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The Effects of Shed Antler Hunting on Ungulate Movement, Space-Use and Resource Selection

Steven B. Bates

A dissertation submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

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ABSTRACT

The Effects of Shed Antler Hunting on Ungulate Movement, Space-Use and Resource Selection

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Doctor of Philosophy

Shed antler hunting has increased in popularity during the past decade, but little is known about how this recreational activity affects ungulate movements and space use. We placed geographic positioning system (gps)-collars on 133 bighorn sheep (*Ovis canadensis*), bison (*Bison bison*), and mule deer (*Odocoileus hemionus*) to quantify their movements, space use, and resource selection during shed antler hunts on Antelope Island Utah, USA, from 2012 to 2015.

In Chapter 1, we calculated means and 95% confidence intervals for distance moved during 90-minute segments (16 points/day); pre-event (control, seven consecutive days prior to event), event (one to two days), and post-event (seven consecutive days after event) for shed hunts and helicopter surveys. We also compared each species use of space during these events. Female bighorn sheep did not increase distance moved or substantially change space use during shed hunts and helicopter surveys. Male bighorn sheep increased distance moved 41% on average during shed hunts and by 2.02 times during helicopter surveys but did not change space use during those events. Female bison increased distance moved 15% on average during shed hunts and 30% during helicopter surveys. Mule deer increased distance moved and altered space use the most during shed hunts; females increased distance moved 97%, and 54% of females moved a mean distance of 742 ± 642 (SD) m outside of their home ranges during those hunts for a mean of 9.2 ± 9.4 hours (range = 1.5 to 41 hr). Male mule deer increased distance moved by 2.10 times on average during shed hunts, and 82% of males moved a mean distance of 1,264 ± 732 m outside of their home ranges during those hunts for a mean of 12.6 ± 7.6 hours. In Chapter 2, we analysed 177,138 gps locations to quantify space use and movements of 12 mule deer and 25 bighorn sheep in response to shed hunting. Twenty-five percent of mule deer and 44% of bighorn sheep responded differently to shed antler hunting across two years. We tracked four mule deer for three and four consecutive years, and all those deer responded to shed hunting differently across subsequent years. Mule deer increased movement (paired t-test = -3.9, $p < 0.001$) during shed hunts compared to pre-event movement. Bighorn sheep increased movement (paired t-test = -6.9, $p < 0.001$) during shed hunts compared to pre-event movement. In Chapter 3, we placed gps-collars on 27 mule deer and 29 bighorn sheep to quantify habitat selection during shed hunts compared with resources selection seven days prior and seven days following these hunts. Mule deer ($n = 6$) remained in the same area (response 1), moved to another area within their home range ($n = 7$; response 2), or moved beyond their home range boundaries ($n = 14$; response 3). Bighorn sheep ($n = 17$) remained in the same area (response 1), moved to another area within their home range ($n = 11$; response 2), or moved beyond their home range boundaries ($n = 1$; response 3). Shifts in resource selection by mule deer and bighorn sheep were detected during shed hunts regardless of the initial response of the individual animal during those hunts.

Keywords: habitat, movements, resource selection, shed antler hunting, space use, ungulate

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CHAPTER 1

Comparison of Effects of Shed Antler Hunting and Helicopter Surveys on Ungulate Movements and Space Use

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Doctor of Philosophy

ABSTRACT

Shed antler hunting (i.e., collecting cast cervid antlers) has increased in popularity during the past decade, but little is known about how this recreational activity affects ungulate movements and space use. We placed global positioning system (GPS)-collars on 133 female and male bighorn sheep (*Ovis canadensis*), bison (*Bison bison*), and mule deer (*Odocoileus hemionus*) to quantify their movements and space use during shed antler hunts compared with those behaviors during helicopter surveys in Utah, USA, from 2012 to 2015. For each species, we calculated means and 95% confidence intervals for distance moved during 90-minute segments (16 points/day); pre-event (control, 7 consecutive days prior to event), event (1–2 days), and post-event (7 consecutive days after event) for shed antler hunts and helicopter surveys. We also compared each species use of space during these events. Female bighorn sheep did not increase distance moved or substantially change space use during shed antler hunts and helicopter surveys. Male bighorn sheep increased distance moved 41% on average during shed antler hunts and by 2.02 times during helicopter surveys but did not change space use during those events. Female bison increased distance moved 15% on average during shed antler hunts and 30% during helicopter surveys. Mule deer increased distance moved and altered space use the most during shed antler hunts; females increased distance moved 97%, and 54% of females moved a mean distance of 742 ± 642 (SD) m (range = 9–3,778 m) outside of their home ranges during those hunts for a mean of 9.2 ± 9.4 hours (range = 1.5 to 41 hr). Male mule deer increased distance moved by 2.10 times on average during shed antler hunts, and 82% of males moved a mean distance of 1,264 ± 732 m (range = 131–3,637 m) outside of their home ranges during those hunts for a mean of 12.6 ± 7.6 hours (range = 4.5–33 hr). Our results provide timely information about how legal shed antler hunting affects movements and space use of female and male ungulates, especially mule deer, and can guide the conservation of ungulate populations and their habitat.

INTRODUCTION

Human recreation in natural areas can influence movements and space use of wildlife (Kerbiriou et al. 2009, Gutzwiller et al. 2017). Additionally, wildlife management activities, including ground and aerial surveys, can also affect movements and space use of wildlife (Frid and Dill 2002, Rabe et al. 2002, McRoberts et al. 2011). Changes in movements and space use can influence the ability of displaced animals to acquire resources in their home ranges (Belotti et al. 2012, Heinemeyer et al. 2019) and can also increase predation risk (Rominger et al. 2004, McKinney et al. 2006). Minimizing conflict between recreationists and wildlife is a pressing challenge for wildlife managers (Larson et al. 2016, Gutzwiller et al. 2017). As these conflicts increase in natural areas, successful habitat conservation and land-use planning will depend on identifying how wildlife react to varying levels of human activities (Dzialak et al. 2011, Harju et al. 2011).

Disturbance to wildlife from recreation is increasing as human populations expand and standards of living increase. People now have greater access to—and spend more time recreating in—natural areas (Gander and Ingold 1997, Huhtala and Pouta 2009). This increased access to, and time in, natural areas can result in varying degrees of disturbance to wildlife, including disrupting activity and movement patterns (Gander and Ingold 1997, Stankowich 2008). For example, mule deer (*Odocoileus hemionus*) moved away from humans that were afoot, on bicycle, or riding snowmobiles (Freddy et al. 1986, Taylor and Knight 2003a). Bighorn sheep (*Ovis canadensis*) were displaced by individual or small groups of hikers, mountain bikers, and vehicles (Papouchis et al. 2001, Wiedmann and Bleich 2014, Sproat et al. 2019). Additionally, elk (*Cervus canadensis*) movement increased in response to off-road activity of bikers, hikers, equestrian riders, and all-terrain vehicle enthusiasts (Naylor et al. 2009, Wisdom et al. 2018). Little is known, however, about how wildlife movements are influenced during events where recreationists are competing against each other for collection of a limited, valuable resource, such as shed antlers.

Ungulate antlers have been prized throughout human history. Antlers historically provided tools, medicines, and spiritual connection to nature (Olsen 1994, Villa and D'Errico 2001, Tejero et al. 2012). The importance of antlers to humans has been documented since Paleolithic times (Vitezović 2017), frequently appearing in pictographs, used in jewelry, and as material for tools (Villa and D'Errico 2001). These boney structures have also been used in Asia for medicinal compounds for millennia (Wu et al. 2013). Antlers were also important in early European history; trophy hunting was considered a prestigious practice. Trophy hunting is well developed, has a strong competitive component, and is frequently practiced in many parts of the world (Monteith et al. 2013, Schoenebeck and Peterson 2014). Although antlers have long been used and valued by humans, shed antler hunting for recreation—and as a source of income—is a relatively modern activity increasing in popularity during the past decade (Western Association of Fish and Wildlife Agencies 2015, Mimiaga 2018). No studies have determined how shed antler hunting influences ungulate movements and space use, and how this recreational activity compares with other activities.

Another activity that can influence movement and displace wildlife is helicopter surveys, which is a technique commonly used by biologists to estimate and monitor ungulate populations (Rabe et al. 2002, Reilly et al. 2017). Biologists use aircraft (small airplanes and helicopters) to conduct these surveys, often flushing and counting animals. These surveys can influence movement and space use of ungulates (Bleich et al. 1990, McRoberts et al. 2011). For example, Dall's sheep (*O. dalli*) were observed fleeing up to 1.5 km while being counted from a helicopter (Frid 2003). Bison (*Bison bison*), after being pursued by helicopter during capture, returned to normal movement patterns but only after 10 days (Jung et al. 2019). Conversely, no change in heart rate was detected in Rocky Mountain bighorn sheep (*O. c. canadensis*) when overflown by helicopters at distances >400 m (Macarthur et al. 1982). Survey flights for ungulates, however, typically involve approach <60 m away and circling pursuit while group, age, and sex compositions are determined (Bleich et al. 1990, Linklater and Cameron 2002, Walter and Hone 2003). Though helicopter surveys are common, little is known about how this monitoring technique compares with other forms of disturbance to ungulates.

We quantified how female and male bighorn sheep, bison, and mule deer responded to shed antler hunts compared with helicopter surveys on Antelope Island State Park, Utah, USA, from 2012 to 2015. We hypothesized that distances moved and space use would be altered for those ungulates during those events. Because legal year-round access in our study area by recreationists was restricted to limited roads and trails, ungulates were less likely to encounter recreationists off trails. Therefore, we predicted that female and male bighorn, female bison, and female and male mule deer would increase mean distance moved during shed antler hunts and helicopter surveys conducted across the island when compared with pre-event movements. We also predicted that each species and each sex would increase distance moved in response to shed antler hunters more than in response to helicopter surveys. Additionally, we predicted that more bighorn sheep and mule deer would be displaced from their home ranges during shed antler hunts than during helicopter surveys, and that mule deer would be displaced farther and longer from their home ranges than bighorn sheep because of documented behavioral responses of each species to disturbance (Valdez and Krausman 1999, Koizumi and Derocher 2019, Lowrey et al. 2019). We also predicted that these responses would differ by the sexes (Bowyer 1984, 2004; Bleich et al. 1997), with male bighorn and mule deer being displaced farther and for a longer duration than females of each species.

MATERIALS AND METHODS

Study Area

Antelope Island State Park (40°57´N, 112°13´W) is in the Great Salt Lake (Fig. 1–1), Utah, USA. This island is 24 km long, 8.3 km wide, and is approximately 11,300 ha (Whiting et al. 2009a,b). Elevation ranges from 1,280 m to 2,011 m (Rogerson et al. 2008). This island is managed for natural resources and outdoor recreation. Average annual visitation during our study from 2012 to 2015 was 320,732 people (Utah State Parks 2018). Outside of 2 open access events in March and October—4 days each year—where a regulated number of visitors (100–300 individuals) could access the entire island, visitors were restricted to trails and roadways (Kaze et al. 2016: figure 1). A central ridge, oriented north and south, is the major topographic feature on the island and essentially divides the island in half. Vegetation consisted of semi-arid grasslands at lower elevations with sagebrush (Artemisia spp.) communities prevalent at higher elevations (Brookshier and Fairbanks 2003). The eastern side of the island had the most diverse vegetation, including pockets of Wyoming big sagebrush (A. tridentata wyomingensis) and stands of bigtooth maple (Acer grandidentatum) along riparian corridors and isolated stands of Utah juniper (Juniperus ostiosperma). The west side of the island was drier, had more topographical relief, and was dominated by purple threeawn (Aristida purpurea) and cheatgrass (Bromus tectorum; Taylor et al. 2020). From 1875 to 2020, mean temperature was 11.2° C and mean annual precipitation was 39.8 cm (Western Regional Climate Center, https://wrcc.dri.edu/, accessed 07 Jan 2021). Seasons were categorized as winter (January–March), spring (April–June), summer (July–September) and fall (October–December). Four species of ungulates occupied Antelope Island during our study. Twenty-three bighorn sheep were reintroduced on the island in 1996 (Hill 2002). During our study, the mean (± SD) population count of bighorn sheep was 122 ± 25 animals. Bison on the island originated from 12 animals released in 1893 (Harward 1996), and a base herd of 532 ± 19 animals was maintained during our study. Bison numbers were controlled during our study through annual culling (221 ± 27 individuals) after being gathered by horse riders in October. Mule deer are indigenous to the island, and annual numbers varied by winter severity. During our study, mean population count of mule deer was 543 ± 181 animals. Pronghorn (*Antilocapra americana*) were reintroduced to the island in 1993 (Fairbanks and Tullous 2002), and during our study there was a mean population of 210 ± 30 animals. Throughout our study, 2 bighorn sheep, 6–8 bison, and 2 mule deer permits were allowed for hunters each November to December. Predators of those ungulates—particularly of young animals—on the island were coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and golden eagles (*Aquilia chrysaetos*).

Wildlife Capture

In February 2012 and January through March 2014, contractors hired by the Utah Division of Wildlife Resources captured bighorn sheep and mule deer via net gunning from a helicopter (Krausman and Bleich 2013, Taylor et al. 2020). They captured animals across the range of their distribution on the island. Contractors either transported animals to a processing station where biologists collected weights, measurements, and disease monitoring samples (5 bighorns, 8 mule deer) and then released them on site; or contractors collared and released animals at point of capture (39 bighorns, 33 mule deer). The processing station was located within mule deer habitat but was 2 km from bighorn habitat. During captures in February 2012, contractors collared 20 bighorn sheep (8 males, 12 females) and 19 mule deer (7 males, 12 females) with Lotek global positioning system (GPS) 7000S store-onboard collars (Lotek Wireless, St. John's, Newfoundland, Canada; Taylor et al. 2020). In January through March 2014, they fitted 24 bighorn (16 males, 8 females) and 22 mule deer (11 males, 11 females) with either Lotek 7000S or ATS G2110D GPS-collars (Advanced Telemetry Systems, Isanti, MN, USA; Taylor et al. 2020). Collars collected data at 90-minute intervals (16 points/day) 2 weeks prior, during, and 2 weeks following shed antler hunts and helicopter surveys.

We collared bison in 2013 (25 females) and 2014 (23 females) during the annual roundup in November (Utah State Parks 2001). Prior to 2005, we gathered bison with helicopters. Since 2005, riders on horseback have gathered bison. To select individual bison for collaring, we first generated a random list of mature females (≥2 yr old, = 6.4 ± 4.3 yr old, range = 2–17 yr old). We then identified those selected females during roundup, and subsequently collared each pregnant female with a Lotek 3300L GPS-collar. All collars were programmed to collect data at 30-minute intervals (48 points/day) 2 weeks prior, during, and 2 weeks following shed antler hunts and helicopter surveys. Bison collars were programmed to collect data more frequently to satisfy conditions of associated bison research. Capturing and handling of animals were conducted in accordance with guidelines from the American Society of Mammalogists (Sikes et al. 2019), and protocols established by the National Bison Association for penning and handling of bison (Carter et al. 2010). In addition, protocols for helicopter capture and handling were reviewed by the Institutional Animal Care and Use Committee at Brigham Young University (protocol number 150110).

Events

From 2012 to 2015, we quantified movements and space use of ungulates during 2 annual events on Antelope Island during late winter (Whiting et al. 2009a, 2010): shed antler hunts and helicopter surveys (Table 1–1). Those events occurred in areas used extensively by bighorn sheep, bison, and mule deer (Fig. 1–1). An annual shed antler hunt was held for 2 consecutive days each March (Table 1–1). For those hunts, we divided the island into 2 areas (east and west sides) using the north to south central ridge of the island as a general boundary between sides. We used that division of the island to provide wildlife a place of retreat during shed antler hunts on the opposite side. Shed antler hunters were selected either through a random draw the morning of the hunt or by a first-come, first-serve online sale of tags. The random draw began at 0730 with the first participant reaching the island by 0800. Searching for antlers could continue throughout the day until sunset at approximately 1900 annually (Fig. 1–1; Table 1–1). During the first day of the shed antler hunt, participants could search the entire east side of the island. Accessibility was greatest on that side because of a 16-km paved road near the shoreline of the island, which provided participants on foot or by horse access to most of that side. On day 2, participants were allowed on the west side of the island. No vehicle access existed for that side of the island; therefore, participants used backcountry trails to access that area on foot or by horse.

We conducted 4 helicopter surveys, 1 flight each February, using an Airbus AS350-B2 helicopter (Airbus, Marignane, France). Helicopter surveys have been used to monitor ungulate populations on the island since 2000. We spent a similar amount of time searching during each survey (Table 1–1) and flew a consistent grid pattern each year. During flights, we attempted to complete a survey of the island at 50–100 m above ground. When we observed ungulates, we circled them to quantify species, sex, and age composition (Linklater and Cameron 2002, Walter and Hone 2003). Survey flights commenced at 0800 and finished prior to 1300 each year.

Statistical Analysis

We retrieved collars when we recaptured animals, when animals died, or when collars fell off. We located collars using a telemetry receiver (Communications Specialists, R1000, Orange, CA, USA) with a Yagi antenna (Kaze et al. 2016). We downloaded collar data and removed locations with a dilution of precision value ≥10 to ensure GPS location accuracy (D'Eon and Delparte 2005, Lendrum et al. 2012, Lendrum et al. 2013). For estimation of average movement distances, we excluded data points >92 minutes apart for bighorn sheep and mule deer and >31 minutes apart for bison. We then calculated distance moved between sequential points in R (R Foundation for Statistical Computing, Vienna, Austria) using the Haversine method (Sinnott 1984, Allen et al. 2014, Buderman 2017). For sexes of each species, we calculated means and 95% confidence intervals for distance moved during 90-minute segments (16 points/day) of the pre-event (control, 7 consecutive days prior to event), event (1–2 days), and post-event (7 consecutive days after event) phases for shed hunts and helicopter surveys.

Distance moved (m) was our response variable. To analyze this response variable for ungulates during shed antler hunts and helicopter surveys, we used mixed-effects models and model selection in R with package lme4 (Bates et al. 2014), MuMIn (Barton 2009), and package AIC_cmodavg (Mazerolle and Mazerolle 2017). Mixed-effects models included random effects for year and animal identification with fixed effects associated with time (phases of each event), species, sex, and event (shed antler hunts and helicopter surveys; Table 1–2). We forced the variable timelag (continuous variable calculated as the minutes between the current and previous GPS fix) into each model to account for data points skipped during the GPS data collection process. We formulated 25 a priori models, and then used model selection to rank each model based on minimization of Akaike's Information Criterion adjusted for small sample sizes (AICc; Burnham and Anderson 2003). Prior to development of models, we checked for collinearity and avoided adding highly correlated variables ($|r| \geq 0.6$) in the same models. Because many of our explanatory variables were categorical, we also used the generalized variance inflation factor (GVIF) from the car package to assess collinearity (Fox and Monette 1992, Fox and Weisberg 2019). We used a cutoff for GVIF ≤ 10 to identify any potential problems with multicollinearity (Hair et al. 1995). When models contained more than 90 percent of AICc weight, we did not model average.

