



# Free-roaming horses disrupt greater sage-grouse lekking activity in the Great Basin

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## ABSTRACT

Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) and free-roaming horses (*Equus caballus*) co-occur within large portions of sagebrush ecosystems within the Great Basin of western North America. In recent decades, sage-grouse populations have declined substantially while concomitant free-roaming horse populations have increased drastically. Although multiple studies have reported free-roaming horses adversely impacting native ungulate species, direct interactions between free-roaming horses and sage-grouse have not been documented previously. We compiled sage-grouse lek count data and associated ungulate observations during spring of 2010 and 2013–2018. We used Bayesian multinomial logistic models to examine the response of breeding male sage-grouse to the presence of native (i.e. mule deer, pronghorn) and non-native (i.e. cattle, free-roaming horses) ungulates on active sage-grouse leks (traditional breeding grounds). We found sage-grouse were approximately five times more likely to be present on active leks concurrent with native ungulates compared to non-native ungulates. Of the four different ungulate species, sage-grouse were least likely to be at active leks when free-roaming horses were present. Our results indicate that free-roaming horse presence at lek sites negatively influences sage-grouse lekking activity. Because sage-grouse population growth is sensitive to breeding success, disruption of leks by free-roaming horses could reduce breeding opportunities and limit breeding areas within sage-grouse habitat.

## 1. Introduction

Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) are a sagebrush-obligate species that require specific habitat types within sagebrush communities during various life-history stages, such as nesting, brood-rearing, and wintering (Patterson, 1952). Accordingly, population viability largely hinges on a diversity of habitats across large spatial extents and resulting population trends can serve as a proxy for the ecological integrity of sagebrush ecosystems (Rowland et al., 2006). In recent decades, greater sage-grouse populations have declined substantially throughout their range in western North America (Garton et al., 2015). Declining populations have been attributed to multiple perturbations affecting sagebrush ecosystems in different portions of their range, including anthropogenic alterations associated with energy development (Green et al., 2017), wildfire and invasive grasses (Coates et al., 2016), and pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) expansion (Baruch-Mordo et al., 2013).

Expanding populations of free-roaming horses (*Equus caballus*) represent another significant stressor to sagebrush ecosystem processes

(Beever et al., 2018; Boyd et al., 2017). Although native North American horses became extinct following the Pleistocene, non-native horses imported during European settlement are now well-established across western North America (Beever et al., 2018). Free-roaming horse establishment was largely facilitated by The Wild Free-Roaming Horses and Burros Act of 1971 (Public Law 92–195, 1971) which, as amended, afforded protections to free-roaming equids on public lands and tasked the Bureau of Land Management (BLM) with managing the population on those lands. The BLM primarily manages free-roaming horses in designated Horse Management Areas (HMAs) and sets lower and upper population bounds that define an Appropriate Management Level (AML) to facilitate long-term management of these large herbivores within a designated area (BLM, 2010). The AML upper bound represents the threshold for range deterioration (BLM, 2010). Free-roaming horses are particularly ubiquitous in Nevada within the Great Basin, and the current population estimate of 46,974 horses in that state's HMAs exceeds the AML upper bound of 11,987 by 367% (BLM, 2020). The BLM also oversees Herd Areas (HAs) which are not managed with AMLs but comprise public lands that were occupied by horses when the Wild

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Horse and Burro Act passed (BLM, 2010). Currently, HMAs contain a majority of the free-roaming horses on public lands relative to HAS (BLM, 2020). However, population estimates within HMAs are not representative of the entire free-roaming horse population. Horses also use areas outside the jurisdiction of the BLM such as on state, private, and tribal lands (Beever et al., 2018; Hennig et al., 2018). Furthermore, population estimates for free-ranging large mammals are often difficult to calculate because detectability is compromised over large areas with heterogeneous terrain (Lubow and Ransom, 2016).

