -11.960$, $P < 0.001$) within a group.

The foaling season on the Refuge ranged from February to September, as estimated by ages of foals captured in the fall. The peak of foaling season was between April and June (83.2% of foals born), with on average 90.8% of foals on Sheldon Refuge born by the end of June each year. In comparing peak foaling rates across the larger landscape based from fixed-wing surveys in June 2010, 2011, and 2014, values within adjacent HMAs averaged annually between 7.6 foals:100 adults and 21.0 foals:100 adults compared to the Refuge's average of 7.4 foals:100 adults; the highest observed June foaling rate was 32.2 foals:100 adults documented in the Carter Reservoir HMA in 2014 (Table 3). Observed foaling rates based on helicopter surveys between 2008 and 2014 for the Refuge population ranged from 6.0 foals:100 adults to 18.0 foals:100 adults (Table 4). Actual foaling rates for the Refuge population derived from captured individuals ranged annually from 3.4 foals:100 adults to 21.8 foals:100 adults and were comparable to annual observed estimates from July helicopter surveys (Table 4). Estimates of annual foal recruitment (post-Jul) averaged 100.1% (range 97.4–103.0%); values $>100\%$ represent the small number of foals born after June.

The application of combined fertility control treatments resulted in a decline in the population-level actual foaling rate from >20.0 foals:100 adults to <4.0 foals:100 adults within 4 years (Table 4). In our population, a greater proportion of the males received treatment compared to the number of treated females. We were able to infer that treating approximately 30% of the female population had the potential to result in substantial declines in the expected foaling rate (>20 foals:100 adults with no treatment vs. $\bar{x} = 12.0$ foals:100 adults with only

Table 3. Comparative peak foaling rates of feral horses (foals:100 adult horses) within Sheldon National Wildlife Refuge, and adjacent Bureau of Land Management Herd Management Areas (HMA) and 1 Herd Area (HA) as estimated from fixed-wing aerial survey efforts in June, 2010, 2011, and 2014, Oregon and Nevada, USA.

Survey area	Comparative peak foaling rate			
	2010	2011	2014	$\bar{x}$
Sheldon National Wildlife Refuge, OR	11.4	5.4	5.4	7.4
Beatty Butte HMA, OR	21.6	21.6	19.8	21.0
Bitner HMA, NV	17.5	9.8	11.4	12.9
Carter Reservoir HMA, NV	— ^a	4.7	32.2	18.4
FoxHog HMA, NV	17.2	14.7	8.6	13.5
HighRock HMA, NV	28.8	14.5	7.6	17.0
Massacre Lakes HMA, NV	13.0	3.3	6.5	7.6
NewYears Lake HA, NV	12.4	11.9	16.2	13.5
NutMtn HMA, NV	— ^a	12.1	8.3	10.2
WallCanyon HMA, NV	20.8	19.0	2.8	14.2
Black Rock Range East HMA, NV	16.9	4.0	13.7	11.5
Black Rock Range West HMA, NV	17.6	— ^a	12.3	15.0
Calico Mtns HMA, NV	15.6	13.1	14.9	14.5
Granite Range HMA, NV	30.5	8.3	5.9	14.9
Warm Springs Canyon HMA, NV	16.3	17.3	8.5	14.0

^a Sample size too small for estimate.

Table 4. Feral horse foaling rates for observed (from helicopter surveys), actual (derived from known captured individuals), expected without treatments, and expected with treated females only. We also provide fecundity for untreated females exposed to treated males (no. foals/untreated F) and percent of the population treated by sex (% treated), Sheldon National Wildlife Refuge, Nevada, USA, 2007–2014.

Foaling rates (foals:100 adults)					
Year	Observed	Actual ^a	Expected without treatment	Expected with treated F only (% treated F)	F fecundity with treated M (% treated M)
2007		21.8	20.4		0.48 (1.2)
2008	18.0	20.6	21.4		0.43 (1.1)
2009	14.0	17.0	19.8		0.39 (19.3)
2010	13.0	12.7	20.0	18.4 (8.0)	0.31 (23.4)
2011	11.0	10.5	19.3	15.4 (20.2)	0.31 (35.8)
2012	8.0	6.0	18.1	12.6 (30.3)	0.22 (47.5)
2013	6.0	3.4	16.8	11.9 (28.9)	0.13 (47.4)
2014	9.0	9.7	15.0	11.3 (24.8)	0.39 (47.8)

^a Includes the combined effects of both treatment groups.

females treated, $\bar{x}$ = 28% treated). In addition, treating approximately 23–47% of the male population also likely contributed to substantial declines (30–72%) in untreated female fecundity after 2007–2008 (Table 4).

DISCUSSION

The fertility control treatments we applied did not affect the survival of horses post-release. In addition, fertility control efforts were effective in reducing the population-level annual foaling rate within a short period of time (from >20% to <4% within 4 years). Annual foaling rates across the larger area peaked in June but were variable between years and across the larger landscape. Our estimates of annual foal survival in the Refuge population were high (>97%) and although we were unable to account for potential overwinter mortality during a foal's first year, we suspect it was a small influence on the Refuge, particularly given the high recapture rates over the course of this study. This indicates that free-roaming horse composition counts from aerial surveys conducted in July and later can be used to reasonably approximate annual foal recruitment in populations where annual recruitment is generally high. Although not directly tested for, we did not detect any noticeable shifts in the timing of the foaling season in response to fertility control treatments as postulated by others (Garrott and Siniff 1992, Asa 1999).