To quantify displacement from home ranges by ungulates during shed antler hunts and helicopter surveys, first we used Brownian-bridge movement models to estimate annual home ranges (95% probability bands) for male and female bighorn sheep and mule deer (Sawyer et al. 2009, Kranstauber et al. 2012, Walter and Fischer 2016) in R using package adehabitat (Calenge 2006). We calculated annual home ranges from date of capture through collar failure, animal death, the end of the study, or 31 December (the end date we used to calculate home ranges).

Second, to categorize displacement from home ranges, we considered ungulate responses during shed antler hunts and helicopter surveys as follows: the individual continued using the same area within their annual home range following the event (response A), the individual moved (≥500 m) to and remained in a new area within their annual home range following the event (response B), or the individual moved beyond the boundary of their calculated home range in response to the event and then re-entered their home range (response C; Fig. 1–2). We treated data from annual movements of each animal as independent samples for calculating both movement and space use (Table 1–1). Female bison used the entire island; therefore, we did not categorize their response to events as we did for bighorn sheep and mule deer. To document the distance traveled outside of home ranges (response 3), we measured the shortest distance (m) from the edge of the estimated home range to the farthest point outside the home range using the Near tool in ArcMap (Esri, Redlands, CA, USA). We also quantified duration (min) when animals were outside of their home ranges by calculating the difference in time from the first point out of their home range to the first point back in their home range after events.

RESULTS

Global Model Summary

From 2012 to 2015, we evaluated responses of 36 bighorn sheep (19 females and 17 males) and 31 mule deer (19 females and 12 males) to shed antler hunts and helicopter surveys (Table 1–1). We also evaluated the response of 48 female bison from 2014 to 2015 to those same events (Table 1–1). During our study, we documented 65,060 GPS locations of bighorn sheep (7,495 locations of females and 8,032 locations of males), bison (37,650 locations of females), and mule deer (6,898 locations of females and 4,985 locations of males). Of our 25 models, the highest ranked model accounted for nearly 100% of AICc weight (Appendix A) therefore we did not model average. The top model was the global model which included the 4-way interaction of our explanatory variables (event, phase, sex, species) and all lower-order interactions and constituent terms (Appendix A). The top model supported our prediction that distances moved during shed antler hunts and helicopter surveys were largely influenced by species, sex, and time since event and highlighted complexities of responses to those disturbances (Table A1–1).

Bighorn Sheep

Bighorn sheep moved more during helicopter surveys than during shed antler hunts (Fig. 1–3). Females moved little in response to shed antler hunts (18% increase in distances moved) and helicopter surveys (19% increase in distance moved) compared with pre-event distances moved (Fig. 1–3). Males, however, increased distance moved by 41% on average during shed antler hunts moved twice as far during helicopter surveys compared with pre-event distances moved (Fig. 1–3).

Mean size of annual home ranges for female bighorn sheep was 9.4 ± 2.1 km^2 and for males was 16.8 ± 5.1 km^2. For space use in relation to annual home ranges, 17 females continued using pre-event areas within their home range, 11 relocated to new areas within their home range, and only 1 left her home range during shed antler hunts (Fig. 1–4). That single female moved only 39 m beyond her home range and spent 1.5 hours outside of that range. During helicopter surveys, 11 females continued using pre-event areas within their home range, 17 relocated to new areas within their home range, and only 1 left her home range (Fig. 1–4). That female was different than the one that moved in response to shed antler hunting, and she also moved only 39 m beyond her home range and spent 1.5 hours outside of that range.

For space use in relation to annual home ranges, 5 males continued using pre-event areas within their home ranges, 24 relocated to new areas within their home ranges, and 2 left their home ranges during shed antler hunts, then returned within 6 hours after the shed antler hunt (Fig. 1–4). Those 2 males were displaced a mean distance of 115 ± 49 m (range = 65–164 m) from their home ranges and spent a mean of 3.8 ± 2.3 hours (range = 1.5–6.0 hr) outside of that range. During helicopter surveys, 10 males continued using pre-event areas within their home range, 19 relocated to new areas within their home range, and only 1 left his home range (Fig. 1–4). That male was displaced 435 m from his home range for 16.5 hours.

Bison

Female bison increased distance moved by 15% on average during shed antler hunts and by 30% on average in response to helicopter surveys (Fig. 1–3). Females used the entire island as their home range; therefore, we did not measure space use in relation to home ranges during shed antler hunts and helicopter surveys for those animals.

Mule Deer

Mule deer moved more during shed antler hunts than during helicopter surveys (Fig. 1–3). Females moved 97% more on average in response to shed antler hunts and 50% more on average in response to helicopter surveys compared with distance moved before those events (Fig. 1–3). Males moved 2.10 times farther on average during shed antler hunts, but only 4% more during helicopter surveys compared with distance moved before those events (Fig. 1–3). Mean size of annual home ranges for female mule deer was 9.4 ± 5.1 km^2 and for males was 12.8 ± 5.7 km^2. For space use in relation to annual home ranges, 6 females continued using pre-event areas within their home ranges, 7 relocated to new areas within their home ranges, and 15 left their home ranges during shed antler hunts (Fig. 1–4). Those females were displaced a mean distance of 742 ± 642 m (range = 9–3,778 m) outside of their home ranges and spent a mean of 9.2 ± 9.4 hours (range = 1.5–40.5 hr) outside of those ranges. During helicopter surveys, 12 females continued using pre-event areas within their home ranges, 8 relocated to new areas within their home ranges, and 5 left their home ranges (Fig. 1–4). Those females were displaced a mean distance of 1,820 ± 1,186 m (range = 56–3,726 m) outside of their home ranges and spent a mean of 9.8 ± 7.1 hours (range = 1.5–21.0 hr) outside of those ranges.

For space use in relation to annual home ranges, 3 males continued using pre-event areas within their home ranges, and 14 males left their home ranges during shed antler hunts (Fig. 1–4). Those males were displaced a mean distance of 1,264 ± 732 m (range = 131–3,637 m) outside of their home ranges and spent a mean of 12.6 ± 7.6 hours (range = 4.5–33.0 hr) outside of those ranges. During helicopter surveys, 7 males continued using pre-event areas within their home ranges, 4 relocated to new areas within their home ranges, and only 1 left his home range (Fig. 1–4). That male was displaced 316 m from his home range for 1.5 hours.

DISCUSSION

Overview

Our prediction that ungulates would move greater distances during shed antler hunts compared with helicopter surveys was supported for mule deer but was not supported for bison or bighorn sheep (Fig. 1–3). Additionally, our prediction that bighorn sheep and mule deer would be displaced from their home ranges more during shed antler hunts than during helicopter surveys was supported for mule deer but not for bighorn sheep (Fig. 1–4). Other studies have documented difference in movements and space use by these ungulates in relation to various recreational activities (Papouchis et al. 2001, Taylor and Knight 2003*b*, Wisdom et al. 2004, Sproat et al. 2019); none of those studies, however, compared responses of bighorn sheep and mule deer to shed antler hunts simultaneously across 4 years, and only 1 study documented differences between sexes in movement (Papouchis et al. 2001). In that study, however, animals were watched only until they quit fleeing (<15 min) after disturbance. We documented responses of females and males up to 7 days after shed antler hunts and helicopter surveys. Female and male bighorn sheep and mule deer sexually segregate (Bleich et al. 1997, Bowyer et al. 2002, Bowyer 2004); in our study, that segregation was associated with varying responses of the sexes to shed antler hunts and helicopter surveys. Below we focus on movements and space use of species and sexes to shed antler hunts and helicopter surveys.

Bighorn Sheep

Female bighorn sheep did not increase distance moved in response to shed antler hunts and helicopter surveys compared with distance moved before those events (Fig. 1–3). Male bighorn sheep, however, increased distance moved during both shed antler hunts and helicopter surveys compared with distance moved before those events. These outcomes supported our prediction that responses would differ by the sexes. Female bighorn sheep in our study area had smaller home ranges than males (Whiting et al. 2010), and females remain closer to escape terrain than do males where risk of predation is reduced (Berger 1991, Bleich et al. 1997, Schroeder et al. 2010). Bighorn females and males respond to predators by fleeing to escape terrain (Bleich 1999, Valdez and Krausman 1999, Koizumi and Derocher 2019). The larger home ranges of males allow them to access resources to maximize body size and horn growth (Geist 1966, 1971; Bleich et al. 1997). The increased distance moved by male bighorns during shed antler hunts and helicopter surveys that we documented could be attributed to males having larger home ranges and using areas farther away from escape terrain (Bleich et al. 1997, Rachlow and Bowyer 1998, Schroeder et al. 2010).

Female bighorn responded differently to shed antler hunts than to helicopter surveys. During shed antler hunts, 59% of females moved little and continued using the same pre-event areas within their home ranges, and the same proportion of females (59%) moved to new areas within their home ranges in response to helicopter surveys. Conversely, male bighorn sheep responded similarly to both events by moving to new locations within their home range (Rachlow and Bowyer 1998). Again, because male bighorn range wider and use less rugged terrain than females (Berger 1991, Bleich et al. 1997, Schroeder et al. 2010), males likely have a higher probability of encountering shed antler hunters. Intensive levels of erratic and unpredictable movement of human hikers can cause female bighorn sheep to eventually abandon habitat, especially near lambing areas, leading to poor recruitment rates and population decline. For example, female bighorn encountering excessive numbers of hikers during lambing failed to return to historical high-valued lambing areas (Papouchis et al. 2001, Wiedmann and Bleich 2014). Such behavior by females can be detrimental as bighorn lambing areas are increasingly being recognized as important habitat features for population growth (Smith et al. 2015, Karsch et al. 2016, Robinson et al. 2019).

Bison

Female bison increased distance moved in response to shed antler hunts and helicopter surveys compared with distance moved before those events. Bison were rounded-up by riders on horseback; however, prior to 2004, bison were rounded-up each autumn with helicopters. Some of those bison were still on the island during our study. The observed increase in distance moved during helicopter surveys may be a result of a learned behavior to flee from helicopters by some of those bison; indeed, bison move great distances when responding to helicopter capturing and surveying (Jung et al. 2019). Bison are large and can move quickly (Reynolds et al. 1982), and these ungulates will approach, become vigilant, or flee in response to people on foot (Fortin and Andruskiw 2003, Taylor and Knight 2003*b*). Close approach by people on foot to bison often leads to people getting injured (Cherry et al. 2018). We observed shed hunters approaching bison closely (≤50 m) while searching for antlers on Antelope Island State Park. Potential aggressive responses from bison need to be considered when allowing shed antler hunts on public land occupied by bison (e.g., Custer State Park, SD; Henry Mountains, UT).

Mule Deer

Female and male mule deer doubled distance moved during shed antler hunts compared with distance moved before those events, an outcome that supported our predictions. People are perceived as predators by deer and these ungulates respond by fleeing (Ciuti et al. 2012, Lowrey et al. 2019). Predation is a main cause of mortality for mule deer (Bleich and Taylor 1998, Ballard et al. 2001, Forrester and Wittmer 2013). Consequently, both sexes increased movement in response to people on foot during shed antler hunts. Further, females significantly increased distance moved during helicopter surveys, whereas males did not. Desert mule deer (*O. h. emericus*) habituated to low-flying aircraft (Krausman et al. 1986). In our study, limited movement by males provides further evidence of male mule deer habituating to low-flying aircraft. The increased movement by females, compared with movement of male mule deer, during helicopter surveys was likely related to sexual segregation and resultant habitat use (Bowyer 1984, Main and Coblentz 1996). During helicopter surveys, we encountered females in treeless areas, and those females would often flee long distances when disturbed; whereas, males tended to use wooded riparian areas that most likely provided secure habitat reducing the need to flee from the disturbance.

The majority of female and male mule deer moved outside the boundary of their home ranges during shed antler hunts, and remained outside of those boundaries 3.63 times longer on average when compared with time spent outside of home ranges by bighorn sheep; again, an outcome that supported our predictions. Conversely, female and male mule deer reacted similarly during helicopter surveys with the majority of both sexes remaining in their home ranges. On Antelope Island mule deer flee from hikers (Taylor and Knight 2003*b*); whereas, in montane regions of Oregon, USA, hikers did not influence deer movement (Wisdom et al. 2004). Forest cover minimizes effects of human disturbance on those ungulates (Kufeld et al. 1988), and Antelope Island is a sparsely vegetated sagebrush-steppe landscape. Those differences in vegetative cover may account for the differing responses we observed. Mule deer also avoid areas with high levels of human activity (Sawyer et al. 2017, Coe et al. 2018).

CONCLUSION

Shed Antler Hunting

Antelope Island State Park offers a unique opportunity to study wildlife-human interactions (Whiting et al. 2008, Kaze et al. 2016, Taylor et al. 2020) because this island is a closed system. Consequently, caution is needed when applying our results to a broader scale. Our study documents responses of both sexes from multiple ungulates to shed antler hunting, and our results will provide important data to guide policy and management of these species and their habitat, especially mule deer. Currently, to protect mule deer on winter ranges, half of the state wildlife agencies in the western United States have limits on shed antler hunting. The other half have no restrictions. Where many states are open to shed antler hunting year-round, mule deer in these areas would be more susceptible to increased movement and potential displacement from home ranges. Those states that have a closed season may limit disturbance to mule deer because these ungulates may leave winter range before shed hunting is allowed. In areas where resident deer remain on winter range, these animals may experience an acute disturbance on opening day of shed antler hunts—similar to what we documented—and then be exposed to lower levels of chronic disturbance through months that shed antler hunting persists. Future research needs to document how mule deer will respond to varying levels of shed antler hunting across different weather conditions, group sizes, and migratory statuses.

Demand for cervid antlers is growing exponentially worldwide (Kwak et al. 1994, Xingtao 1998, Apollonio et al. 2010, Kuba et al. 2015), and price/kg of antlers has tripled over the past decade (Koshmrl 2019). This increased demand ostensibly will continue to affect wild populations, and protection of cervids on winter range has become more difficult as shed antler hunting grows in popularity (Koshmrl 2019). Additionally, mule deer are an important species in western North America and are an integral part of the ecosystems of the western United States (Kie et al. 2002, Bishop et al. 2009, Smedley et al. 2019). Many populations of mule deer have declined in the past few decades (Ballard et al. 2001, Forrester and Wittmer 2013, Bergman et al. 2015). We quantified how bighorn sheep, bison, and mule deer responded to shed antler hunts, and documented that distances moved and space use differed by species and sex. Further, female and male mule deer moved the farthest, were displaced the most, and for the longest time from their home ranges during shed antler hunts. Our results will help wildlife managers understand the effects of legal shed antler hunting on movement and space use of female and male ungulates and provide timely information that can help guide conservation of ungulate populations and their habitat.

Management Implications

In our study, female bighorn sheep moved short distances to potentially more secure areas within their home ranges during shed antler hunts. Wildlife managers need to consider that response in areas with consistent levels of shed antler hunters overlapping potential lambing habitat. Most male bighorn responded to shed antler hunting by moving to new areas within their home ranges. Movements of male bighorn sheep could be affected by shed antler hunters gathering antlers on winter range that is used by mule deer and bighorn sheep. Where this overlap occurs, the timing of shed antler hunts could be delayed until animals have left the area. Mule deer are in poor condition during late winter and early spring. If deer are displaced beyond their home ranges during those seasons, they may be exposed to greater predation risk and starvation—searching for food resources in unfamiliar territory—both of which are leading causes of mortality for mule deer. Moreover, female and male mule deer may respond and move differently when exposed to lower densities of shed antler hunters than we documented and across extended periods of time, which occurs across many areas of mule deer range in western North America. Successful habitat conservation for this species will depend on identifying areas where shed antler hunting is increasing and then mitigating for that increase.

LITERATURE CITED

Allen, M., L. Elbroch, D. Casady, and H. Wittmer. 2014. Seasonal variation in the feeding ecology of pumas (*Puma concolor*) in northern California. Canadian Journal of Zoology 92:397–403.

Apollonio, M., R. Andersen, and R. Putman. 2010. European ungulates and their management in the 21st century. Cambridge University Press, Cambridge, United Kingdom.

Ballard, W. B., D. Lutz, T. W. Keegan, L. H. Carpenter, and J. C. deVos, Jr. 2001. Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99–115.

Barton, K. 2009. MuMIn: multi-model inference. R package version 0.12.0. http://r-forge.r-project.org/projects/mumin/. Accessed July 2019.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2014. lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-23. https://cran.r-project.org/web/packages/lme4/index.html. Accessed July 2019.

Belotti, E., M. Heurich, J. Kreisinger, P. Sustr, and L. Bufka. 2012. Influence of tourism and traffic on the Eurasian lynx hunting activity and daily movements. Animal Biodiversity and Conservation 35:235–246.

Berger, J. 1991. Pregnancy incentives, predation constraints and habitat shifts - experimental and field evidence for wild bighorn sheep. Animal Behaviour 41:61–77.

Bergman, E. J., P. F. Doherty, G. C. White, and A. A. Holland. 2015. Density dependence in mule deer: a review of evidence. Wildlife Biology 21:18–29.

Bishop, C. J., G. C. White, D. J. Freddy, B. E. Watkins, and T. R. Stephenson. 2009. Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs 172:1–28.

Bleich, V. C. 1999. Mountain sheep and coyotes: patterns of predator evasion in a mountain ungulate. Journal of Mammalogy 80:283–289.

Bleich, V. C., and T. J. Taylor. 1998. Survivorship and cause-specific mortality in five populations of mule deer. Great Basin Naturalist 58:265–272.

Bleich, V. C., R. T. Bowyer, and J. D. Wehausen. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134:1–50.

Bleich, V. C., R. T. Bowyer, A. M. Pauli, R. L. Vernoy, and R. W. Anthes. 1990. Responses of mountain sheep to helicopter surveys. California Fish and Game 76:197–204.

Bowyer, R. T. 2004. Sexual segregation in ruminants: definitions, hypotheses, and implications for conservation and management. Journal of Mammalogy 85:1039–1052.

Bowyer, R. T., K. M. Stewart, S. A. Wolfe, G. M. Blundell, K. L. Lehmkuhl, P. J. Joy, T. J. McDonough, and J. G. Kie. 2002. Assessing sexual segregation in deer. Journal of Wildlife Management 66:536–544.

Bowyer, R. T. 1984. Sexual segregation in southern mule deer. Journal of Mammalogy 65:410–417.

Brookshier, J. S., and W. S. Fairbanks. 2003. The nature and consequences of mother-daughter associations in naturally and forcibly weaned bison. Canadian Journal of Zoology-Revue Canadienne De Zoologie 81:414–423.

Buderman, F. E. 2017. Statistical methods for modeling the movement and space-use of carnivores. Dissertation, Colorado State University, Fort Collins, USA.

Burnham, K. P., and D. R. Anderson. 2003. Model selection and multimodel inference: a practical information-theoretic approach. Springer Science & Business Media, New York, New York, USA.

Calenge, C. 2006. The package “adehabitat” for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516–519.