Given the rapid population increase, growing evidence suggests that free-roaming horses can directly and indirectly disrupt native wildlife populations inhabiting sagebrush ecosystems, yet most research has focused on intra-guild competition among large herbivores. For example, free-roaming horses monopolize and actively exclude native ungulates from limited water sources through interference competition (Hall et al., 2018). In contrast, relatively few studies have evaluated interspecific interactions between free-roaming horses and avian wildlife in sagebrush ecosystems, including sage-grouse. Potential for direct interactions exists given the high degree of range overlap between sage-grouse and free-roaming horses (Beever and Aldridge, 2011). Authors have suggested indirect impacts on sage-grouse by reductions in perennial vegetation cover and arthropod abundance, increases in annual grass cover and soil-surface hardness, and multiplicative effects with cattle grazing and drought (Beever and Aldridge, 2011; Davies et al., 2014). Aggressive or dominant behavior exhibited by free-roaming horses (Berger, 1985) that is directed towards sage-grouse, or avoidance by sage-grouse of space occupied by horses, could manifest as a type of competitive interaction that negatively affects sage-grouse reproduction but remains largely unquantified.

During spring, male sage-grouse congregate on traditional breeding grounds, known as leks, to court and mate with visiting females (Schroeder et al., 1999). Counts of males attending leks are a widely used index of sage-grouse population abundance (Connelly et al., 2003), so factors that influence behavior at leks have important ramifications on breeding success and accurate population estimation. Although sage-grouse demonstrate high site fidelity to individual leks (Fremgen et al., 2017), they are also sensitive to natural and anthropogenic disturbances that can reduce attendance rates and ultimately drive lek abandonment (Hess and Beck, 2012). Persistent disruptions at leks may present additional obstacles for population maintenance (Green et al., 2017) for a species that is already sensitive to relatively low reproductive rates (Taylor et al., 2012).

Our study objective was to identify outcomes of interactions between large herbivores on breeding sage-grouse by quantifying male sage-grouse lekking activity in relation to the presence of non-native (horses, cattle) and native (mule deer, pronghorn) ungulates across multiple leks at 14 sites in the Great Basin during 2010 and 2013–2018. Based on literature documenting intra-guild competition between horses and ungulates (Berger, 1985; Hall et al., 2018), we hypothesized that free-roaming horses would be most disruptive to sage-grouse lekking activity.

## 2. Methods

We compiled ungulate observations from two sources. Because of limited data during 2010, we compiled ungulate sightings recorded during lek counts within field notes. Ungulate sightings were not recorded during 2011 and 2012. By 2013, we established a protocol that recorded native and non-native ungulates on leks during lek counts. We conducted 3–4 surveys per known lek site during spring (March–May) across 14 study areas within California, Idaho, and Nevada during 2013–2018 (Fig. 1). Lek surveys typically lasted 10–15 min, were equally spaced through the breeding season and conducted between 30 min before sunrise and 90 min after sunrise in accordance with standardized lek survey protocols (Connelly et al., 2003). We used binoculars or a spotting scope to survey sage-grouse from a suitable location

with view of the entire lek. At lek survey locations, we recorded presence and behavior of all native and non-native ungulates when they were present within or on the lek perimeter boundary. While subjective to an extent, the boundary was determined by the perimeter of the outermost males with an approximate 10–20 m buffer. We categorized each lek as active or inactive. A lek was considered active if two or more breeding males were observed during at least two of the previous 5 years and inactive if two or more males had been observed only once during the previous 5 years. We compiled a subset of data consisting of counts for all active leks in which free-roaming horses or cattle (non-native ungulates), or mule deer or pronghorn (native ungulates) were observed at least once. Although burros were present at some sites, we did not observe them occupying sage-grouse leks. Lek surveys without any ungulates present were classified as “none”. We categorized male sage-grouse activity into three classes: present, absent, and flushed. Sage-grouse were considered present if they remained on the lek for the entire duration of the count without flushing; absent if they were not present at the established lek coordinates during a lek count, even if fresh sign was present or if a satellite lek was found in the vicinity; and flushed if they were present but then displaced from the lek by ungulate activity. We did not include five lek surveys in which multiple ungulate species were observed to simplify the analysis and facilitate interpretation.