Within the relatively open habitats of the Refuge, our population estimates generated from the fixed-wing double-count technique tended to underestimate population size, although the method provided the ability to calculate confidence intervals and account for animals not seen, and the derived population size generally fell within those ranges. In contrast, uncorrected direct counts via helicopter generally tended to overestimate population size, particularly as the population began to decline as a result of increasing management activities between 2011 and 2014, and did not provide the ability to estimate confidence intervals. Helicopters were used to conduct direct count surveys and to capture the horses, and as a result individuals became increasingly familiar with and reactive to the

presence of the helicopter over time; we did not observe the same degree of reactivity to the fixed-wing platform used during double-count surveys. We suspect the overestimation from the direct counts were the result of inadvertently double-counting a proportion of increasingly reactive individuals that were moving between areas and between days in response to the presence of the survey helicopter.

Limiting fertility through the use of immunocontraceptives and other techniques is becoming a more commonly considered tool for controlling free-roaming horse abundance; although the physiological changes that may accompany some of these tools have the potential to influence individual behavioral changes and alter family group structure and population dynamics (Nuñez et al 2010, Ransom et al. 2014b). Fertility control treated males in our study showed no difference in measurements of normal testicular endocrine function compared to untreated individuals (Scully et al. 2015), suggesting there should be no change in male breeding behaviors or social status (Asa 1999). We documented that all treated individuals appeared to maintain group associations and there were no groups consisting only of treated males or only treated females. We documented mixed-sex groups consisting of multiple treated males in all years. The social structure of free-roaming horse groups generally consists of a harem stallion, occasionally a satellite stallion, and females and offspring (Roelle et al. 2010). The duration of multiple-male bands has been thought to be short-lived, from several hours to a year (Berger 1986, Roelle et al. 2010), although Bowling and Touchberry (2001) reported that 39% of their harem bands contained multiple males; differences between populations relative to multiple male bands may be associated more with sex ratio and population density (Kirkpatrick and Turner 1986). Further, male offspring may remain with their maternal band for up to 4 years (Berger 1986) and this also could account for some of our observations. Regardless, the complexity of social behaviors among free-roaming horses is not entirely centered on reproductive receptivity, and fertility control treatments that suppress the reproductive system and reproductive behaviors should contribute to minimal changes to social behavior (Ransom et al. 2014a).

Cost is another factor for consideration, and there are 2 categories associated with fertility control in free-roaming horses: cost of the treatments themselves and costs associated with treatment application. The 2 commonly used temporary agents are formulations of porcine zona pellucida (PZP; ZonaStat-H and PZP-22; Science and Conservation Center, Billings, MT, USA) and are approximately \$35.00/dose and \$325.00/dose, respectively (A. B. Shepherd, Bureau of Land Management, personal communication). In comparison, the permanent techniques we used ranged from approximately \$125/horse to \$150/horse (i.e., vasectomy and ovariectomy, respectively). However, both temporary agents require repeated dosing approximately every 12 months to maintain reproductive control. Thus, assuming the average free-roaming horse lives to be at least 20 years old, estimated costs of re-dosing would range from \$590/horse to \$5,500/horse over the individual's lifetime. In addition are the costs associated with application; of the currently available techniques, all require the

animals to be captured and handled. Even in the case of temporary agents being used by the Bureau of Land Management, the horses are typically captured, transported to holding facilities (both temporary and permanent), and then held in captivity for days to months while individuals slated for treatment and release are selected (A. B. Shepherd, personal communication). Thus, although capture, transport, and holding would be a one-time expense in the case of permanent treatments, the repeated dosing required for temporary treatments also would require repeated handling and substantially increase the cost per horse (i.e., >\$1,000/horse/capture). Further, each additional capture event also increases the risk of injury or death to individuals. In very rare cases, some free-roaming horse herds have been sufficiently habituated to humans and are able to be approached (<36 m) and remotely darted with a temporary contraceptive agent (A. B. Shepherd, personal communication). In those specific circumstances, long-term reproductive control could potentially be maintained without repeated capture events; however, although this approach is gaining popularity with some members of the public, this scenario is not realistic for the majority of free-roaming horse herds occupying public rangelands in the western United States.

As discussed, social structure may be an important consideration in the efficacy of fertility control in free-roaming horses. For example, previous efforts to control fertility in male free-roaming horses reported that permanent sterilization limited to socially dominant males may be effective in reducing foaling rates in individual, stable groups. However, it was postulated that it might not effectively suppress overall population growth unless a large proportion of the males were treated (Garrott and Siniff 1992, Eagle et al. 1993, Ransom et al. 2014b). Hence, our efforts did not target only socially dominant individuals but sought to saturate the study area with permanently treated animals, both males and females, and as such, we saw an almost immediate reduction in foaling rates at the group- and population-levels. Our results indicate that a combination of effective measures are currently available that can reduce annual foaling rates without the majority of individuals maintained as non-reproductive, and that these measures can be used to successfully control population growth in large populations of free-roaming horses.

MANAGEMENT IMPLICATIONS

One primary advantage of permanent fertility control is that treated animals do not require repeated exposure to potentially risky capture and handling to maintain reproductive control. Our findings demonstrate that maintaining a proportion of a population as permanently non-reproducing has the potential to safely reduce annual foaling rates within a short period of time, and provide managers the ability to start to attain and then maintain free-roaming horse herds at desired management levels. Regardless of the technique selected, foregoing any measures to control annual foaling rates will require the continuation of frequent, high-profile, controversial capture operations, with the consequent, unsustainable management of free-roaming horses and associated declines in rangeland ecological health, unless even more drastic measures are undertaken.

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