Carter, D., J. Matheson, and T. Kremeniuk. 2010. The bison producers’ handbook: a complete guide to production and marketing. National Bison Association, Westminster, Colorado, USA.

Cherry, C., K. M. Leong, R. Wallen, and D. Buttke. 2018. Risk-enhancing behaviors associated with human injuries from bison encounters at Yellowstone National Park, 2000–2015. One Health 6:1–6.

Ciuti, S., J. M. Northrup, T. B. Muhly, S. Simi, M. Musiani, J. A. Pitt, and M. S. Boyce. 2012. Effects of humans on behaviour of wildlife exceed those of natural predators in a landscape of fear. PloS One 7:e50611.

Coe, P. K., D. A. Clark, R. M. Nielson, S. C. Gregory, J. B. Cupples, M. J. Hedrick, B. K. Johnson, and D. H. Jackson. 2018. Multiscale models of habitat use by mule deer in winter. Journal of Wildlife Management 82:1285–1299.

D'Eon, R. G., and D. Delparte. 2005. Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. Journal of Applied Ecology 42:383–388.

Dzialak, M. R., S. M. Harju, R. G. Osborn, J. J. Wondzell, L. D. Hayden-Wing, J. B. Winstead, and S. L. Webb. 2011. Prioritizing conservation of ungulate calving resources in multiple-use landscapes. PloS One 6:e14597.

Fairbanks, W. S., and R. Tullous. 2002. Distribution of pronghorn (*Antilocapra americana* Ord) on Antelope Island State Park, Utah, USA, before and after establishment of recreational trails. Natural Areas Journal 22:277–282.

Forrester, T. D., and H. U. Wittmer. 2013. A review of the population dynamics of mule deer and black-tailed deer *Odocoileus hemionus* in North America. Mammal Review 43:292–308.

Fortin, D., and M. Andruskiw. 2003. Behavioral response of free-ranging bison to human disturbance. Wildlife Society Bulletin 31:804–813.

Fox J, and S. Weisberg (2019). An R companion to applied regression, Third edition. Sage, Thousand Oaks, California, USA. Accessed Aug 2019.

Fox, J. and G. Monette (1992). Generalized collinearity diagnostics. Journal of the American Statistical Association 87:178-183.

Freddy, D. J., W. M. Bronaugh, and M. C. Fowler. 1986. Responses of mule deer *Odocoileus hemionus* to disturbance by persons afoot and snowmobiles. Wildlife Society Bulletin 14:63–68.

Frid, A. 2003. Dall's sheep responses to overflights by helicopter and fixed-wing aircraft. Biological Conservation 110:387–399.

Frid, A., and L. Dill. 2002. Human-caused disturbance stimuli as a form of predation risk. Conservation Ecology 6:article 11.

Gander, H., and P. Ingold. 1997. Reactions on male alpine chamois (*Rupicapra r. rupicapra*) to hikers, joggers and mountainbikers. Biological Conservation 79:107–109.

Geist, V. 1971. Mountain sheep. A study in behavior and evolution. University of Chicago Press, Chicago, Illinois, USA.

Geist, V. 1966. The evolutionary significance of mountain sheep horns. Evolution 20:558–566.

Gutzwiller, K. J., A. L. D'Antonio, and C. A. Monz. 2017. Wildland recreation disturbance: broad-scale spatial analysis and management. Frontiers in Ecology and the Environment 15:517–524.

Hair, J. F. J., R. E. Anderson, R. L. Tatham, and W. C. Black. 1995. Multivariate data analysis. Third edition. Macmillan, New York, New York, USA.

Harju, S. M., M. R. Dzialak, R. G. Osborn, L. D. Hayden-Wing, and J. B. Winstead. 2011. Conservation planning using resource selection models: altered selection in the presence of human activity changes spatial prediction of resource use. Animal Conservation 14:502–511.

Harward, M. 1996. Where the buffalo roam, life on Antelope Island. Harward, Farmington, Utah, USA.

Heinemeyer, K., J. Squires, M. Hebblewhite, J. J. O'Keefe, J. D. Holbrook, and J. Copeland. 2019. Wolverines in winter: indirect habitat loss and functional responses to backcountry recreation. Ecosphere 10:e02611.

Hill, M. D. 2002. Potential foraging constraints on an introduced population of bighorn sheep (*Ovis canadensis californiana*) imposed by resident bison (*Bos bison*) and mule deer (*Odocoileus hemionus*) on Antelope Island State Park, Utah. Thesis, University of Nebraska, Omaha, USA.

Huhtala, A., and E. Pouta. 2009. Benefit incidence of public recreation areas-have the winners taken almost all? Environmental & Resource Economics 43:63–79.

Jung, T. S., S. M. Konkolics, P. M. Kukka, Y. N. Majchrzak, A. K. Menzies, M. P. Oakley, M. J. L. Peers, and E. K. Studd. 2019. Short-term effect of helicopter-based capture on movements of a social ungulate. Journal of Wildlife Management 83:830–837.

Karsch, R. C., J. W. Cain, E. M. Rominger, and E. J. Goldstein. 2016. Desert bighorn sheep lambing habitat: parturition, nursery, and predation sites. Journal of Wildlife Management 80:1069–1080.

Kaze, J., J. C. Whiting, E. D. Freeman, S. B. Bates, and R. T. Larsen. 2016. Birth-site selection and timing of births in American bison: effects of habitat and proximity to anthropogenic features. Wildlife Research 43:418–428.

Kerbiriou, C., I. Le Viol, A. Robert, E. Porcher, F. Gourmelon, and R. Julliard. 2009. Tourism in protected areas can threaten wild populations: from individual response to population viability of the chough *Pyrrhocorax pyrrhocorax*. Journal of Applied Ecology 46:657–665.

Kie, J. G., R. T. Bowyer, M. C. Nicholson, B. B. Boroski, and E. R. Loft. 2002. Landscape heterogeneity at differing scales: effects on spatial distribution of mule deer. Ecology 83:530–544.

Koizumi, C. L., and A. E. Derocher. 2019. Predation risk and space use of a declining Dall sheep (*Ovis dalli dalli*) population. PloS One 14:e0215519.

Koshmrl, M. 2019. What it takes to catch antler thieves. National Geographic. https://www.nationalgeographic.com/animals/2019/ catching-antler-thieves/. Accessed July 2019.

Kranstauber, B., R. Kays, S. D. LaPoint, M. Wikelski, and K. Safi. 2012. A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. Journal of Animal Ecology 81:738–746.

Krausman, P. R., and V. C. Bleich. 2013. Conservation and management of ungulates in North America. International Journal of Environmental Studies 70:372–382.

Krausman, P. R., B. D. Leopold, and D. L. Scarbrough. 1986. Desert mule deer response to aircraft. Wildlife Society Bulletin 14:68–70.

Kuba, J., T. Landete-Castillejos, and J. Udala. 2015. Red deer farming: breeding practice, trends and potential in Poland- a review. Annals of Animal Science 15:591–599.

Kufeld, R. C., D. C. Bowden, and D. L. Schrupp. 1988. Influence of hunting on movements of female mule deer. Journal of Range Management 41:70–72.

Kwak, W., K. Kim, C. Kim, B. Jeon, and S. Lee. 1994. Deer farming in Korea: on-farm survey in Kyung-Kee and Chung-Buk provinces. Asian-Australasian Journal of Animal Sciences 7:347–355.

Larson, C. L., S. E. Reed, A. M. Merenlender, and K. R. Crooks. 2016. Effects of recreation on animals revealed as widespread through a global systematic review. PloS One 11:e0167259.

Lendrum, P. E., C. R. Anderson, K. L. Monteith, J. A. Jenks, and R. T. Bowyer. 2013. Migrating mule deer: effects of anthropogenically altered landscapes. PloS One 8:e64548.

Lendrum, P. E., C. R. Anderson, R. A. Long, J. G. Kie, and R. T. Bowyer. 2012. Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. Ecosphere 3:1–19.

Linklater, W. L., and E. Z. Cameron. 2002. Escape behaviour of feral horses during a helicopter count. Wildlife Research 29:221–224.

Lowrey, C., K. M. Longshore, D. M. Choate, J. R. Nagol, J. Sexton, and D. Thompson. 2019. Ecological effects of fear: how spatiotemporal heterogeneity in predation risk influences mule deer access to forage in a sky-island system. Ecology and Evolution 9:7213–7226.

Macarthur, R. A., V. Geist, and R. H. Johnston. 1982. Cardiac and behavioral responses of mountain sheep (*Ovis canadensis canadensis*) to human disturbance. Journal of Wildlife Management 46:351–358.

Main, M. B., and B. E. Coblentz. 1996. Sexual segregation in Rocky Mountain mule deer. Journal of Wildlife Management 60:497–507.

Mazerolle, M. J. 2019. AICcmodavg: model selection and multimodel inference based on (Q)AIC(c). R package version 2.2-2. https://cran.r-project.org/package=AICcmodavg. Accessed July 2019.

McKinney, T., J. C. Devos, W. B. Ballard, and S. R. Boe. 2006. Mountain lion predation of translocated desert bighorn sheep in Arizona. Wildlife Society Bulletin 34:1255–1263.

McRoberts, J. T., M. J. Butler, W. B. Ballard, H. A. Whitlaw, D. A. Haukos, and M. C. Wallace. 2011. Detectability of lesser prairie-chicken leks: a comparison of surveys from aircraft. Journal of Wildlife Management 75:771–778.

Mimiaga, J. 2018. New regulation limits growing practice of antler collection. The Journal, Ballantine Communications, Cortez, Colorado, USA. https://the-journal.com/articles/86281-new-regulation-limits-growing-practice-of-antler-collection. Accessed Jun 2018.

Monteith, K. L., R. A. Long, V. C. Bleich, J. R. Heffelfinger, P. R. Krausman, and R. T. Bowyer. 2013. Effects of harvest, culture, and climate on trends in size of horn-like structures in trophy ungulates. Wildlife Monographs 183:1–28.

Naylor, L. M., M. J. Wisdom, and R. G. Anthony. 2009. Behavioral responses of North American elk to recreational activity. Journal of Wildlife Management 73:328–338.

Olsen, S. L. 1994. Exploitation of mammals at the Early Bronze Age site of West Row Fen (Mildenhall 165), Suffolk, England. Annals of Carnegie Museum 63:115–153.

Papouchis, C. M., F. J. Singer, and W. B. Sloan. 2001. Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65:573–582.

Rabe, M. J., S. S. Rosenstock, and J. C. deVos. 2002. Review of big-game survey methods used by wildlife agencies of the western United States. Wildlife Society Bulletin 30:46–52.

Rachlow, J. L., and R. T. Bowyer. 1998. Habitat selection by Dall's sheep (*Ovis dalli*): maternal trade-offs. Journal of Zoology 245:457–465.

Reilly, B. K., H. J. van Hensbergen, R. J. Eiselen, and P. J. S. Fleming. 2017. Statistical power of replicated helicopter surveys in southern African conservation areas. African Journal of Ecology 55:198–210.

Reynolds, H. W., R. D. Glaholt, and A. L. W. Hawley. 1982. Bison. Pages 972-1007 *in* J. A. Chapman, and G. A. Feldhamer, editors. Wild mammals of North America. John Hopkins University Press, Baltimore, Maryland, USA.

Robinson, R. W., J. C. Whiting, J. M. Shannon, D. D. Olson, J. T. Flinders, T. S. Smith, and R. T. Bowyer. 2019. Habitat use and social mixing between groups of resident and augmented bighorn sheep. Scientific Reports 9:14984.

Rogerson, J. D., W. S. Fairbanks, and L. Cornicelli. 2008. Ecology of gastropod and bighorn sheep hosts of lungworm on isolated, semiarid mountain ranges in Utah, USA. Journal of Wildlife Diseases 44:28–44.

Rominger, E. M., H. A. Whitlaw, D. L. Weybright, W. C. Dunn, and W. B. Ballard. 2004. The influence of mountain lion predation on bighorn sheep translocations. Journal of Wildlife Management 68:993–999.

Sawyer, H., N. M. Korfanta, R. M. Nielson, K. L. Monteith, and D. Strickland. 2017. Mule deer and energy development-long-term trends of habituation and abundance. Global Change Biology 23:4521–4529.

Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19:2016–2025.

Schoenebeck, C. W., and B. C. Peterson. 2014. Evaluation of hunter antler-size selection through an age-specific comparison of harvested and naturally cast antler metrics. Journal of Fish and Wildlife Management 5:167–173.

Schroeder, C. A., R. T. Bowyer, V. C. Bleich, and T. R. Stephenson. 2010. Sexual segregation in Sierra Nevada bighorn sheep, *Ovis canadensis sierrae*: ramifications for conservation. Arctic Antarctic and Alpine Research 42:476–489.

Sikes, R. S., T. A. Thompson, and J. A. Bryan, II. 2019. American Society of Mammalogists: raising the standards for ethical and appropriate oversight of wildlife research. Journal of Mammalogy 100:763–773.

Sinnott, R. W. 1984. Virtues of the Haversine. Sky and Telescope 68:159–159.

Smedley, D. C., M. van de Kerk, B. R. McMillan, K. R. Hersey, J. C. Whiting, and R. T. Larsen. 2019. Movements, space use and site fidelity of translocated and resident mule deer (*Odocoileus hemionus*). Wildlife Research 46:509–517.

Smith, J. B., T. W. Grovenburg, and J. A. Jenks. 2015. Parturition and bed site selection of bighorn sheep at local and landscape scales. Journal of Wildlife Management 79:393–401.

Sproat, K. K., N. R. Martinez, T. S. Smith, W. B. Sloan, J. T. Flinders, and J. W. Bates. 2019. Desert bighorn sheep responses to human activity in southeastern Utah. Wildlife Research 47:16-24.

Stankowich, T. 2008. Ungulate flight responses to human disturbance: a review and meta-analysis. Biological Conservation 141:2159–2173.

Taylor, A. R., and R. L. Knight. 2003*a*. Behavioral responses of wildlife to human activity: terminology and methods. Wildlife Society Bulletin 31:1263–1271.

Taylor, A. R., and R. L. Knight. 2003*b*. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13:951–963.

Taylor, J. C., S. B. Bates, J. C. Whiting, B. R. McMillan, and R. T. Larsen. 2020. Optimising deployment time of remote cameras to estimate abundance of female bighorn sheep. Wildlife Research doi:10.1071/wr20069.

Tejero, J.-M., M. Christensen, and P. Bodu. 2012. Red deer antler technology and early modern humans in Southeast Europe: an experimental study. Journal of Archaeological Science 39:332–346.

Utah State Parks. 2018. Park visitation records. Utah Department of Natural Resources, Salt Lake City, USA. https://stateparks.utah.gov/resources/park-visitation-data/. Accessed 5 Apr 2018.

Utah State Parks. 2001. Antelope Island State Park: wildlife management plan update. Utah Department of Natural Resources, Salt Lake City, USA.

Valdez, R., and P. R. Krausman. 1999. Mountain sheep of North America. University of Arizona Press, Tucson, USA.

Villa, P., and F. D'Errico. 2001. Bone and ivory points in the Lower and Middle paleolithic of Europe. Journal of Human Evolution 41:69–112.

Vitezović, S. 2017. Antler exploitation and management in the Vinča culture: an overview of evidence from Serbia. Quaternary International 450:209–223.

Walter, M. J., and J. Hone. 2003. A comparison of 3 aerial survey techniques to estimate wild horse abundance in the Australian Alps. Wildlife Society Bulletin 31:1138–1149.

Walter, W. D., and J. W. Fischer. 2016. Manual of applied spatial ecology. Pennsylvania State University, State College, Pennsylvania, USA.

Western Association of Fish and Wildlife Agencies. 2015. WAFWA home page. Mule Deer Woking Group. MDWG Fact Sheet #16 Shed antler hunting. https://wafwa.org/publications/mdwg-factsheets/. Accessed July 2015.

Whiting, J. C., R. T. Bowyer, J. T. Flinders, V. C. Bleich, and J. G. Kie. 2010. Sexual segregation and use of water by bighorn sheep: implications for conservation. Animal Conservation 13:541–548.

Whiting, J. C., R. T. Bowyer, and J. T. Flinders. 2009*a*. Annual use of water sources by reintroduced Rocky Mountain bighorn sheep *Ovis canadensis canadensis*: effects of season and drought. Acta Theriologica 54:127–136.

Whiting, J. C., R. T. Bowyer, and J. T. Flinders. 2009*b*. Diel use of water by reintroduced bighorn sheep. Western North American Naturalist 69:407–412.

Whiting, J. C., R. T. Bowyer, and J. T. Flinders. 2008. Young bighorn (*Ovis canadensis*) males: can they successfully woo females? Ethology 114:32–41.

Wiedmann, B. P., and V. C. Bleich. 2014. Demographic responses of bighorn sheep to recreational activities: a trial of a trail. Wildlife Society Bulletin 38:773–782.

Wisdom, M. J., H. K. Preisler, L. M. Naylor, R. G. Anthony, B. K. Johnson, and M. M. Rowland. 2018. Elk responses to trail-based recreation on public forests. Forest Ecology and Management 411:223–233.

Wisdom, M. J., A. A. Ager, H. K. Preisler, N. J. Cimon, and B. K. Johnson. 2004. Effects of off-road recreation on mule deer and elk. Transactions of the North American Wildlife and Natural Resources Conference 69:531–550.

Wu, F. F., H. Q. Li, L. J. Jin, X. Y. Li, Y. S. Ma, J. S. You, S. Y. Li, and Y. P. Xu. 2013. Deer antler base as a traditional Chinese medicine: a review of its traditional uses, chemistry and pharmacology. Journal of Ethnopharmacology 145:403–415.

Xingtao, Z. 1998. Studying on Work of Crossing Work of Deer in China . Journal of Economic Animal 4.