We used a Bayesian multinomial logistic model (Darrah et al., 2018) to estimate the likelihood of sage-grouse activity in the presence of ungulates. The model took the form:

$$y_i \sim \text{multinomial}([P_{pi}, P_{ai}, P_{fi}], 1)$$

where sage-grouse activity  $y_i$  at each lek  $i$  follows a multinomial distribution. Possible sage-grouse activities were present ( $p$ ), absent ( $a$ ), and flushed ( $f$ ). We then regressed predictors of ungulate presence (i.e. horse, cattle, pronghorn, mule, none) on the likelihood of each sage-grouse activity. For example, the equation for sage-grouse absence took the form:

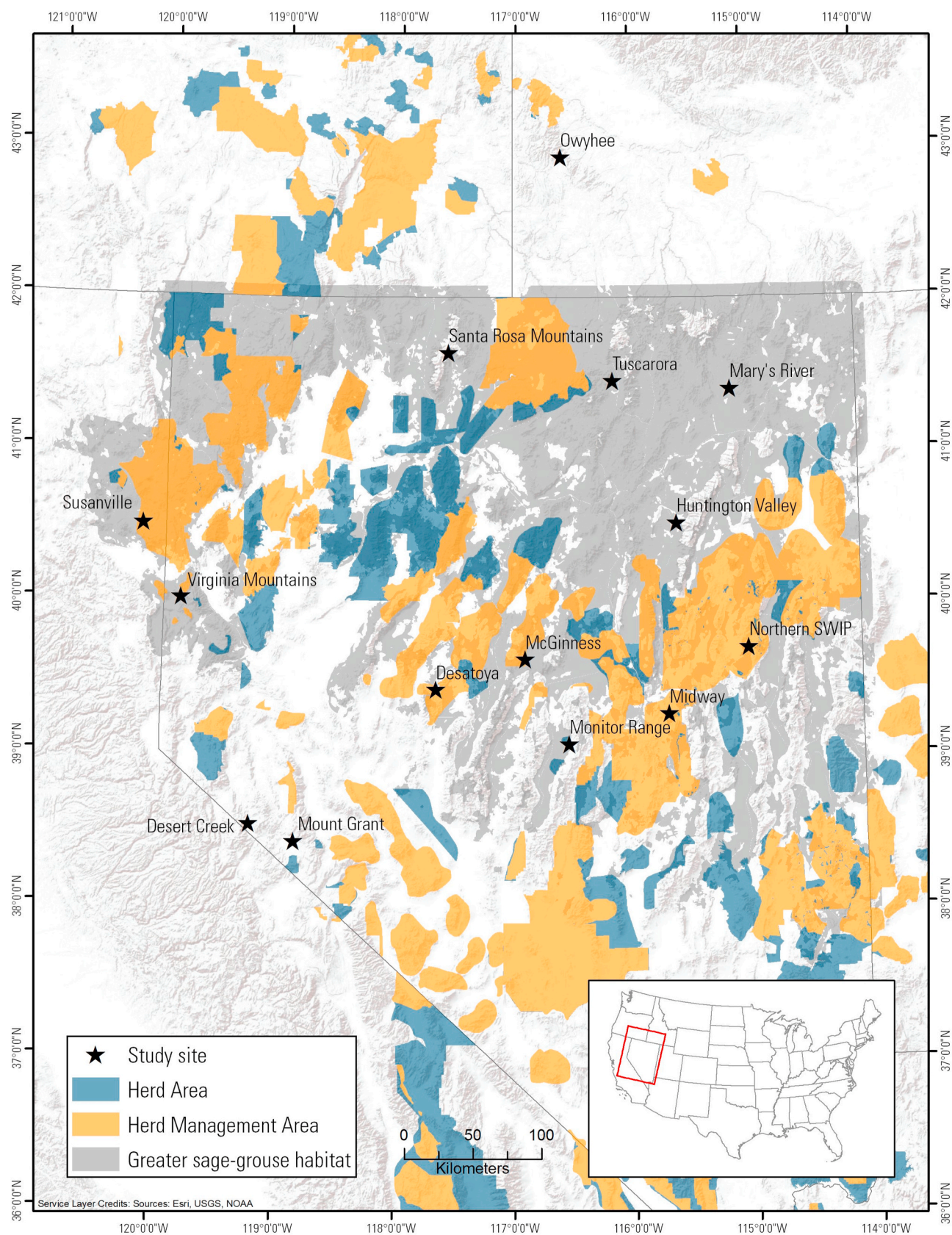
$$\eta_{ai} = \beta_0 + \beta_h x_i + \beta_c x_i + \beta_p x_i + \beta_m x_i + \beta_n x_i$$