FIGURES

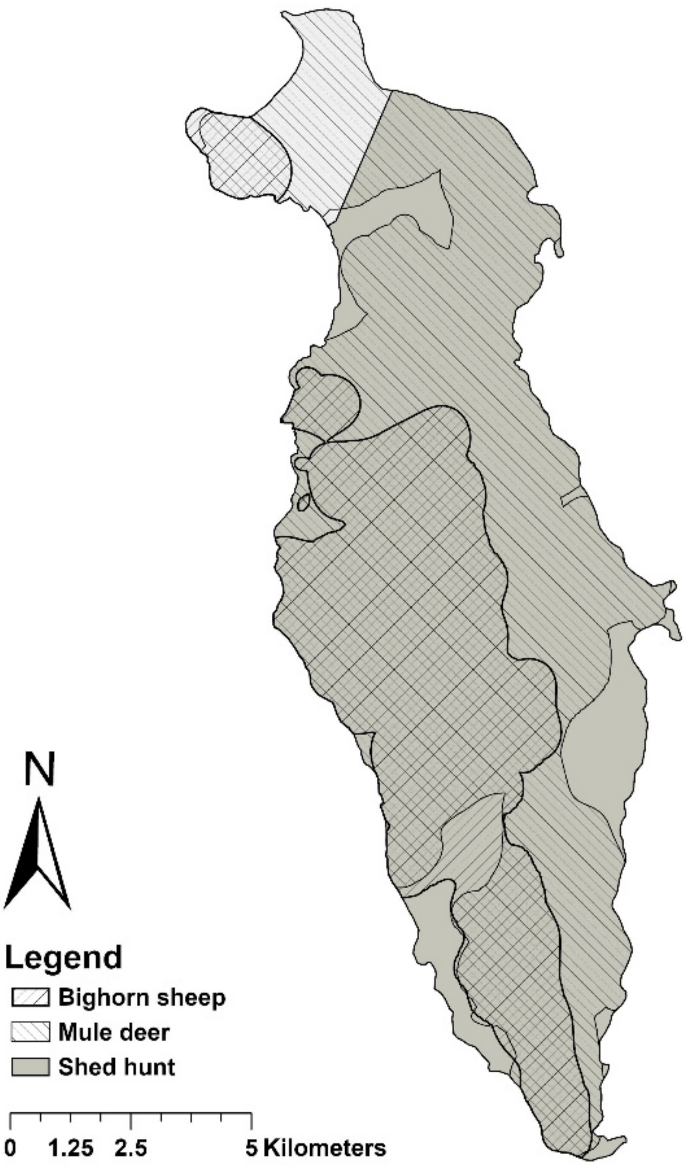

Figure 1-1. Antelope Island State Park, Utah, USA, where we documented movements and space use of bighorn sheep, bison, and mule deer during shed antler hunts and helicopter surveys in winter, 2012–2015. Helicopter surveys covered the entire island and do not appear on the map. Stippled polygons represent annual home ranges of 36 collared bighorns and 31 collared mule deer. Collared bison (*n* = 48) used the entire island.

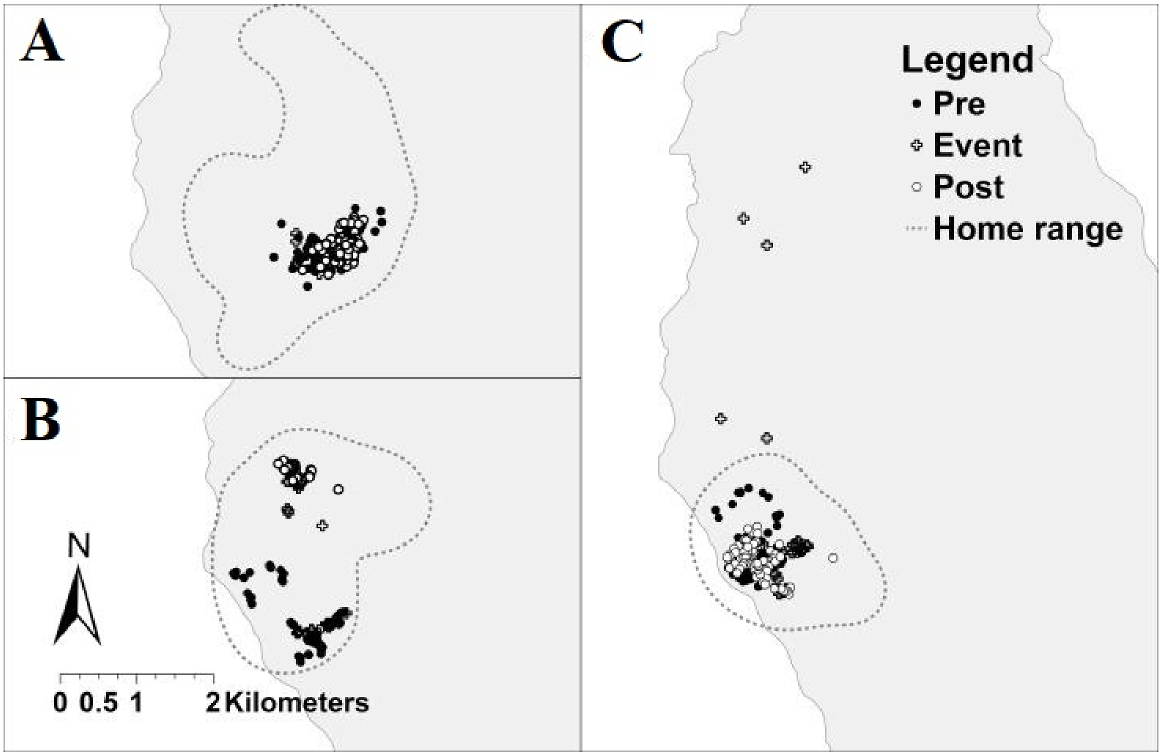

Figure 1-2. Examples of responses we used to categorize disturbance of bighorn sheep and mule deer to shed antler hunts and helicopter surveys conducted on Antelope Island State Park, Utah, USA, 2012–2015. A) An animal continued using pre-event areas within their home range following the event, B) an animal moved to a new location within their home range during the event, and C) an animal moved out of their home range during the event but returned to their home range within 7 days after the event.

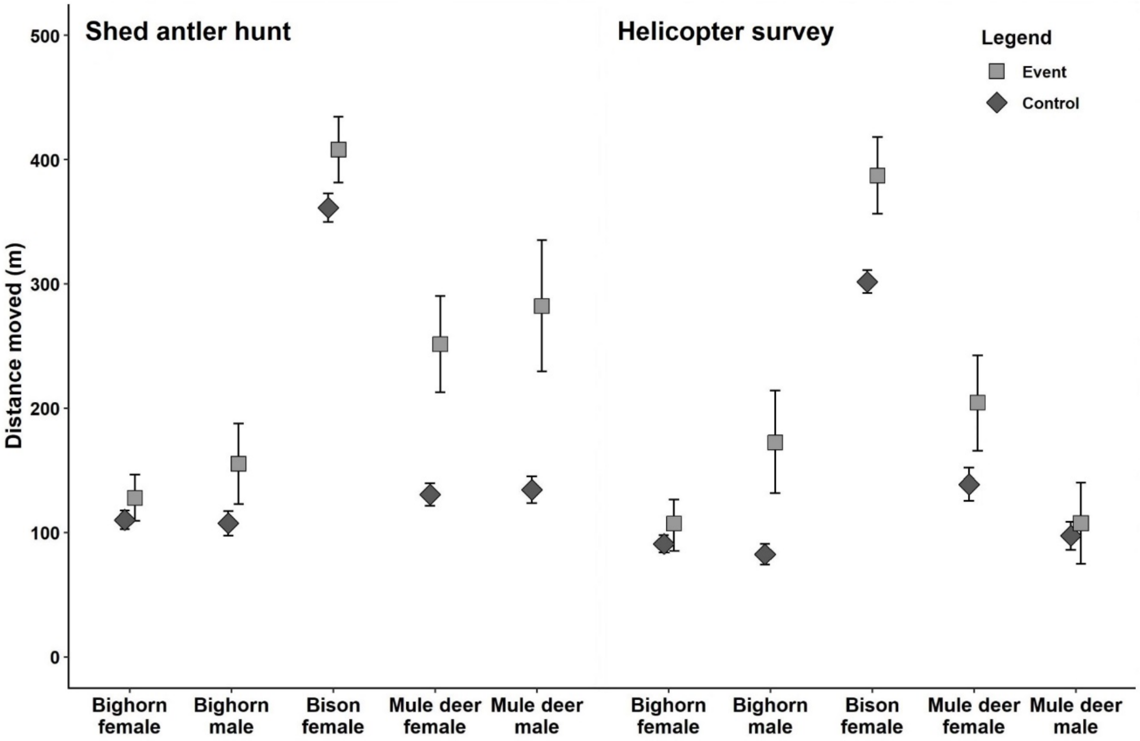

Figure 1-3. Mean distance (m) moved (±95% CI) combined across years by ungulates during shed antler hunts and helicopter surveys on Antelope Island State Park, Utah, USA, 2012–2015. Control values are mean distance moved during the 7 days preceding an event. These values are for distance moved during 90-minute segments.

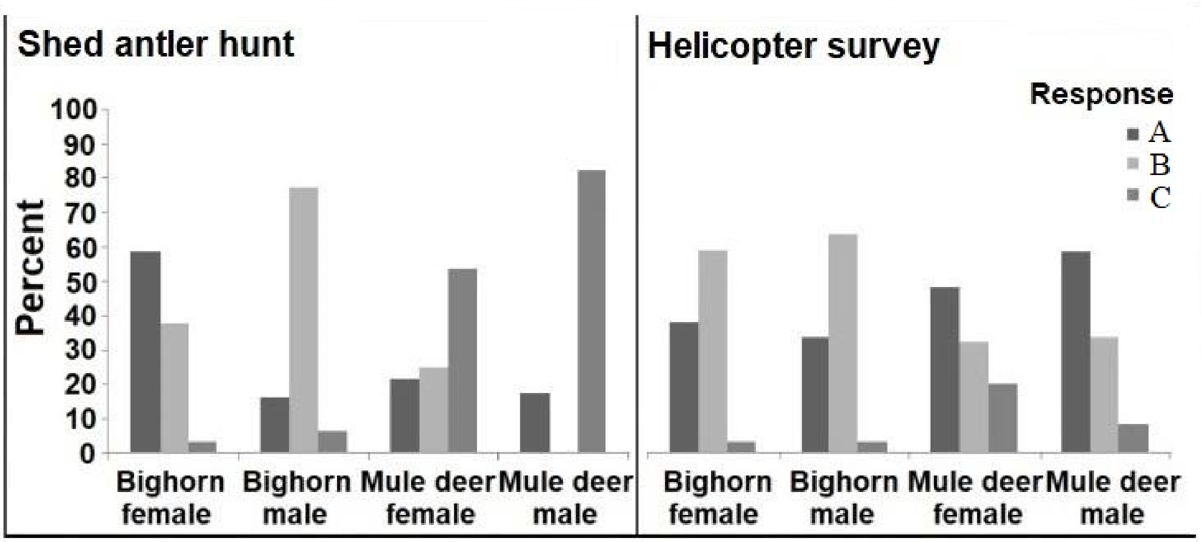

Figure 1-4. Responses to shed antler hunts and helicopter surveys by ungulates on Antelope Island State Park, Utah, USA, 2012–2015. Responses were categorized as A) individual moved within their 95% annual home range but remained in approximate pre-event location, B) individual moved to new location within their annual home range, or C) individual moved beyond the boundary of their annual home range but re-entered their home range boundaries within 7 days after the event. Female bison used the entire island and therefore response patterns are not shown for that species.

TABLES

Table 1-1. Event type, mean, standard deviation, number of people participating, percent of area involved, length of time, dates of events, and number of global positioning system (GPS)-collared animals used in our study on Antelope Island State Park, Utah, USA, 2012–2015. Sample sizes for GPS-collared individuals are combined across years by species and sex, which meant that we collected data for some individuals across multiple years. Because of mortalities and collar failures, not all individuals contributed sample units each year. The 115 individuals included in our analyses provided 152 samples during shed antler hunts and 143 samples during helicopter surveys.

Event	Number of participants	SD	Area affected	Length of time (hr)	SD	Dates	Bighorn female	Bighorn male	Bison female	Mule deer female	Mule deer male
Shed antler hunt	192	13.9	94%	22	0	9–13 Mar	29	31	47	28	17
Helicopter survey	4	0	100%	3.6	0.9	11–23 Feb	29	30	47	25	12

Table 1-2. Variable descriptions for potential factors influencing distances (m) moved by bighorn sheep, bison, and mule deer related to shed hunts and helicopter surveys on Antelope Island State Park, Utah, USA, 2012–2015.

Variable type	Description
Species	Categorical variable of bighorn, bison, or mule deer
Sex	Categorical variable of female or male
Individual	Random effect accounting for individual animal
Event	Categorical variable indicating shed antler hunt or helicopter survey
Phase	Categorical effect of pre-event (7 days before), event (1 or 2-day event), or post-event (7 days after event)
Year	Random effect of year of data collection (2012–2015)
Timelag	Random effect accounting for missed global positioning system (GPS) data fixes. We specified data collection intervals as 30 min for bison and 90 min for bighorn and mule deer during Jan–Dec (2012–2015). Not all scheduled GPS fixes were acquired. Thus, this variable allowed us to control for any missed fixes.

Table 1-3. Scaled β coefficients for mean distance moved by bighorn sheep, bison, and mule deer in response to shed antler hunts and helicopter surveys on Antelope Island State Park, Utah, USA, 2012–2015. The intercept is species = bighorn sheep, sex = female, and event = shed antler hunts.

Parameter	β	SE	*t*	*P*
(Intercept)	126.20	11.68	10.81	<0.001
Species bison	−2.78	11.53	−0.24	0.810
Species mule deer	124.50	13.22	9.41	<0.001
Sex male	14.70	13.11	1.12	0.263
Event survey	−17.85	11.36	−1.57	0.116
Phase post	−24.25	7.34	−3.30	<0.001
Phase pre	−19.39	7.34	−2.64	0.008
Species mule deer × sex male	11.63	19.20	0.61	0.545
Species bison × event survey	8.77	12.38	0.71	0.479
Species mule deer × event survey	−31.52	16.21	−1.95	0.052
Sex male × event survey	49.68	15.67	3.17	0.002
Species bison × phase post	20.70	8.02	2.58	0.009
Species mule deer × phase post	−76.94	10.33	−7.45	<0.001
Species bison × phase pre	1.93	8.03	0.24	0.810
Species mule deer × phase pre	−104.60	10.38	−10.08	<0.001
Sex male × phase post	−0.16	10.02	−0.02	0.987

SUPPLEMENTAL MATERIAL

Table A1-1. Models describing mean distance moved (D) by bighorn sheep, bison, and mule deer (species) in response to shed antler hunts and helicopter surveys (event) on Antelope Island State Park, Utah, USA, 2012–2015. Phase indicates whether the distance was recorded before, during, or after the event. We report Akaike's Information Criterion adjusted for small sample sizes (AIC_c), difference in AIC_c value from the top model (ΔAIC_c), AIC_c model weight (w_i), and degrees of freedom (df). Random effects for year (2012–2015), timelag (missed global positioning system data fixes; 888), and individual (*n* = 115) were included in all models.

Model structure	AIC_c	ΔAIC_c	w_i	df
D (species + sex + event + phase + sex × species + event × species + phase × species + event × sex + phase × species + event × sex + phase × sex + event × phase + event × sex × species + event × phase × species + event × phase × sex + phase × sex × species + event × phase × sex × species)	1,587,599	0	1	34
D (species + event + phase + event × species + phase × species + event × phase + event × phase × species)	1,587,794	195	0	22
D (sex + event + phase + event × sex + phase × sex)	1,588,185	586	0	16
D (species + phase + phase × species)	1,588,200	600	0	13
D (species + sex + sex + phase)	1,588,290	691	0	11
D (species + event + phase)	1,588,294	695	0	10
D (event + phase + event × phase)	1,588,323	724	0	10
D (sex + event + phase)	1,588,326	727	0	9
D (event + phase)	1,588,330	731	0	8
D (sex + phase + phase × sex)	1,588,451	851	0	10
D (species + phase)	1,588,518	919	0	9
D (sex + phase)	1,588,551	951	0	8

CHAPTER 2

Space Use and Movements of Individual Mule Deer and Bighorn Sheep in Response to Shed Antler Hunting

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ABSTRACT

Shed antler hunting (i.e., gathering of cast cervid antlers) has increased in popularity during the past decade. Little is known, however, about how this recreational activity affects space use and movements of individual ungulates across multiple years. We analysed 177,138 global positioning system locations to quantify space use and movements of 12 mule deer (*Odocoileus hemionus*) and 25 bighorn sheep (*Ovis canadensis*) with multiple years of data in response to shed antler hunting from 2012 to 2015, on Antelope Island State Park in Utah, USA. We hypothesised that individual animals would respond similarly to shed antler hunting across multiple years. We predicted that animals that stayed in the same location in their home range, moved to another area in their home range, or left their home range during shed antler hunts, would respond similarly in subsequent years. We further predicted that mean distance (m) moved during 90-minute intervals by those ungulates would be similar across years, and that mule deer moving beyond the boundaries of their home range during shed antler hunts would move a similar distance (m) outside of those ranges in the subsequent year. Twenty-five percent of mule deer and 44% of bighorn sheep responded differently to shed antler hunting across two years. We tracked four mule deer for three and four consecutive years, and each of those deer responded to shed antler hunting differently across subsequent years. Mule deer increased movement (paired t-test = -3.9, $p < 0.001$) during shed antler hunts when compared to pre-event time periods. From year one to year two, however, distances moved were not different (paired t-test = 0.33, p = 0.75) with mean increase in year one at 216 ± 78 m and year two at 197 ± 68 m. Bighorn sheep increased movement (paired t-test = -6.9, $p < 0.001$) during shed antler hunts when compared to pre-event time periods. From year one to year two, these movements decreased 39% (paired t-test = 2.36, p = 0.027) with mean distance in year one at 60 ± 13 m and year two at 40 ± 9 m. Our results provide insight into how individual mule deer and bighorn sheep responded to shed antler hunting across multiple years.

INTRODUCTION

Ungulate use of space and movements within their home ranges allow individuals to obtain adequate nutrition, find security cover, and experience social interactions (Gaillard et al. 2000; Merems et al. 2020; Owen-Smith and Traill 2017; Pérez-Solano et al. 2017). Human recreational activities, however, may influence how ungulates use space and move within their home ranges (Gutzwiller et al. 2017; Kerbiriou et al. 2009; Nix et al. 2018). Human activities can displace animals, prevent individuals from accessing essential resources, displace them from secure locations, and interrupt social and reproductive behaviors (Bishop et al. 2009; Clair and Forrest 2009; Nix et al. 2018; Thiel et al. 2007). Wildlife biologists often try to mitigate any negative influences to wildlife from interaction with human recreationists (Gill et al. 2001; Gutzwiller et al. 2017; Larson et al. 2016). Interactions between recreationists and wildlife can better be managed with improved understanding of how recreationists competing against one another for a limited resource—e.g., gathering shed antlers (i.e., cast cervid antlers)—influence movement and use of space by ungulates, especially across multiple years (Bates et al. 2021).

Cervid antlers have been collected and used by humans for medicinal, spiritual, and industrial purposes throughout history (Tejero et al. 2012; Villa and D'Errico 2001; Vitezović 2017). Shed antler hunting, however, for recreation or as a source of income, is a modern activity that has recently become popular during the past decade (Western Association of Fish and Wildlife Agencies 2015; Mimiaga 2018). Mule deer (*Odocoileus hemionus*) and bighorn sheep (*Ovis canadensis*) respond to shed antler hunters by increasing distance moved in comparison to normal movement and these ungulates either stayed in the same location in their home range, moved to a new area in their home range, or left their home range during shed antler hunts (Bates et al. 2021). Whether or not individual mule deer and bighorn sheep responded similarly across multiple years to shed antler hunting, however, is unknown.