where  $\eta_{ai}$  is the probability that sage-grouse were absent at lek  $i$ . The variable  $\beta_0$  represents the average rate of sage-grouse absence while  $\beta_h$ ,  $\beta_c$ ,  $\beta_p$ ,  $\beta_m$ , and  $\beta_n$  represent the effects of presence of horse ( $h$ ), cattle ( $c$ ), pronghorn ( $p$ ), mule deer ( $m$ ), and no ungulates ( $n$ ), respectively, on rates of sage-grouse absence, given conditions ( $x$ ) at lek  $i$ .

We conducted the Bayesian multinomial model analysis in R 3.4.3 (R Core Team, 2018) and JAGS 4.2.0 using the package rjags (Plummer, 2016). We ran 10,000 iterations of three chains with a thinning rate of two and a burn-in of 1000. We evaluated chain convergence visually using trace plots and numerically using the Gelman-Rubin diagnostic (R-hat; Gelman and Hill, 2007). We determined that chains had converged when R-hat < 1.1 for all parameters in the model. We used uninformative priors with normal distributions of mean zero and precision 0.01 for all parameters.

## 3. Results and discussion

We observed free-roaming horses on leks at five study areas: Desatoya, Huntington Valley, Midway, Monitor Range, and Northern SWIP. Excluding Huntington Valley, these overlapped with the Desatoya HMA, Pancake HMA, Butler Basin HA, and Triple B HMA, respectively. We compiled data from 255 lek surveys for 2010 and 2013–2018 and recorded 89 instances of single native ( $n = 74$ ) and non-native ( $n = 15$ ) ungulate species at active sage-grouse leks at all study areas. Pronghorn were the most commonly observed ungulate during surveys ( $n = 60$ , 67.0% of ungulate observations), followed by mule deer ( $n = 14$ , 16.0%), free-roaming horses ( $n = 9$ , 10.0%), and cattle ( $n = 6$ , 7.0%). Of the six lek surveys where cattle were present, male sage-grouse were present at two (33.3%), absent at three (50.0%), and flushed at one



**Fig. 1.** Study sites of sage-grouse lek surveys and ungulate surveys in relation to Herd Areas, Herd Management Areas, and sage-grouse habitat (Coates et al., 2020) during 2010 and 2013–2018.

(16.7%). Of the nine lek surveys where free-roaming horses were present, male sage-grouse were present at one (11.1%), absent at seven (77.8%), and flushed during one (11.1%). Of the 74 lek surveys where single native ungulate species were present, male sage-grouse were present at 54 surveys (73.0%), absent at 17 (23.0%), and flushed during three (4.0%). Pronghorn appear to have been responsible for the three flushes. Otherwise, observers generally noted that sage-grouse appeared unperturbed by pronghorn and mule deer and continued displaying.