Global positioning system (GPS) technology enhances the ability of biologists to study movement and space use of individual animals (Abaigar et al. 2018; Adrados et al. 2003; Jiang 2020), especially when animals are influenced by human recreationists. For example, GPS tracking systems, applied simultaneously to both study animals and recreationists, were used to evaluate changes in the selection of habitat by wolverines (*Gulo gulo*) in response to motorised and non-motorised recreation (Heinemeyer et al. 2019). Likewise, elk (*Cervus canadensis*) monitored with GPS technology sought refuge from predators in spatial zones too close to human activity for predatorial approach, but were sufficiently removed from human activity to obtain a sense of security (Rogala et al. 2011). Indeed, GPS technology has increased our understanding of behavioral ecology including migration, risk of and response to predation, birth-site selection, and resource selection (Bastille-Rousseau and Wittemyer 2020; Bates et al. 2021; Kays et al. 2015; McLaren et al. 2017; Rominger 2018).

Understanding how wildlife respond to varying levels of human recreational activities will lead to sound land-use planning and successful conservation of wildlife and their habitats (Bates et al. 2021; Dzialak et al. 2011; Harju et al. 2011; Margules and Pressey 2000). GPS data have provided unique insights into animal behavior (Tomkiewicz et al. 2010) and to our understanding of how shed antler hunts affect ungulates (Bates et al. 2021). Nonetheless, little is known about the response of individual mule deer and bighorn sheep to shed antler hunting across multiple years. We hypothesised that individual mule deer and bighorn sheep would exhibit the same response to shed antler hunters in subsequent years. Specifically, we predicted that individual mule deer and bighorn sheep with two years of data that stayed in the same location in their home range, moved to a new area in their home range, or left their home range during shed antler hunting would respond similarly in the subsequent year. Further, we predicted that mule deer with up to four years of data would respond similarly to shed antler hunting across all years. We also predicted that mean distance (m) moved by mule deer and bighorn sheep in response to shed antler hunting would be similar across years, and that mule deer moving beyond the boundaries of their home range would move a similar distance outside of those ranges during shed antler hunts in the subsequent year. Our results will provide insight into how mule deer and bighorn sheep respond individually to shed antler hunting across multiple years, aiding implementation of strategies to minimize energetic costs to these ungulates during critical stress periods of late winter. These results can improve management and habitat conservation for these ungulates.

MATERIALS AND METHODS

Study Area

Antelope Island State Park (40°57´N, 112°13´W) is located on the largest island within the Great Salt Lake (Fig. 2–1). This island is approximately 11,300 ha, 24 km long by 8.3 km wide, with elevation ranging from 1,280 m to 2,011 m (Rogerson *et al.* 2008; Whiting *et al.* 2009a; Whiting *et al.* 2009b). A north-south central ridge is the major topographic feature of the island and divides the island in half (Bates *et al.* 2021). Vegetation on the island consists mainly of semi-arid grasslands at lower elevations, while big sagebrush (*Artemisia tridentata* spp.) communities occur at higher elevations (Brookshier and Fairbanks 2003). Vegetation on the eastern side of the island is the most diverse, including stands of Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*), bigtooth maple (*Acer grandidentatum*) along riparian corridors and isolated stands of Utah juniper (*Juniperus osteosperma*). The west side of the island is drier and more rugged. The dominate vegetation is purple threeawn (*Aristida purpurea*) and cheatgrass (*Bromus tectorum*) (Bates *et al.* 2021; Taylor *et al.* 2020). During our study, four species of ungulates occupied Antelope Island: 543 ± 181 mule deer, 122 ± 25 bighorn sheep, 532 ± 19 bison (*Bison bison*), and 210 ± 30 pronghorn (*Antilocapra americana*) (Bates *et al.* 2021). Predators that primarily preyed on the young of those ungulates were coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and golden eagles (*Aquilia chrysaetos*) (Whiting *et al.* 2009a; Whiting *et al.* 2009b). From 1875 to 2020, mean temperature was 11.2° C, and mean annual precipitation was 39.8 cm (Western Regional Climate Center, https://wrcc.dri.edu/, accessed 07 Jan 2021). Seasons were categorised as winter (January–March), spring (April–June), summer (July–September), and fall (October–December) (Bates *et al.* 2021).

Antelope Island was established as a State Park to provide opportunities for human recreation (e.g., hiking, biking, wildlife viewing, and swimming) and conservation of wildlife habitat (Parks 2001). From 2012 to 2015, average annual visitation was 320,732 people (range = 282,145 to 380,611) (Parks 2018). Recreationists were restricted to trails and roadways except for four days annually; two consecutive days in March (shed antler hunt) and two consecutive days in October (bison round-up) (Bates *et al.* 2021). During those events, a regulated number of visitors (100–300 individuals) could access the entire island (Bates *et al.* 2021; Kaze *et al.* 2016).

Wildlife Capture

In February 2012 and January through March 2014, net-gunners captured mule deer and bighorn sheep from helicopters (Bates *et al.* 2021; Krausman and Bleich 2013; Taylor *et al.* 2020). A few individuals (8 mule deer, 5 bighorn sheep) were transported to a processing station. At that station, we weighed, measured, and collected samples for disease monitoring followed by releasing processed individuals on site. The processing station was located within mule deer habitat but was 2 km from bighorn sheep habitat (Bates *et al.* 2021). All other individuals were collared and released at the point of capture. In 2012, we collared 19 mule deer (7 males, 12 females) and 20 bighorn sheep (8 males, 12 females) with Lotek global positioning system (GPS) 7000S store-onboard collars (Lotek Wireless Inc., St. John's, Newfoundland, Canada) (Taylor *et al.* 2020). In 2014, we fitted either Lotek 7000S or ATS G2110D GPS collars (Advanced Telemetry Systems, Isanti, MN) on 22 mule deer (11 males, 11 females) and 24 bighorn sheep (16 males, 8 females) (Bates *et al.* 2021; Taylor *et al.* 2020). Collars collected data at 90-min intervals two weeks prior, during, and two weeks following shed antler hunts. We followed guidelines from the American Society of Mammalogists (Sikes *et al.* 2019) for the capturing and handling of animals. Additionally, the Institutional Animal Care and Use Committee at Brigham Young University (protocol number 130105) reviewed helicopter capture and handling protocols.

We recovered collars when animals were recaptured, died, or after collars fell off. We located collars using a telemetry receiver (Communications Specialists, R1000, Orange, CA, USA) with a Yagi antenna (Kaze *et al.* 2016). We downloaded collar data, and discarded locations with a dilution of precision value ≥10 to ensure GPS location accuracy (D'Eon and Delparte 2005; Lendrum *et al.* 2012; Lendrum *et al.* 2013). We excluded data points >92 min apart when calculating distance movements to eliminate bias towards over estimating distances moved during the 90-minute sample intervals (Bates *et al.* 2021).

Shed Antler Hunts

We quantified space use and movements of mule deer (5 males, 7 females) and bighorn sheep (13 males, 12 females) during shed antler hunts on Antelope Island held for two consecutive days annually during the dates of March 9 to 13, 2012-2015 (Bates *et al.* 2021). Shed antler hunting occurred in areas used extensively by mule deer and bighorn sheep (Fig. 2–1). We divided the island into two areas (east and west sides) using the north to south central ridge of the island as a general boundary. We separated that area by east-west to avoid displacing wildlife across the entire island during shed antler hunts (Bates *et al.* 2021). Each year we selected approximately 200 ($\bar{x}$ = 192 ± 14, range = 186 to 200) shed antler hunters either through a random draw or by a first-come, first-serve online sale of tags. Participants were selected by randomly pulling cards—with one or two names per card—deposited by people gathered at the entrance station the morning of shed antler hunt dates. Random draws began at 0730 with the first participant reaching the island by 0800 (Bates *et al.* 2021). Shed antler hunters could search for antlers throughout the day until sunset at approximately 1900 annually. We opened the east side of the island during day one. Accessibility was greatest on that side because of a 16-km paved road near the shoreline of the island, however, vehicles could not leave the roadway, and shed antler hunters searched the area either on foot or by horseback (Bates *et al.* 2021; Kaze *et al.* 2016). On day two, we allowed participants on the west side. No vehicle access existed for that side of the island; therefore, participants accessed that area from backcountry trail heads or traversed the east side using the trail system to reach the west side (Kaze *et al.* 2016). Similarly, shed antler hunters on the east side of the island, west side participants were either on foot or traveling by horse.

Analyses

Twelve mule deer and 25 bighorn sheep had at least two and up to four consecutive years of location data during shed antler hunts. From those data we used Brownian-bridge movement models to estimate annual home ranges (95% probability bands) for each individual mule deer and bighorn sheep for each year (Bates *et al.* 2021; Kranstauber *et al.* 2012; Sawyer *et al.* 2009; Walter and Fischer 2016) in R using package Adehabitat (Calenge 2006). We calculated annual home ranges starting from date of capture and ending through collar failure, animal death, or December 31 annually (Bates *et al.* 2021). Next, we categorised ungulate response to shed antler hunting into the following three categories: the individual continued using the same area in their annual home range following the hunt (response A), the individual moved (≥500 m) to and remained in a another area in their annual home range following the hunt (response B), or the individual moved beyond the boundary of their home range in response to the hunt and then returned to their home range within seven days after the hunt (response C; Fig. 2–2; Bates *et al.* 2021). We used t-tests to detect change in mean distances moved in response to shed antler hunting by comparing distances moved during pre-event and event time frames. To calculate mean (90-minute interval) distance moved (m) by individual ungulates during shed antler hunts, we selected data from each animal starting the morning of the shed antler hunt (0800 hrs) until sunset at approximately 1900 hrs. We used 90-minute movements from the seven days prior to the event to obtain the mean 90-min interval distance moved during the pre-event phase. For individual mule deer and bighorn sheep, we used paired *t*-tests to detect if the change between normal movement (pre-event) and movement during shed antler hunts (event), varied from year one to year two in response to shed antler hunters.

Using only those individual mule deer ($n = 6$) that moved outside of their home range boundaries (response C) during year one, we also measured the shortest distance (m) from the edge of the estimated home range to the farthest point outside the home range using the Near Tool in ArcMap (Esri, Redlands, CA, USA) for each individual and each year (Bates *et al.* 2021). Then using paired *t*-tests, we compared mean distance moved (m) for each individual animal during year one with those distances moved during year two.

RESULTS

Individual mule deer (5 males and 7 females) were collared a mean (± *SD*) of 47 days (± 20 days, range = 6 to 61 days) before their first shed antler hunt. Twenty-five percent of mule deer altered their second-year response from their response to shed antler hunting during year one (Fig. 2–3). Additionally, we tracked four of those individual mule deer for three or four consecutive years. All deer tracked for three or four years responded to shed antler hunting differently across those years (Fig. 2–4). Mule deer increased distance moved (*paired t-test* = -3.9, $df = 23$, $p < 0.001$) during shed antler hunts compared to pre-event periods. Further, when comparing whether this increased movement among mule deer ($n = 12$) was sustained year to year, no difference (*paired t-test* = 0.33, *df* = 11, *p* = 0.75) was observed. In response to shed antler hunting, the mean increase in distanced moved by mule deer during year one was 216 ± 78 (*se*) m (range -73 to 781 m) and the mean increase in distanced moved during year two was 197 ± 68 m (range -479 to 907 m). However, evaluation of the six mule deer that left their home ranges (response C) during shed antler hunts showed that these individuals reduced the distance moved beyond those home range boundaries by 55% (*paired t-test* = 4.849, *df* = 5, *p* = 0.005) from year one ($\bar{x}$ = 2,096 m, *se* = 523) to year two ($\bar{x}$ = 936 m, *se* = 380).

Individual bighorn sheep (males = 13, females = 12) were collared a mean of 49 days (± 15 days, range = 6 to 63 days) before subsequent shed antler hunts. Forty-four percent of bighorn sheep responded differently to shed antler hunts across 2 years (Fig. 2–3). Moreover, during year one of our study, 25% (*n* = 3) of female bighorn sheep responded by moving to another area within their home range during shed antler hunts. During year two, the percentage of females moving to other areas increased to 75% (*n* = 9). Bighorn sheep increased distance moved (*paired t-test* = -6.9, *df* = 49, *p* < 0.001) during shed antler hunts compared to distances moved duringthe week prior to these disturbances (pre-event). Further, when comparing whether this increased movement among bighorn sheep (*n* = 25) was sustained year to year, a 39% decrease (*paired t-test* = 2.36, *df* = 24, *p* = 0.027) in the distance moved during year two was observed. In response to shed antler hunting, the mean increase in distanced moved by bighorn sheep during year one was 60 ± 13 (*se*) m (range -10 to 212 m) and the mean increase in distanced moved during year two was 40 ± 9 m (range -18 to 158 m). Only one bighorn sheep left its home range during year two and moved 65 m beyond that boundary.

DISCUSSION

Space use

Our results did not support our prediction that mule deer would respond to shed antler hunting consistently across years. Indeed, 25% of mule deer responded differently in year two compared with year one, and all deer monitored for up to four years responded differently across years to shed antler hunting. The degree of disturbance among those animals during encounters with shed antler hunters likely varied annually, leading to differing responses by each individual across years. Each encounter an animal has with a human recreational activity (e.g., shed antler hunting) is influenced by a host of variables (e.g., duration and timing of stimulus, repetition of short-term stimuli, and group size and behavior, etc.) (Beale 2007; Larson *et al.* 2016; Wisdom *et al.* 2004). For example, as human approach shifted from an indirect to a direct approach, mule deer increased vigilance as well as increased gap distance prior to flight (Taylor and Knight 2003), and when human activity near campgrounds increased, mule deer activity declined in those areas, and then mule deer increased activity as human presence declined in those areas (Nix *et al.* 2018). Moreover, mule deer are less likely to move away from hikers when they use a consistent trail corridor (Freddy *et al.* 1986). Shed antler hunters on Antelope Island, and other locations, however, are not restricted to trail corridors and move in erratic and unpredictable patterns as they search for shed antlers (Bates *et al.* 2021). Erratic movements by shed antler hunters likely affect how individual mule deer respond to that activity.

Our results did not support our prediction that bighorn sheep would respond to shed antler hunters consistently across years. Indeed, almost two times more bighorn sheep (44%) responded differently to shed antler hunting in year two compared with year one. Moreover, the number of females moving to other areas within their home ranges tripled during year two. Again, erratic movements by shed antler hunters likely affected how individual bighorn sheep responded to shed antler hunting (Bates *et al.* 2021; Wiedmann and Bleich 2014). Intensive levels of erratic and unpredictable movement by hikers eventually can lead to female bighorn sheep abandoning habitat, especially near lambing areas, leading to poor recruitment rates and population decline (Papouchis *et al.* 2001; Singer *et al.* 2000; Wiedmann and Bleich 2014). Bighorn sheep lambing areas are recognised as important habitat features essential for population growth (Macarthur *et al.* 1982; Robinson *et al.* 2019; Smith *et al.* 2015). Potential abandonment of lambing habitat by female bighorn sheep needs to be considered when allowing for shed antler hunts in bighorn sheep habitat, especially when lambing areas and shed antler hunting overlap (Bates *et al.* 2021).

Movement

The distance moved by mule deer during shed antler hunts on Antelope Island remained constant, supporting our prediction that increased movement by mule deer in response to shed antler hunters would be similar from year to year. Regardless of differences in movements across years, individual deer consistently increased distance moved during shed antler hunts. Shed antler hunting on Antelope Island occurred during critical stress periods at the end of winter and just prior to spring green-up. The increased distance moved by mule deer could be costly energetically (Parker *et al.* 2009; Parker *et al.* 1984). The increase in energetic costs to individuals could be an important consideration on when to open areas to shed antler hunting, especially in areas where mule deer are exposed to this activity over an extended period. Shed antler hunting can be unpredictable, occurs mainly off trail, and has varying densities and numbers of participants in each locale exposing individual animals to varying degrees of pressure.

We suggest that the reduction in distance moved by individual mule deer that moved beyond their home range boundaries can be attributed to an individual's familiarity with secure habitats in its own home range versus searching for secure sites in unfamiliar terrain. Ungulates heighten vigilance, increase distance and rate of movement, alter habitat use, and demonstrate either temporal or spatial avoidance in relation to people participating in outdoor recreation (Bates *et al.* 2021; Nix *et al.* 2018; Papouchis *et al.* 2001; Sproat *et al.* 2019; Taylor and Knight 2003; Wisdom *et al.* 2004). The ability of wildlife to adapt behaviors or habituate to changing conditions varies among species (Blumstein 2016; Price *et al.* 2014; Sawyer *et al.* 2017). During the four years of our study, we only found a decline in distance moved by individuals that moved beyond their home range boundaries (response C). For the other animals, we observed that mule deer continued to increase movement significantly when compared to reference (pre-event) time periods in response to shed antler hunting and did not appear to acclimate to that event.

Shed Antler Hunting

From medicinal use to home décor (Mimiaga 2018; Wu *et al.* 2013), demand is growing for the collection of cervid antlers across the globe (Apollonio *et al.* 2010; Koshmrl 2019; Kuba *et al.* 2018; Kwak *et al.* 1994). Over the past decade, the price/kg of cervid antlers has tripled, which will increase demand for cervid antlers (Koshmrl 2019). In western North America, mule deer and bighorn sheep are important and iconic species essential in maintaining ecosystem integrity (Bates *et al.* 2021; Bishop *et al.* 2009; Kie *et al.* 2002; Smedley *et al.* 2019). In many areas, mule deer populations have declined over recent decades (Ballard *et al.* 2001). Likewise, bighorn occur on only a fraction of their former range (Singer *et al.* 2000). We documented short-term response of mule deer and bighorn sheep to shed antler hunting in a highly regulated environment where shed hunting was limited in duration and participation. Our situation is different from other situations where chronic affects from shed antler hunting over an extended period and unregulated number of participants may be more problematic. However, through use of GPS technology, we are able to provide insights that will help ecologists understand the effects that shed antler hunting has on space use and movement of mule deer and bighorn sheep, thus providing timely information that can help guide conservation measures for these ungulates and their habitat.

CONCLUSION

We evaluated how space use and movement by individual mule deer and bighorn sheep changed in response to shed antler hunting. Our study was the first to document effects of shed antler hunting on these ungulates across multiple years. Often, the focus of wildlife management is to obtain population level demographics through counting and classifying individuals while also evaluating habitat selection and resource use at that same level (Martin 1998; Pollock *et al.* 2002). These outcomes are often used to justify or change management strategies. However, there is increasing interest in understanding how individual behavior and response patterns influence population dynamics (Jolles *et al.* 2020; Shaw 2020). The foundation of population dynamics occurs through natural selection at the individual level (Austin *et al.* 2004; Clutton-Brock and Sheldon 2010). Therefore, disruptive factors (such as encounters with shed antler hunters) may negatively affect individual animals and ultimately influence population dynamics (Merrick and Koprowski 2017). We documented differential responses by mule deer and bighorn sheep to shed antler hunting across years providing novel information for these species that can be used in conservation planning and management.

LITERATURE CITED

Abaigar, T., Cano, M., and Ensenyat, C. (2018). Time allocation and patterns of activity of the dorcas gazelle (*Gazella dorcas*) in a sahelian habitat. Mammal Research 63, 73-82. doi: 10.1007/s13364-017-0334-0.

Adrados, C., Verheyden-Tixier, H., Cargnelutti, B., Pepin, D., and Janeau, G. (2003). GPS approach to study fine-scale site use by wild red deer during active and inactive behaviors. Wildlife Society Bulletin 31, 544-552.

Apollonio, M., Andersen, R., and Putman, R. (2010) 'European ungulates and their management in the 21st century.' (Cambridge University Press.)

Austin, D., Bowen, W. D., and McMillan, J. I. (2004). Intraspecific variation in movement patterns: modeling individual behaviour in a large marine predator. Oikos 105, 15-30. doi: 10.1111/j.0030-1299.1999.12730.x.

Ballard, W. B., Lutz, D., Keegan, T. W., Carpenter, L. H., and deVos Jr, J. C. (2001). Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin, 99-115.

Bastille-Rousseau, G. and Wittemyer, G. (2020). Characterizing the landscape of movement to identify critical wildlife habitat and corridors. Conservation Biology 0, 1-14. doi: 10.1111/cobi.13519.

Bates, S. B., Whiting, J. C., and Larsen, R. T. (2021). Effects of shed antler hunting on ungulate movements and space use The Journal of Wildlife Management 85, 437-448. doi: doi.org/10.1002/jwmg.22008.

Beale, C. M. (2007). The behavioral ecology of disturbance responses. International Journal of Comparative Psychology 20, 111-120.

Bishop, C. J., White, G. C., Freddy, D. J., Watkins, B. E., and Stephenson, T. R. (2009). Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs, 1-28. doi: 10.2193/2008-107.

Blumstein, D. T. (2016). Habituation and sensitization: new thoughts about old ideas. Animal Behaviour 120, 255-262.

Brookshier, J. S. and Fairbanks, W. S. (2003). The nature and consequences of mother-daughter associations in naturally and forcibly weaned bison. Canadian Journal of Zoology-Revue Canadienne De Zoologie 81, 414-423. doi: 10.1139/z03-010.

Calenge, C. (2006). The package “adehabitat” for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197, 516-519.

Clair, C. C. S. and Forrest, A. (2009). Impacts of vehicle traffic on the distribution and behaviour of rutting elk, Cervus elaphus. Behaviour 146, 393-413. doi: 10.1163/156853909x410973.

Clutton-Brock, T. and Sheldon, B. C. (2010). Individuals and populations: the role of long-term, individual-based studies of animals in ecology and evolutionary biology. Trends in Ecology & Evolution 25, 562-573. doi: 10.1016/j.tree.2010.08.002.

D'Eon, R. G. and Delparte, D. (2005). Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. Journal of Applied Ecology 42, 383-388. doi: 10.1111/j.1365-2664.2005.01010.x.

Dzialak, M. R., Harju, S. M., Osborn, R. G., Wondzell, J. J., Hayden-Wing, L. D., Winstead, J. B., and Webb, S. L. (2011). Prioritizing conservation of ungulate calving resources in multiple-use landscapes. PloS One 6. doi: 10.1371/journal.pone.0014597.

Freddy, D. J., Bronaugh, W. M., and Fowler, M. C. (1986). Responses of mule deer *Odocoileus hemionus* to disturbance by persons afoot and snowmobiles. Wildlife Society Bulletin 14, 63-68.

Gaillard, J. M., Festa-Bianchet, M., Yoccoz, N. G., Loison, A., and Toigo, C. (2000). Temporal variation in fitness components and population dynamics of large herbivores. Annual Review of Ecology and Systematics 31, 367-393. doi: 10.1146/annurev.ecolsys.31.1.367.

Gill, J. A., Norris, K., and Sutherland, W. J. (2001). Why behavioural responses may not reflect the population consequences of human disturbance. Biological Conservation 97, 265-268. doi: 10.1016/s0006-3207(00)00002-1.

Gutzwiller, K. J., D'Antonio, A. L., and Monz, C. A. (2017). Wildland recreation disturbance: broad-scale spatial analysis and management. Frontiers in Ecology and the Environment 15, 517-524.

Harju, S. M., Dzialak, M. R., Osborn, R. G., Hayden-Wing, L. D., and Winstead, J. B. (2011). Conservation planning using resource selection models: altered selection in the presence of human activity changes spatial prediction of resource use. Animal Conservation 14, 502-511. doi: 10.1111/j.1469-1795.2011.00456.x.

Heinemeyer, K., Squires, J., Hebblewhite, M., O'Keefe, J. J., Holbrook, J. D., and Copeland, J. (2019). Wolverines in winter: indirect habitat loss and functional responses to backcountry recreation. Ecosphere 10. doi: 10.1002/ecs2.2611.

Jiang, Z. G. (2020). Using the new technologies and the Internet to track wild animals, bringing new opportunities for wildlife research and conservation. Chinese Science Bulletin-Chinese 65, 651-655. doi: 10.1360/tb-2019-0522.

Jolles, J. W., King, A. J., and Killen, S. S. (2020). The role of individual heterogeneity in collective animal behaviour. Trends in Ecology & Evolution 35, 278-291. doi: 10.1016/j.tree.2019.11.001.

Kays, R., Crofoot, M. C., Jetz, W., and Wikelski, M. (2015). Terrestrial animal tracking as an eye on life and planet. Science 348. doi: 10.1126/science.aaa2478.

Kaze, J., Whiting, J. C., Freeman, E. D., Bates, S. B., and Larsen, R. T. (2016). Birth-site selection and timing of births in American bison: effects of habitat and proximity to anthropogenic features. Wildlife Research 43, 418-428. doi: 10.1071/wr15205.

Kerbiriou, C., Le Viol, I., Robert, A., Porcher, E., Gourmelon, F., and Julliard, R. (2009). Tourism in protected areas can threaten wild populations: from individual response to population viability of the chough *Pyrrhocorax pyrrhocorax*. Journal of Applied Ecology 46, 657-665. doi: 10.1111/j.1365-2664.2009.01646.x.

Kie, J. G., Bowyer, R. T., Nicholson, M. C., Boroski, B. B., and Loft, E. R. (2002). Landscape heterogeneity at differing scales: effects on spatial distribution of mule deer. Ecology 83, 530-544. doi: 10.2307/2680033.

Koshmrl, M. (2019). What it takes to catch antler thieves. National Geographic.

Kranstauber, B., Kays, R., LaPoint, S. D., Wikelski, M., and Safi, K. (2012). A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. Journal of Animal Ecology 81, 738-746.

Krausman, P. R. and Bleich, V. C. (2013). Conservation and management of ungulates in North America. International journal of environmental studies 70, 372-382.

Kuba, K., Monz, C., Bardsen, B. J., and Hausner, V. H. (2018). Role of site management in influencing visitor use along trails in multiple alpine protected areas in Norway. Journal of Outdoor Recreation and Tourism-Research Planning and Management 22, 1-8. doi: 10.1016/j.jort.2018.02.002.

Kwak, W., Kim, K., Kim, C., Jeon, B., and Lee, S. (1994). Deer farming in Korea: on-farm survey in Kyung-Kee and Chung-Buk provinces. Asian-Australasian Journal of Animal Sciences 7, 347-355.

Larson, C. L., Reed, S. E., Merenlender, A. M., and Crooks, K. R. (2016). Effects of recreation on animals revealed as widespread through a global systematic review. PloS One 11. doi: 10.1371/journal.pone.0167259.

Lendrum, P. E., Anderson, C. R., Long, R. A., Kie, J. G., and Bowyer, R. T. (2012). Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. Ecosphere 3. doi: 10.1890/es12-00165.1.

Lendrum, P. E., Anderson, C. R., Monteith, K. L., Jenks, J. A., and Bowyer, R. T. (2013). Migrating mule deer: effects of anthropogenically altered landscapes. PloS One 8. doi: 10.1371/journal.pone.0064548.

Macarthur, R. A., Geist, V., and Johnston, R. H. (1982). Cardiac and behavioral responses of mountain sheep (*Ovis canadensis canadensis*) to human disturbance. Journal of Wildlife Management 46, 351-358. doi: 10.2307/3808646.

Margules, C. R. and Pressey, R. L. (2000). Systematic conservation planning. Nature 405, 243-253. doi: 10.1038/35012251.

Martin, K. (1998). The role of animal behavior studies in wildlife science and management. Wildlife Society Bulletin 26, 911-920.

McLaren, A. A. D., Benson, J. F., and Patterson, B. R. (2017). Multiscale habitat selection by cow moose (*Alces alces*) at calving sites in central Ontario. Canadian Journal of Zoology 95, 891-899. doi: 10.1139/cjz-2016-0290.

Merems, J. L., Shipley, L. A., Levi, T., Ruprecht, J., Clark, D. A., Wisdom, M. J., Jackson, N. J., Stewart, K. M., and Long, R. A. (2020). Nutritional-landscape models link habitat use to condition of mule deer (*Odocoileus hemionus*). Frontiers in Ecology and Evolution 8. doi: 10.3389/fevo.2020.00098.

Merrick, M. J. and Koprowski, J. L. (2017). Should we consider individual behavior differences in applied wildlife conservation studies? Biological Conservation 209, 34-44.

Mimiaga, J. (2018). New regulation limits growing practice of antler collection. In 'The Journal'. (The Journal: Ballantine Communications, Inc: The Journal, Ballantine Communications, Cortez, Colorado, USA.)

Nix, J. H., Howell, R. G., Hall, L. K., and McMillan, B. R. (2018). The influence of periodic increases of human activity on crepuscular and nocturnal mammals: Testing the weekend effect. Behavioural Processes 146, 16-21. doi: 10.1016/j.beproc.2017.11.002.

Owen-Smith, N. and Traill, L. W. (2017). Space use patterns of a large mammalian herbivore distinguished by activity state: fear versus food? Journal of Zoology 303, 281-290. doi: 10.1111/jzo.12490.

Papouchis, C. M., Singer, F. J., and Sloan, W. B. (2001). Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65, 573-582. doi: 10.2307/3803110.

Parker, K. L., Barboza, P. S., and Gillingham, M. P. (2009). Nutrition integrates environmental responses of ungulates. Functional Ecology 23, 57-69. doi: 10.1111/j.1365-2435.2009.01528.x.

Parker, K. L., Robbins, C. T., and Hanley, T. A. (1984). Energy expenditures for locomotion by mule deer and elk. The Journal of Wildlife Management, 474-488.

Pérez-Solano, L. A., García-Feria, L. M., and Gallina-Tessaro, S. (2017). Factors affecting the selection of and displacement within core areas by female mule deer (*Odocoileus hemionus*) in the Chihuahuan Desert, Mexico. Mammalian Biology 87, 152-159.

Pollock, K. H., Nichols, J. D., Simons, T. R., Farnsworth, G. L., Bailey, L. L., and Sauer, J. R. (2002). Large scale wildlife monitoring studies: statistical methods for design and analysis. Environmetrics: The official journal of the International Environmetrics Society 13, 105-119.

Price, M. V., Strombom, E. H., and Blumstein, D. T. (2014). Human activity affects the perception of risk by mule deer. Current Zoology 60, 693-699. doi: 10.1093/czoolo/60.6.693.

Robinson, R. W., Whiting, J. C., Shannon, J. M., Olson, D. D., Flinders, J. T., Smith, T. S., and Bowyer, R. T. (2019). Habitat use and social mixing between groups of resident and augmented bighorn sheep. Scientific Reports 9. doi: 10.1038/s41598-019-51370-y.

Rogala, J. K., Hebblewhite, M., Whittington, J., White, C. A., Coleshill, J., and Musiani, M. (2011). Human activity differentially redistributes large mammals in the Canadian Rockies National Parks. Ecology and Society 16.

Rogerson, J. D., Fairbanks, W. S., and Cornicelli, L. (2008). Ecology of gastropod and bighorn sheep hosts of lungworm on isolated, semiarid mountain ranges in Utah, USA. Journal of Wildlife Diseases 44, 28-44.

Rominger, E. M. (2018). The Gordian knot of mountain lion predation and bighorn sheep. Journal of Wildlife Management 82, 19-31. doi: 10.1002/jwmg.21396.

Sawyer, H., Kauffman, M. J., Nielson, R. M., and Horne, J. S. (2009). Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19, 2016-2025.

Sawyer, H., Korfanta, N. M., Nielson, R. M., Monteith, K. L., and Strickland, D. (2017). Mule deer and energy development-long-term trends of habituation and abundance. Global Change Biology 23, 4521-4529. doi: 10.1111/gcb.13711.

Shaw, A. K. (2020). Causes and consequences of individual variation in animal movement. Movement Ecology 8. doi: 10.1186/s40462-020-0197-x.

Sikes, R. S., Thompson, T. A., and Bryan, J. A., II (2019). American Society of Mammalogists: raising the standards for ethical and appropriate oversight of wildlife research. Journal of Mammalogy 100, 763-773. doi: 10.1093/jmammal/gyz019.

Singer, F. J., Papouchis, C. M., and Symonds, K. K. (2000). Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8, 6-13. doi: 10.1046/j.1526-100x.2000.80061.x.

Smedley, D. C., van de Kerk, M., McMillan, B. R., Hersey, K. R., Whiting, J. C., and Larsen, R. T. (2019). Movements, space use and site fidelity of translocated and resident mule deer (*Odocoileus hemionus*). Wildlife Research 46, 509-517. doi: 10.1071/wr19043.

Smith, J. B., Grovenburg, T. W., and Jenks, J. A. (2015). Parturition and bed site selection of bighorn sheep at local and landscape scales. Journal of Wildlife Management 79, 393-401. doi: 10.1002/jwmg.843.

Sproat, K. K., Martinez, N. R., Smith, T. S., Sloan, W. B., Flinders, J. T., and Bates, J. W. (2019). Desert bighorn sheep responses to human activity in southeastern Utah. Wildlife Research 47, 9.

Taylor, A. R. and Knight, R. L. (2003). Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13, 951-963. doi: 10.1890/1051-0761(2003)13[951:wrtraa]2.0.co;2.

Taylor, J. C., Bates, S. B., Whiting, J. C., McMillan, B. R., and Larsen, R. T. (2020). Optimizing deployment time of remote cameras to estimate abundance of female bighorn sheep. Wildlife Research. doi: doi.org/10.1071/WR20069.

Tejero, J.-M., Christensen, M., and Bodu, P. (2012). Red deer antler technology and early modern humans in Southeast Europe: an experimental study. Journal of Archaeological Science 39, 332-346. doi: 10.1016/j.jas.2011.09.018.

Thiel, D., Menoni, E., Brenot, J.-F., and Jenni, L. (2007). Effects of recreation and hunting on flushing distance of capercaillie. Journal of Wildlife Management 71, 1784-1792. doi: 10.2193/2006-268.

Tomkiewicz, S. M., Fuller, M. R., Kie, J. G., and Bates, K. K. (2010). Global positioning system and associated technologies in animal behaviour and ecological research. Philosophical Transactions of the Royal Society B-Biological Sciences 365, 2163-2176. doi: 10.1098/rstb.2010.0090.

Utah State Parks (2001). Antelope Island State Park: wildlife management plan update. Utah Division of Parks and Recreation. Utah Department of Natural Resources, Salt Lake City, USA.

Utah State Parks (2018). Park visitation records. Utah Department of Natural Resources, Salt Lake City, USA.

Villa, P. and D'Errico, F. (2001). Bone and ivory points in the Lower and Middle paleolithic of Europe. Journal of Human Evolution 41, 69-112. doi: 10.1006/jhev.2001.0479.

Vitezović, S. (2017). Antler exploitation and management in the Vinča culture: an overview of evidence from Serbia. Quaternary International 450, 15. doi: 10.1016/j.quaint.2016.12.048.

Walter, W. D. and Fischer, J. W. (2016). Manual of applied spatial ecology.

Western Association of Fish and Wildlife Agencies. (2015). Mule deer shed antler hunting Fact Sheet #16. In 'Mule Deer Woking Group'. (Western Association of Fish & Wildlife Agencies.)

Whiting, J. C., Bowyer, R. T., and Flinders, J. T. (2009a). Annual use of water sources by reintroduced Rocky Mountain bighorn sheep Ovis canadensis canadensis: effects of season and drought. Acta Theriologica 54, 127-136. doi: 10.1007/bf03193168.

Whiting, J. C., Bowyer, R. T., and Flinders, J. T. (2009b). Diel use of water by reintroduced bighorn sheep. Western North American Naturalist 69, 407-412. doi: 10.3398/064.069.0318.

Wiedmann, B. P. and Bleich, V. C. (2014). Demographic responses of bighorn sheep to recreational activities: a trial of a trail. Wildlife Society Bulletin 38, 773-782. doi: 10.1002/wsb.463.

Wisdom, M. J., Ager, A. A., Preisler, H. K., Cimon, N. J., and Johnson, B. K. (2004). Effects of off-road recreation on mule deer and elk. In: Transactions of the 69th North American Wildlife and Natural Resources Conference: 531-550.

Wu, F. F., Li, H. Q., Jin, L. J., Li, X. Y., Ma, Y. S., You, J. S., Li, S. Y., and Xu, Y. P. (2013). Deer antler base as a traditional Chinese medicine: A review of its traditional uses, chemistry and pharmacology. Journal of Ethnopharmacology 145, 403-415. doi: 10.1016/j.jep.2012.12.008.

FIGURES

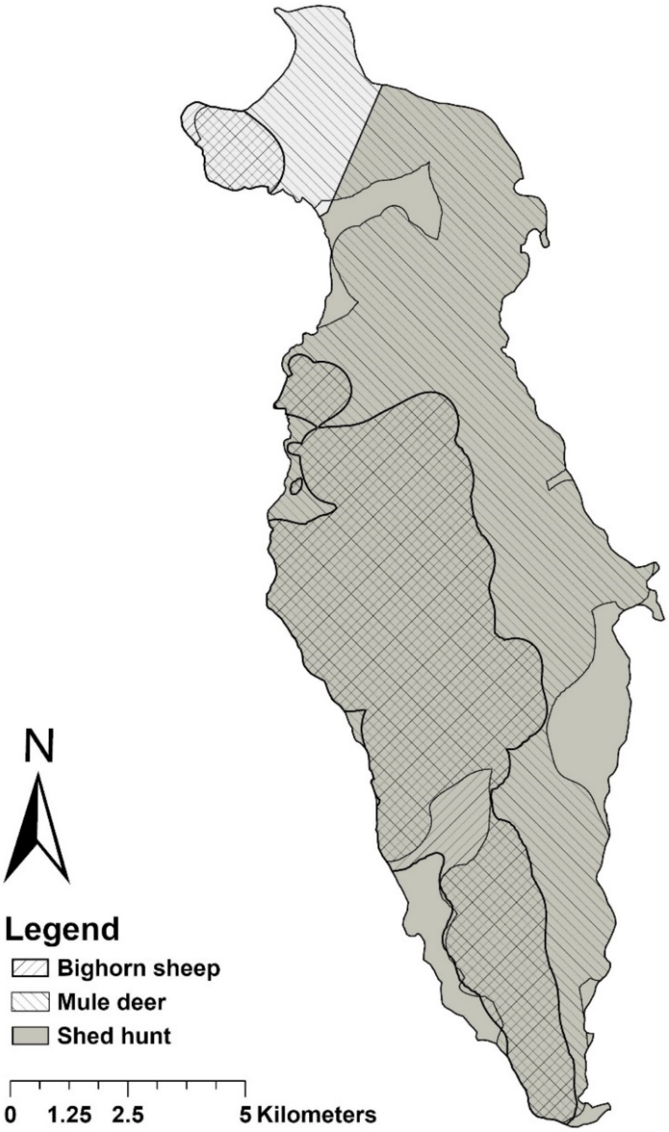

Figure 2-1. Antelope Island State Park, Utah, USA, where we documented space use and movements of individual mule deer and bighorn sheep during shed antler hunts during March 2012–2015. Stippled polygons represent annual home ranges of 31 collared mule deer and 36 collared bighorn sheep (Bates *et al.* 2021).