Sage-grouse activity varied significantly according to ungulate status and species (Fig. 2). Sage-grouse were approximately 5 times more likely to be present concurrent with native ungulates (median: 62.92%, 85% CI: 25.17–85.71%) than when non-native ungulates were present (12.85%, 85% CI: 2.07–44.14%; Fig. 2a) on the lek. Additionally, sage-grouse were 2.6 times more likely to flush in the presence of non-native ungulates (13.75%, 85% CI: 0.88–65.33%) than in the presence of native ungulates (5.28%, 85% CI: 0.75–25.02%). Mule deer and pronghorn were comparatively innocuous, with predicted probabilities of sage-grouse absence at 24.6 (85% CI: 2.04–46.39%) and 19.4% (85% CI: 7.11–32.66%; Fig. 2b), respectively. Predicted probabilities for sage-grouse being present concurrently with mule deer or pronghorn or in the absence of all ungulates were 74.4 (85% CI: 52.76–96.75%), 75.6 (85% CI: 62.84–88.29%), and 83.6% (85% CI: 52.01–96.36%), respectively (Fig. 2b). Meanwhile, predicted probabilities for sage-grouse being present concurrently with cattle or horses were 43.0 (85% CI: 17.15–76.04%) and 17.1% (85% CI: 4.81–38.83%), respectively. Furthermore, the predicted probabilities for sage-grouse absence in the presence of cattle or horses were 44.1 (85% CI: 13.0–73.82%) and 75.4% (85% CI: 50.94–91.40%), respectively. Overall, sage-grouse were least likely to be present and more likely to be absent when horses were on the established leks.

Our findings suggest that male sage-grouse respond differently to native and non-native ungulates on leks (Fig. 3). When pronghorn or mule deer were present, sage-grouse generally appeared unperturbed and continued displaying. In contrast, sage-grouse were usually not detected when free-roaming horses or cattle were on the lek. To our knowledge, our observations are the first recorded interactions between free-roaming horses and male sage-grouse on leks. We only directly observed one event in which horses flushed sage-grouse but, knowing that horses were near other leks, we surmise that similar events occurred outside of the lek count observation period for vacant leks or that the presence of horses discouraged sage-grouse from occupying the lek. This inference is supported by our discovery of a horse-occupied lek containing fresh sage-grouse fecal droppings. Other instances occurred

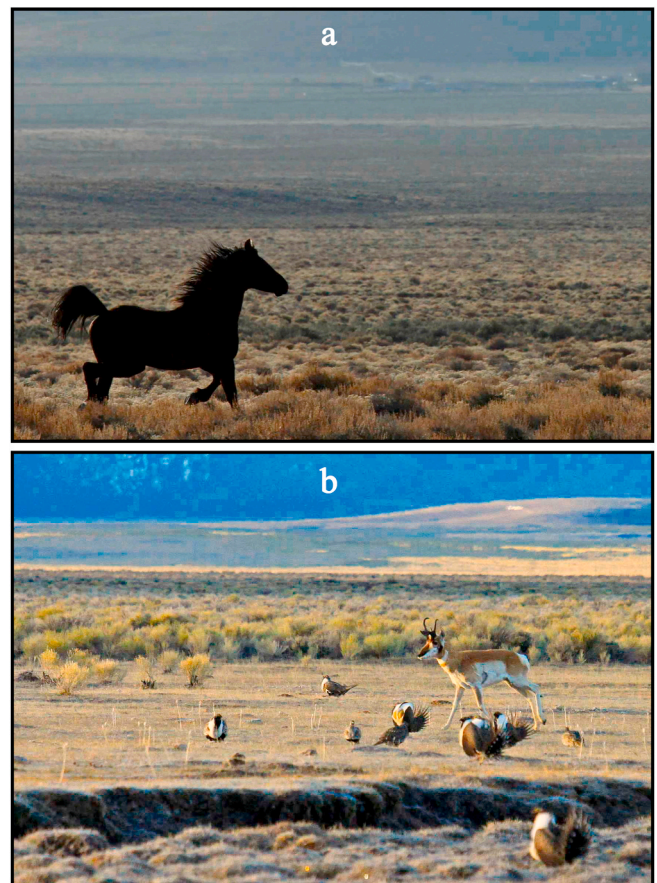


Fig. 3. Ungulates on leks: (a) Free-roaming horse exhibiting aggressive posturing towards observer (b) Pronghorn crossing lek in presence of sage-grouse. Photos by Tatiana Gettelman.