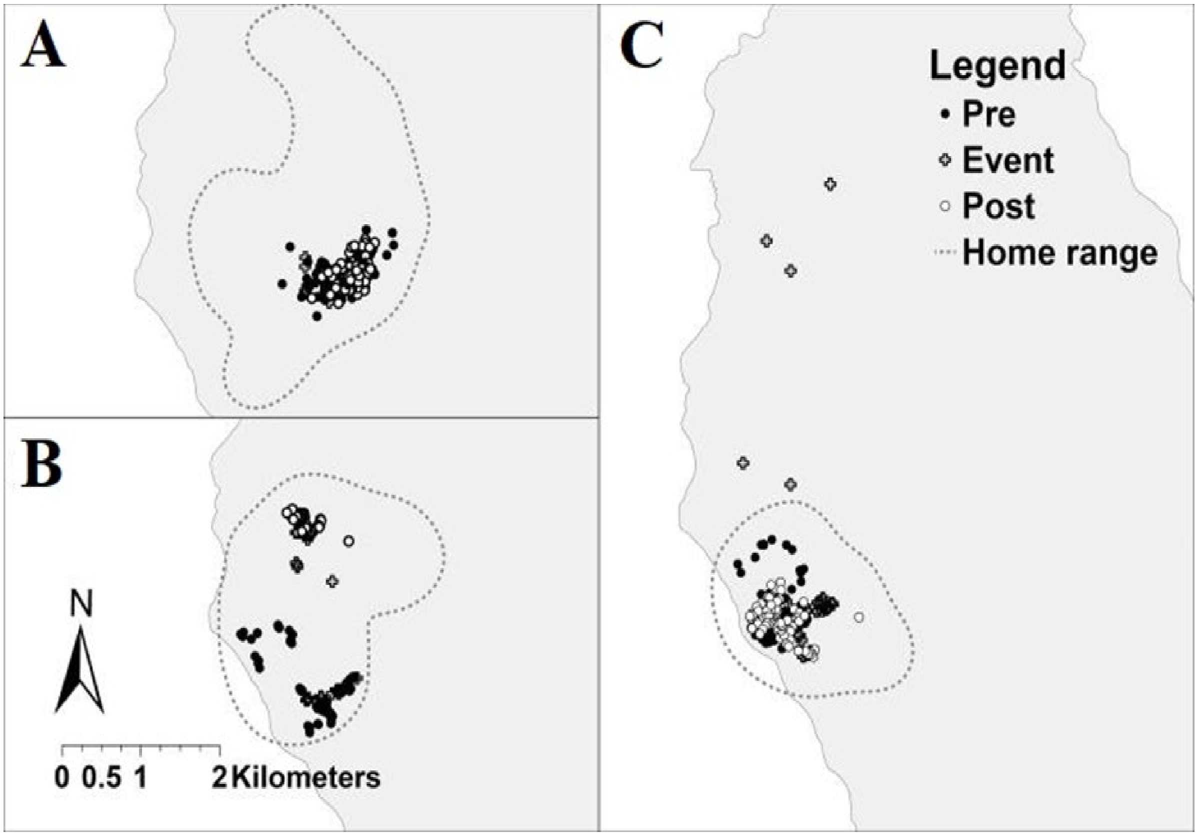

Figure 2-2. Examples of responses by mule deer and bighorn sheep to shed antler hunting on Antelope Island State Park, Utah, USA, 2012–2015. A) an animal continued using pre-hunt areas within their home range following the shed antler hunt, B) an animal moved to another location within their home range during the shed antler hunt, and C) an animal moved out of their home range during the shed antler hunt but returned to their home range within seven days after the hunt (Bates *et al.* 2021).

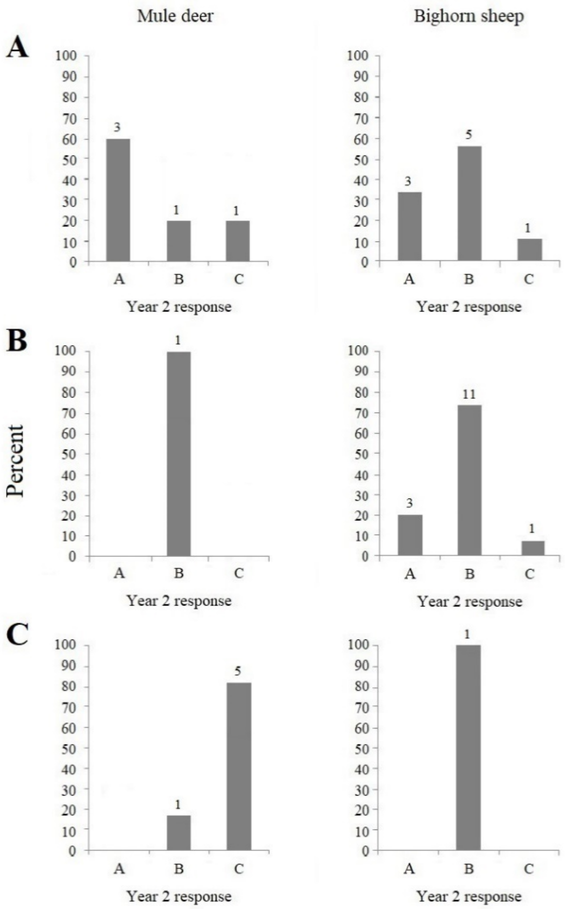

Figure 2-3. Percent of mule deer (n = 12) and bighorn sheep (n = 25) responding to shed antler hunting during year two compared with the initial response of those individuals during year one on Antelope Island State Park, Utah, USA, 2012-2015. Initial response during year one being either: A (5 mule deer, 9 bighorn sheep), B (1 mule deer, 15 bighorn sheep) or C (6 mule deer, 1 bighorn sheep) with those responses defined as A) an animal continued using pre-hunt areas within their home range following the hunt, B) an animal moved to another location within their home range during the hunt, and C) an animal moved out of their home range during the hunt but returned to their home range within seven days after the hunt (Bates *et al.* 2021).

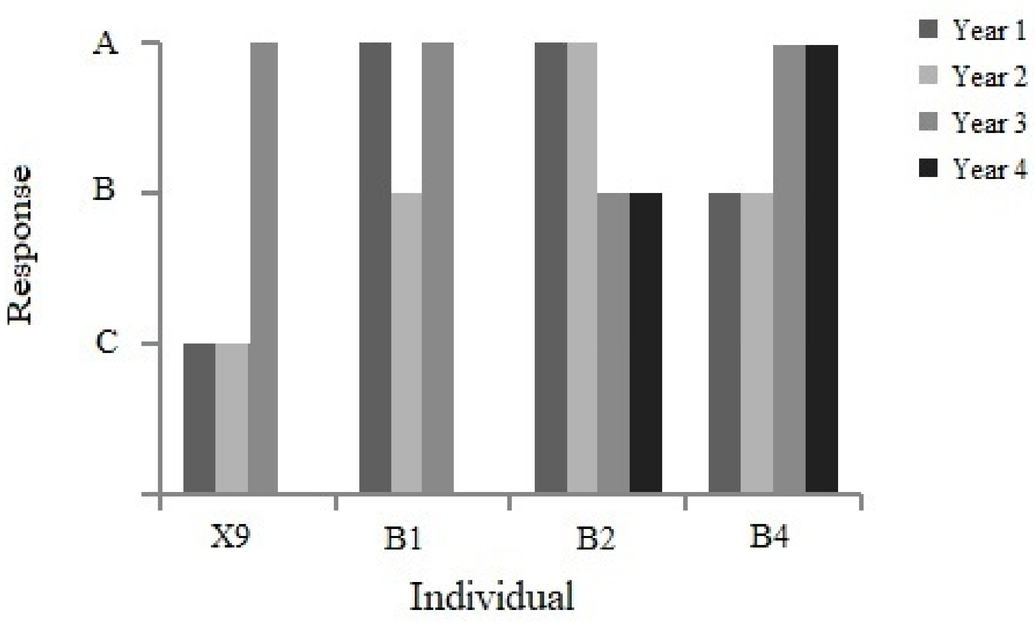

Figure 2-4. Responses of individual mule deer (x axis) with three years or four years (n = 4) of data to shed antler hunting on Antelope Island State Park, Utah, USA, 2012–2015. Response pattern was A) an animal continued using pre-hunt areas within their home range following the hunt, B) an animal moved to another location within their home range during the hunt, and C) an animal moved out of their home range during the hunt but returned to their home range within seven days after the hunt (Bates *et al.* 2021).

CHAPTER 3

Shifts in Resource Selection by Ungulates during late winter in Response to Shed Antler Hunts

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ABSTRACT

Shed antler hunting (i.e., collecting cast cervid antlers) has increased in popularity during the past decade, but little is known about how this recreational activity affects habitat selection by ungulates. We placed global positioning system (GPS)-collars on 27 mule deer (*Odocoileus hemionus*) and 29 bighorn sheep (*Ovis canadensis*) to quantify their habitat use during shed antler hunts compared with resource selection seven days prior and seven days following these hunts on Antelope Island, Utah, USA, from 2012 to 2015. We hypothesized that these ungulates would select different topographic (e.g., slope, aspect, ruggedness), abiotic (e.g., water sources), biotic (e.g., vegetation), and anthropogenic (e.g., distance to roads, trails, and buildings) habitat features both during and after shed antler hunts when compared with habitat features selected by those ungulates before shed antler hunts. We predicted that mule deer and bighorn sheep which remained in the same area in their home range, that moved to another area in their home range (> 500 m), or that moved beyond their home range in response to shed antler hunts would select steeper slopes, higher elevations, and increased distance from trails and roads during and after shed antler hunts. We further predicted that resource selection by mule deer and bighorn sheep would return to similar pre-disturbance patterns within seven days following shed antler hunts. Shifts in resource selection by mule deer and bighorn sheep were detected during shed antler

hunts regardless of the initial response of the individual animal to shed antler hunting. Most mule deer selected lower elevations, rugged terrain, steeper slopes, avoided north aspects but used south aspects in relation to east aspects, stayed close to water sources, avoided roads and trails, and used shrub communities greater than open grasslands in response to disturbance during shed antler hunts. Most bighorn sheep selected rugged terrain disproportionally less than available, steeper slopes, avoided north-facing aspects while selecting for south-facing aspects, used areas far from streams and trails, and used both shrub communities and sparsely vegetated areas at a higher rate than available in response to disturbance during shed antler hunts. Our results will help wildlife managers understand the effects of shed antler hunting on resource selection by mule deer and bighorn sheep and provide timely information that can help guide conservation of these ungulates.

INTRODUCTION

Ungulate winter habitat consists of food, water, cover, space, and the arrangement of those elements on the landscape, which then leads to occupancy of that habitat (Krausman 1999; Coe *et al.* 2018). Within those habitat elements are contained essential resources and how, why, and when those resources are used is based on a myriad of factors and is crucial to the survival of ungulates (Boyce *et al.* 2002; Manly *et al.* 2007; Peignier *et al.* 2019). Winter habitat provides varying resources that meet the differing needs for male and female ungulates (King & Smith 1980; Ager *et al.* 2003; Schroeder *et al.* 2010). Both males and females in late winter and spring face similar circumstances (i.e., decrease in body condition, migration) as well as energetic demands specific to each sex (males-antler growth, females-developing fetus) (Heffelfinger 2018; Rodgers *et al.* 2021). Some topographic, abiotic, and biotic components of winter habitat that may influence habitat selection include slope, aspect, elevation, snow depth, canopy cover, and forage availability (Nicholson, Bowyer & Kie 1997; Gilbert *et al.* 2017). Additionally, understanding how anthropogenic factors influence the ability of animals to use necessary resources is important for conservation.

Anthropogenic influence has altered habitat available to ungulates across the globe (Daszak, Cunningham & Hyatt 2001; Hovick *et al.* 2014). These influences range from urban sprawl (Blair 2004) with its associated noise (Blickley & Patricelli 2010) and light pollution (Longcore & Rich 2004), roads and fencing that fragment habitat and lead to direct mortalities (Jones *et al.* 2019; Reinking *et al.* 2019; Xu *et al.* 2021), and energy extraction whether from green sources (Smith *et al.* 2020; Straka, Fritze & Voigt 2020) or fossil fuels (Ramirez & Mosley 2015). These anthropogenic activities can lead to changes in habitat-use by ungulates. For example, activity and infrastructure associated with fossil fuel extraction altered migration patterns (Lendrum *et al.* 2012; Lendrum *et al.* 2013; Wyckoff *et al.* 2018). Fencing can impede movement and access to habitat for migrating animals and also those within their seasonal home ranges (Wang & Schreiber 2001; Jones *et al.* 2019). Anthropogenic features also influence the ability of bighorn sheep to use necessary resources in their habitat as increased vehicle traffic on roadways not only impacts gene flow (Bleich *et al.* 2016) but also displaces bighorn sheep from adjacent habitats and increases the amount of time bighorn sheep spend in escape terrain (Keller & Bender 2007).

Another anthropogenic feature that affects ungulates is human recreation. People now have more time and ability to be outdoors (Gander & Ingold 1997; Huhtala & Pouta 2009). This increased time in natural areas has affected ungulates. For example, mule deer and bighorn sheep altered foraging behavior in response to hikers and increased road traffic (Pelletier 2006; Becker *et al.* 2012). Wolves (*Canis lupus*) ability to prey on elk (*Cervus canadensis*) was influenced by the presence of snowmobilers (Creel *et al.* 2002). Recreational activities such as sight-seeing from vehicles (Pelletier 2006; Lynch *et al.* 2015; Sproat *et al.* 2019), campground occupation (Nix *et al.* 2018), trail hiking and biking (Taylor & Knight 2003; Wiedmann & Bleich 2014) and off-trail activity (Macarthur, Geist & Johnston 1982; Brown *et al.* 2020; Bates, Whiting & Larsen 2021) can alter behavioral, temporal, and spatial patterns of mule deer and bighorn sheep.

One current form of human recreation that can potentially influence resource use of ungulates is shed antler hunting (i.e., collecting cast cervid antlers) (Mimiaga 2018; Koshmrl 2019). Shed antler hunting affects space use and movement by mule deer and bighorn sheep (Bates, Whiting & Larsen 2021; Bates *et al.* In Review), however, little is known about resource selection of these ungulates during and after shed antler hunting. We investigated how mule deer and bighorn sheep changed their resource selection patterns in response to shed antler hunting on Antelope Island, Utah, USA, from 2012 to 2015. Because of displacement of mule deer and bighorn sheep during shed antler hunts, we hypothesized that these ungulates would select different topographic (e.g., slope, aspect, ruggedness), abiotic (e.g., water sources), biotic (e.g., vegetation), and anthropogenic (e.g., distance to roads, trails, and buildings) habitat features both during and after shed antler hunts when compared with habitat features selected by those ungulates before shed antler hunts. We predicted that mule deer and bighorn sheep which remained in the same area in their home range, that moved to another area in their home range (> 500 m), or that moved beyond their home range in response to shed antler hunts would select steeper slopes, higher elevations, and increased distance from trails and roads during and after shed antler hunts. We further predicted that resource selection by mule deer and bighorn sheep would return to similar pre-disturbance patterns within seven days following shed antler hunts. Our results will provide insight into how shed antler hunting effects resource selection by mule deer and bighorn sheep. These results can improve management and habitat conservation for these ungulates.

MATERIALS AND METHODS

Study Area

Antelope Island State Park (40°57´N, 112°13´W) is located in northern Utah, USA and is surrounded by the Great Salt Lake (Fig. 3–1). Antelope Island is approximately 24 km long, 8.3 km wide, and encompasses approximately 11,300 ha (Whiting, Bowyer & Flinders 2009a; Whiting, Bowyer & Flinders 2009b). Elevation ranges from 1,280 m to 2,011 m (Rogerson, Fairbanks & Cornicelli 2008). A central ridge, oriented north and south, is the major topographic feature on the island and essentially divides the island in half. Semi-arid grasslands dominate at lower elevations with big sagebrush (*Artemisia tridentata* spp.) communities common at higher elevations (Brookshier & Fairbanks 2003). The most diverse vegetation, including pockets of Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*), stands of bigtooth maple (*Acer grandidentatum*) along riparian corridors and isolated stands of Utah juniper (*Juniperus osteosperma*) occur on the eastern side of the island. The west side of the island is more rugged and considerably drier. The west side is dominated by purple threeawn (*Aristida purpurea*) and cheatgrass (*Bromus tectorum*) (Wolfe & Kimball 1989; Taylor *et al.* 2020). From 1910 to 2010, mean temperature was 17.5 °C and mean annual precipitation was 45.6 cm (Western Regional Climate Center, https://wrcc.dri.edu/). During our study, four species of ungulates inhabited Antelope Island. Population estimates obtained through aerial surveys conducted each year were 122 ± 25 bighorn sheep, 532 ± 19 bison (*Bison bison*) 543 ± 181 mule deer, and 210 ± 30 pronghorn (*Antilocapra americana*) (Bates, Whiting & Larsen 2021). Coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and golden eagles (*Aquilia chrysaetos*) were the primary predators of those ungulates—particularly of young animals.

Antelope Island was purchased by the state of Utah in 1981 to provide recreational opportunities (e.g., hiking, biking, wildlife viewing, swimming) and for the conservation of wildlife and its habitat (Utah State Parks 2001). During our study, average annual visitation was 320,732 people (range = 282,145 to 380,611) (Utah State Parks 2018). On the island, travel was restricted to trails and roadways except for 4 days annually; 2 consecutive days in March (shed antler hunt) and 2 consecutive days in October (bison round-up) when travel was unrestricted (Bates, Whiting & Larsen 2021). However, during those days of open-access, the number of visitors was restricted to 100–300 individuals (Kaze *et al.* 2016; Bates, Whiting & Larsen 2021) to minimize displacement of the island's wildlife.