where sage-grouse were absent from a lek only when free-roaming horses were present. For example, one lek averaged 12 male sage-grouse and another averaged nine males when horses were absent. In contrast, both leks were devoid of sage-grouse when horses were present. Lastly, sage-grouse did not return to some leks at subsequent lek counts following visitation by horses but may have formed or moved to nearby satellite leks. Since we did not individually mark sage-grouse

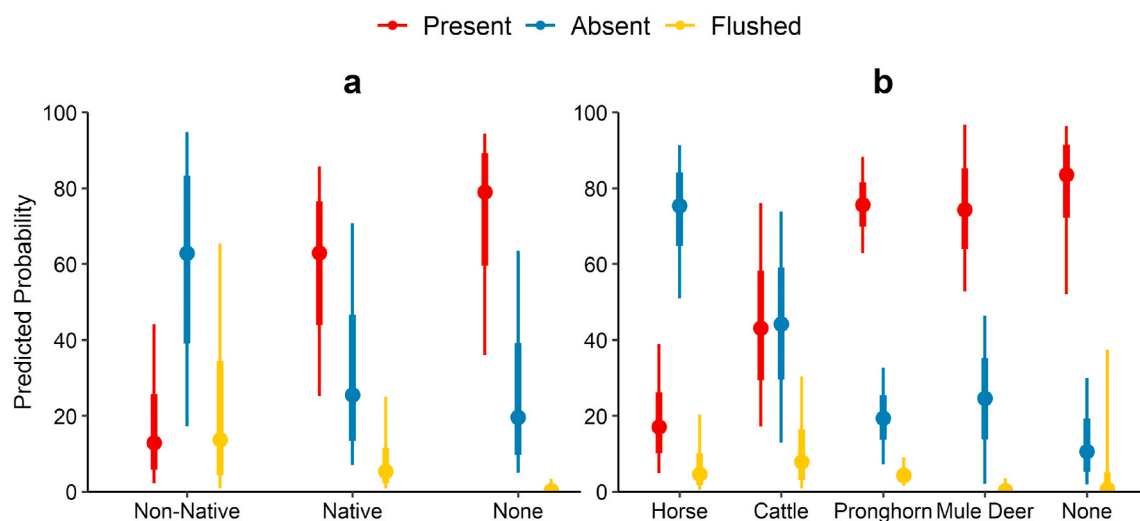


Fig. 2. Estimated median probabilities of sage-grouse activity according to ungulate (a) native status and (b) species in 2010 and 2013–2018. Points represent posterior median estimates, thick lines represent 50% credible intervals, and thin lines represent 85% credible intervals.

with identifiable markers, it is difficult to ascertain whether the satellite leks were composed of the same individuals as the original leks. Nevertheless, we no longer detected male sage-grouse at the original location following intrusion by free-roaming horses. Although we seldom observed concurrent occupation of a lek by both sage-grouse and horses during our lek surveys, we have previously observed at least two occasions of horses exhibiting aggressive (e.g. kicking) or playful behavior towards sage-grouse.

We speculate that differences in sage-grouse lekking activity may be influenced potentially by differences in size, novelty, or behavior of Great Basin ungulates. First, sage-grouse were most likely to be absent in the presence of cattle and horses, which were the largest ungulates observed in our study. Sage-grouse may assess ungulates as a threat beyond a certain body size threshold that pronghorn and mule deer fall under. Second, sage-grouse may be less accustomed to free-roaming horses and cattle introduced to the Great Basin during European settlement in comparison to native ungulates. Finally, behavioral differences between ungulate species may account for the variation in sage-grouse response. Despite similarities in time since introduction and size, sage-grouse were more likely to be present when cattle were present relative to horses. Although our data do not allow identification of the behavioral mechanisms driving decreased lekking activity in association with free-roaming horses, competitive amensalism, where one organism causes a negative effect on another without being affected in return (Odum, 1983), is possible given well-documented aggressive behavior displayed by horses towards conspecifics and native ungulates (Berger, 1985; Hall et al., 2018). Although we do not know whether this behavior manifests through current (e.g. horses kicking and chasing sage-grouse) or past (e.g. sage-grouse vacating leks when horses come near because of past negative experience) interactions, future studies that utilize remote videography on leks likely to encounter horses would help answer this important question.

Free-roaming horses present a unique management problem in the United States (Beever et al., 2018; Scasta et al., 2018). Although cattle distribution and grazing impacts on native wildlife can be limited through fencing, appropriate grazing practices, and permitting; free-roaming horse management heavily relies on managing population levels (Beever and Aldridge, 2011). The BLM currently attempts to limit horse population growth through immunocontraception and by periodic gathers where animals are removed from the range and brought into captivity for adoption (Beever et al., 2018). Protections under the Wild Free-Roaming Horse and Burro Act of 1971 severely limit the development of additional management options that could mitigate the potential impact of free-roaming horses on sage-grouse. This is especially important owing to extensive overlap of the two species and mutual need for limited resources (e.g. water, herbaceous forage) across large portions of the Great Basin (Fig. 1).

Mating success for male sage-grouse is conditional on the amount of time that they spend displaying on the lek (Gibson and Bradbury, 1985). Despite our limited sample sizes for non-native ungulates, our results strongly indicate that free-roaming horses reduce lekking activity when they do visit leks and constitute a non-trivial stressor to sage-grouse population growth through reduced breeding opportunities to a species already sensitive to disturbance. Negative effects on sage-grouse population growth can compound further as the reproductive cycle progresses, particularly when mesic resources required during the brood-rearing phase become degraded by horse utilization (Beever and Aldridge, 2011; Davies et al., 2014). Improved understanding of free-roaming horse resource use and movements within sagebrush ecosystems, and sage-grouse response to free-roaming horse presence and behavior at crucial life stages may help develop practices that mitigate ecological impacts of free-roaming horses. We propose that managers and researchers account for free-roaming horse presence as a potential source of bias when conducting annual sage-grouse lek surveys, as our results suggest that they can influence observed counts. Population assessments may be underestimated if free-roaming horses disrupt lek

activity prior to counting male sage-grouse during the survey.

Finally, the ecological impacts of free-roaming horses are not limited to the United States. Free-roaming horses occupy a wide range of ecosystems across multiple countries and are associated with reductions in environmental quality, ecosystem function, and plant community composition (Eldridge et al., 2020). Community composition, which includes measures of species diversity and richness, appears particularly susceptible to free-roaming horse activity in arid environments (Eldridge et al., 2020). Globally, most studies on free-roaming horse impacts have primarily focused on plants and soil while few have investigated responses by other animals (Eldridge et al., 2020). However, studies on responses by birds, reptiles, and small mammals to free-roaming horses are increasing (Hall et al., 2016; Cherubin et al., 2019). Our study has filled a much-needed gap in our understanding of how native non-ungulate animals respond to free-roaming horses outside of a direct competition perspective. Additional research on interactions between free-roaming horses and wildlife both in the United States and abroad is imperative to allow a more comprehensive understanding of free-roaming horse impacts on biodiversity and ecosystems. Ultimately, filling such knowledge gaps will help inform management decisions, especially those involving species of conservation concern.

#### CRediT authorship contribution statement

**Diana A. Muñoz:** Data curation, Formal analysis, Writing - original draft, Visualization, Methodology, Writing - review & editing. **Peter S. Coates:** Conceptualization, Investigation, Supervision, Project administration, Funding acquisition, Visualization, Methodology, Writing - review & editing. **Mark A. Ricca:** Project administration, Funding acquisition, Writing - original draft.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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