Wildlife Capture

To capture mule deer and bighorn sheep, we contracted with a private helicopter capture company that used net guns during February 2012 and January through March 2014 (Krausman & Bleich 2013; Taylor *et al.* 2020; Bates, Whiting & Larsen 2021). Capture occurred across the range of those animals reflective of their distribution on the island. Upon capture, most animals (33 mule deer, 39 bighorn sheep) were collared and immediately released. A few individuals (8 mule deer, 5 bighorn sheep) were transported to a processing station where weights, measurements, and disease monitoring samples were collected. These individuals were then released at the processing station which was within mule deer habitat but was 2 km from bighorn sheep habitat (Bates, Whiting & Larsen 2021). In 2012, Lotek global positioning system (GPS) 7000S store-onboard collars (Lotek Wireless Inc., St. John's, Newfoundland, Canada) were fitted on 19 mule deer (7 males, 12 females) and 20 bighorn sheep (8 males, 12 females; Taylor *et al.*

2020; Bates, Whiting & Larsen 2021). In 2014, either Lotek 7000S or ATS G2110D GPS collars (Advanced Telemetry Systems, Isanti, MN) were fitted on 22 mule deer (11 males, 11 females) and 24 bighorn sheep (16 males, 8 females; Taylor *et al.* 2020; Bates, Whiting & Larsen 2021). Location data were collected at 90-min intervals two weeks prior, during, and two weeks following shed antler hunts. Animals were captured and handled in accordance with guidelines from the American Society of Mammalogists (Sikes, Thompson & Bryan 2019). Additionally, the Institutional Animal Care and Use Committee at Brigham Young University (protocol number 130105) reviewed helicopter capture and handling protocols.

Shed Antler Hunts

We quantified resource selection among mule deer and bighorn sheep in response to shed antler hunting on Antelope Island during late winters from 2012 to 2015 (Bates, Whiting & Larsen 2021). Shed antler hunts were held for two consecutive days each March (range = March 9 to March 13) and occurred in areas used extensively by mule deer and bighorn sheep (Fig. 3–1). We held random draws to select participants for shed antler hunting each morning of the hunts or we selected participants through a first-come, first-serve online sale of permits. Each year we selected approximately 200 (192 ± 14, range = 186 to 200) participants; 100 assigned to the east side of the island day 1 and 100 assigned to the west side of the island on day 2. Regardless of selection process, hunting for antlers commenced at 0800 and continued throughout the day until sunset at approximately 1900 annually (Bates, Whiting & Larsen 2021). Shed antler hunters searched the east side of the island on day one. A 16-km paved road near the east shoreline provided participants abundant access to that side of the island where they could then search the area on foot or horseback. On day two, participants searched the west side of the island. Access to the west side was by foot or on horse only as no vehicle access existed for that side of the island. Through this spatial and temporal division, we provided wildlife a place of retreat during shed antler hunts (Bates, Whiting & Larsen 2021).

Analyses

After we retrieved collars, data were downloaded and locations with a dilution of precision (DOP) value ≥10 were removed to ensure GPS location accuracy (D'Eon & Delparte 2005; Lendrum *et al.* 2012; Lendrum *et al.* 2013). For our analyses, we used data from 27 mule deer (9 males, 18 females) and 29 bighorn sheep (13 males, 16 females; Table 3–1). We used Brownian-bridge movement models to estimate annual home ranges (95% probability bands) for mule deer and bighorn sheep (Sawyer et al. 2009, Kranstauber et al. 2012, Walter and Fischer 2016) in R using package adehabitat (Calenge 2006). We then calculated annual home ranges from date of capture through collar failure, animal death, the end of the study, or 31 December annually (the end date we used to calculate home ranges). Next, we categorized ungulate response to shed antler hunting into the following three categories: the individual continued using the same area in their annual home range following the hunt (response 1), the individual moved (≥500 m) to and remained in a new area within their annual home range following the hunt (response 2), or the individual moved beyond the boundary of their home range in response to the hunt and then returned to their home range within seven days after the hunt (response 3; Bates, Whiting & Larsen 2021). To test for changes in resource selection, we then assigned data to pre-event (seven days prior to shed antler hunts), event (two day shed antler hunt), and post-event (seven days after shed antler hunts) phases.

GIS Explanatory Variables

Using ArcGIS Pro 2.3$^{®}$ (Environmental Systems Research Incorporated, Redlands, CA), we extracted topographic, anthropogenic, and biologic variables (Table 3–2) for each animal and randomly generated use point. Through the State of Utah's Geographic Information Database (SGID), located in the Utah Automated Geographic Reference Center (AGRC), we acquired topographic variables using 10-m Digital Elevation Models (DEM's) generated by the United States Geological Survey (USGS). We used sub-meter 4-band imagery from the National Agriculture Imagery Program (NAIP) to classify biological features (Westover *et al.* 2016). For anthropogenic features we used data obtained from Antelope Island State Park. We standardized all continuous variables for integration in each model $[(x_i - \overline{x})/s]$. We also calculated normalized difference vegetation index (NDVI, Rouse *et al.* 1974) using sub-meter 4-band NAIP imagery collected in 2018 and made available by the AGRC.

For distance variables, we calculated the Euclidean distance and then converted them using a distance decay function because wildlife response to features typically declines as distance from that feature increases (Dinkins *et al.* 2014). The decay function we used is expressed as:

$$\text{Decay} = \exp^{(\text{Euclidean distance to feature/- decay distance})}$$

The resulting decay value is between 0 and 1, with closer features approaching a value of 1. We used a decay function of 560 m (Fedy *et al.* 2014).

Resource selection analysis

We modeled resource selection for mule deer and bighorn sheep in a use-availability design where use was coded as a 1 and availability as a 0 (Manly *et al.* 2007). We generated 20,113 random points to adequately characterize the study area to exceed a density of 100 points per km^2 (Baxter *et al.* 2017). We down weighted the random points to have the same weight as use locations in each model. We used mixed-effects models and model selection in R with package lme4 (Bates *et al.* 2014), MuMIn (Barton 2009), and package AIC$_c$modavg (Mazerolle & Mazerolle 2017) to evaluate resource selection by bighorn sheep and mule deer during pre, event, and post phases of shed antler hunts. Because our interest was in relative selection across pre, event and post-event timeframes in relation to shed antler huntin, we used a single model containing a combination of topographic, abiotic, biotic, and anthropogenic variables (Table 3–2) known to be important elements of mule deer and bighorn sheep habitat (Sawyer *et al.* 2006; Anderson *et al.* 2012; Robinson *et al.* 2019). We used this model for each animal response type (1, 2, 3) during each event phase of shed antler hunting (pre, event, post) by those species. We checked for collinearity and avoided adding highly correlated variables ($|r| \geq 0.6$) into the model. Because many of our explanatory variables were categorical, we also used the generalized variance inflation factor (GVIF) from the car package to assess collinearity (Fox & Monette 1992; Fox & Weisberg 2019). We used a cutoff for GVIF ≤ 10 to identify any potential problems with multicollinearity (Hair *et al.* 1995; Holloran, Fedy & Dahlke 2015). Additionally, we performed a k-folds cross validation with $k = 5$ to determine the predictive availability of our model (Long *et al.* 2009; Baxter *et al.* 2017). For each species and within each response type and each phase of shed antler hunts, we randomly assigned each point to one of five partitions of approximate equal number of points. For each iteration, one partition (approximately 20% of the use points) was withheld from the model to be used in evaluation while the remaining four partitions (80% of the use points) were used to estimate model coefficients. Each partition was used as both a test set and part of the training set.

After determining and validating our model for each response type and phase of shed antler hunts for both species, we generated a predictive surface showing the relative probability of selection for each raster pixel in the study area. We resampled each relevant layer so that the pixels aligned with the 10-meter elevation raster, to which we applied raster math to calculate relative probability of use.

RESULTS

From 2012 to 2015, we evaluated changes in resource selection by individual mule deer (9 males, 18 females) and bighorn sheep (13 males, 16 females) during March in response to shed antler hunts on Antelope Island. We used a single model that included abiotic, biotic, and anthropogenic variables (Table 3–2). Shifts in resource selection by mule deer and bighorn sheep were detected during shed antler hunts regardless of the initial response of the individual animal to shed antler hunting (Fig. 3–2; Fig. 3–3). Mule deer and bighorn sheep selected habitat based on elevation, ruggedness, slope, aspect, distance to any water source, distance to streams, distance to trails, and vegetative community (Fig. 3–4; Fig. 3–5). Due to the multiple combination of tests, results are presented by species.

Mule Deer

In response to shed antler hunting, six mule deer remained in the same area of their home range (response 1). When compared to resource availability prior to the shed antler hunt, those deer used lower elevations, more rugged terrain, steeper slopes, south-facing aspects, greater TPI, and were found closer to all water sources, but were farther away from trails (Table 3–3; Fig. 3–4). In response to shed antler hunting activity, those same deer shifted habitat use to shorelines of the Great Salt Lake that were densely vegetated with phragmites (*Phragmites spp.*) and they also increased use of wooded ravines. Also, during shed antler hunts, these deer used higher elevations, less rugged terrain, steeper slopes, all cardinal aspects, increased distance from water, decreased distance from streams, did not avoid trails, and increased their use of open grasslands (Table 3–3; Fig. 3–4). Following shed antler hunts, these deer selected areas and resources similar to those resources used prior to shed antler hunts (Table 3–3; Fig. 3–2).

In response to shed antler hunting, seven mule deer moved to another area of their home range (response 2). When compared to resource availability prior to the shed antler hunt, those deer used lower elevations, selected south and west aspects in relation to east aspects, stayed close to water sources, avoided trails, and used shrub communities more frequently when compared to available locations (Table 3–3; Fig. 3–4). In response to shed antler hunting, those same deer shifted habitat use to the densely vegetated shorelines of Great Salt Lake. These deer demonstrated no preferential selection of elevation, moved from west aspects in relation to east aspects, increased distance from water, decreased distance from streams, did not avoid trails, and did not preferentially select shrub habitat (Table 3–3; Fig. 3–4). Although there was similar use of resources such as lower elevations and proximity to water sources, following shed antler hunts in the post-event phase, these mule deer's use of habitat shifted due to the avoidance of west aspects, increased distance from streams, and decreased distance to trails (Table 3–3; Fig. 3–4).

In response to shed antler hunting, 14 mule deer moved beyond the boundaries of their home range (response 3). When compared to resource availability prior to the shed antler hunt, those deer used lower elevations, rugged terrain, steeper slopes, avoided north aspects but used south aspects in relation to east aspects, stayed close to water sources, avoided roads and trails, and used shrub communities greater than open grasslands (Table 3–3; Fig. 3–4). In response to shed antler hunting, these deer shifted habitat use to densely vegetated shorelines of Great Salt Lake. These deer increased use of lower elevations, less rugged terrain, gentler slopes, all cardinal aspects, increased distance from water, decreased distance from streams, did not avoid trails, and increased their use open grasslands (Table 3–3; Fig. 3–4). Although there was similar use of resources such as lower elevations and proximity to water sources, following shed antler hunts in the post-event phase, these mule deer's use of habitat shifted due to the avoidance of south and west aspects, increased distance from water sources, and avoidance of sparsely vegetated areas (Table 3–3; Fig. 3–4).

Bighorn Sheep

In response to shed antler hunting, 17 bighorn sheep remained in the same area of their home range (response 1). When compared to resource availability prior to the shed antler hunt, these bighorn sheep used rugged terrain disproportionally less than available, selected for steep slopes, avoided north-facing aspects while selecting for south-facing aspects, used areas far from streams and trails, and used both shrub communities and sparsely vegetated areas at a higher rate than available (Table 3–4; Fig. 3–5). In response to shed antler hunting, these bighorn sheep shifted habitat use to the rugged cliffs on the west side of the island. These bighorn sheep increased use of higher elevations, steeper slopes, south-facing aspects, increased distance from water sources, decreased distance from streams, and increased distance away from trails (Table 3–4; Fig. 3–5). Following shed antler hunts, these bighorn sheep selected habitat resources similar to those resources used prior to shed antler hunts (Table 3–4; Fig. 3–5).

In response to shed antler hunting, 11 bighorn sheep moved to another area of their home range (response 2). When compared to resource availability prior to the shed antler hunt, these bighorn sheep used higher elevations and steeper slopes, avoided north-facing aspects while selecting for south-facing aspects, used areas far from water sources and trails, and used both shrub communities and sparsely vegetated areas at a higher rate than available (Table 3–4; Fig. 3–5). In response to shed antler hunting, these bighorn sheep shifted habitat use to the rugged cliffs on the west side of the island. These bighorn sheep selected higher elevations, in relation to east aspects avoided north-facing aspects and increased use of south and west-facing aspects, decreased TPI, decreased distance from water sources and streams, increased distance from trails, and continued selection of shrub habitats (Table 3–4; Fig. 3–5). Although there was similar use of resources such as the use of rugged terrain and steep slopes, following shed antler hunts in the post-event phase, these bighorn sheep's use of habitat shifted to the use of the island's main, central ridge. This shift is primarily due to the use of higher elevations and the non-preferential selection of aspect (Table 3–4; Fig. 3–5).

In response to shed antler hunting, one bighorn sheep moved beyond the boundary of its home range (response 3). When compared to resource availability prior to the shed antler hunt, that bighorn sheep used higher elevations, stayed close to water sources, avoided trails, and used shrub communities at a higher rate than available (Table 3–4; Fig. 3–5). In response to shed antler hunting, this bighorn sheep shifted habitat use to the rugged cliffs on the west side of the island. This bighorn sheep increased use of lower elevations, used steeper slopes, and used all cardinal aspects, decreased distance from water and streams, avoided trails, and did not select for vegetation type (Table 3–4; Fig. 3–5). Following shed antler hunts in the post-event phase, this bighorn sheep did not return to similar pre-shed antler hunt conditions. This sheep avoided north aspects, moved closer to trails and selected for shrub communities (Table 3–4; Fig. 3–5).

DISCUSSION

Mule Deer

Mule deer have specific habitat requirements and when those needs are not met, population decline ensues (Clements & Young 1997). Anthropogenic features influence the ability of mule deer to extract necessary resources from their habitat. Activity and physical facilities associated with fossil fuel extraction, for example, can alter migration patterns (Lendrum *et al.* 2012; Lendrum *et al.* 2013; Wyckoff *et al.* 2018). Fencing has been shown to impede movement and access into portions of habitat not only among migrating individuals but also within seasonal home ranges (Wang & Schreiber 2001). Recreational activities such as sight-seeing from vehicles (Lynch *et al.* 2015), campground occupation (Nix *et al.* 2018), trail hiking and biking (Taylor & Knight 2003) and off-trail activity (Bates, Whiting & Larsen 2021) can alter behavioral, temporal and space use patterns of mule deer. These factors influence an animal's ability to use resources which can ultimately influence survival (Gaillard *et al.* 2010; Allen *et al.* 2017).

During our study, mule deer that remained within the same area of their home range (response 1) during shed antler hunts constricted their distribution to the western shoreline of the island and the wooded ravines of the east side. These areas of dense vegetation provided concealment. Mule deer in Oregon behaved similarly when they were exposed to hiker and atv traffic as they moved into more heavily wooded areas (Wisdom *et al.* 2004). Within seven days following shed antler hunts, deer on Antelope Island returned to similar resource use patterns within their home ranges allowing them access to optimal conditions for resource selection.

Mule deer that moved to another area within their home range (response 2) during shed antler hunts expanded their use of the island and shifted to shoreline areas found on the east side following this disturbance. With the increase in movement, these deer covered more ground and became exposed to a variety of risks. The movements of these deer brought them into close proximity of trails where increased probability of encountering recreationists hiking and biking could lead to further displacement and additional expenditure of energy (Taylor & Knight 2003; Ciuti *et al.* 2012). The displacement of mule deer during shed antler hunts included those animals crossing roadways which could elevate risk of collision with vehicles. Vehicle strikes contribute significantly to mule deer mortality annually (Bissonette, Kassar & Cook 2008; Olsen *et al.*

2015). These deer moved into dense cover provided by phragmites along the shoreline of the Great Salt Lake. During late winter, the phragmites dominated habitat along the shoreline provides little to no forage value for these deer because associated forbs have not yet begun to grow. Displacement of these deer by shed antler hunters from optimal shrub-dominated habitat to suboptimal phragmites habitat may have reduced foraging opportunities during a critical time of year. The use of suboptimal habitat by ungulates can impact energetics through the expenditure of additional energy avoiding threats and a reduction in nutritional intake due to inferior forage quality which can affect survivorship (Bowyer, Van Ballenberghe & Kie 1998; Allen *et al.* 2017).

Mule deer that moved beyond their home range boundaries (response 3) during shed antler hunts were exposed to similar risks as those that moved areas within their home range (response 2): increased contact with recreationists, hazardous road crossings, and displacement into suboptimal habitat. Additionally, individuals leaving their home ranges may be more susceptible to predation (Forrester, Casady & Wittmer 2015). Those deer altered their use of the island and shifted to shoreline habitat on the east side of the island throughout post-event monitoring. These deer may have remained near the shoreline in anticipation of the impending spring green-up.

Bighorn Sheep

Bighorn sheep select specific habitat features including steep and rugged escape terrain with relatively short vegetation (Smith, Flinders & Winn 1991). Some of these habitat elements have been compromised since the westward expansion during the late 1800’s (Buechner 1960). Additionally, many bighorn populations have been extripated since Euro-American settlement and this species is now regularly translocated into historical range (Singer, Papouchis & Symonds 2000). Although many translocations have been successful, other attempts have been unsuccessful due to influences of anthropogenic features (Smith, Flinders & Winn 1991). Anthropogenic features influence the ability of bighorn sheep to extract necessary resources from their habitat. Increased vehicle traffic on roadways, for example, can impact genetic flow (Bleich *et al.* 2016) displace bighorn sheep from optimal habitats, and increases the amount of time bighorn sheep spend in escape terrain (Keller & Bender 2007). Recreational activities such as sight-seeing from vehicles (Pelletier 2006; Sproat *et al.* 2019), hunting (King 1986), trail hiking and biking (Papouchis, Singer & Sloan 2001; Wiedmann & Bleich 2014), and off-trail activity (Macarthur, Geist & Johnston 1982; Bates, Whiting & Larsen 2021) can further alter behavioral, temporal, and space use patterns of bighorn sheep.

During our study, bighorn sheep that remained within the same area of their home range (response 1) or that moved to another area within their home range (response 2) in response to shed antler hunting, moved from habitats adjacent to escape terrain into the rugged core of escape terrain on the island. Bighorn sheep select rugged and steep habitats to avoid predation (Bleich, Bowyer & Wehausen 1997; Schroeder *et al.* 2010). Recreationists often present themselves as threats to these ungulates and illicit a similar response in bighorn sheep behavior (Ciuti *et al.* 2012; Lowrey & Longshore 2017). Hikers displaced bighorn sheep the least as they remained on a trail and the trail passed down-slope of the sheep (King 1986; Papouchis, Singer & Sloan 2001). However, female bighorn sheep abandoned lambing habitat even when hikers remained on a trail (Wiedmann & Bleich 2014; Karsch *et al.* 2016). During shed antler hunts, hikers are off-trail and move erratically as they search for cast antlers (Bates, Whiting & Larsen 2021; Bates *et al.* In Review). Erratic and unpredictable movement likely causes greater disruption among these ungulates as evidenced by the movement of bighorn sheep into the island's rugged escape terrain.

While escape terrain is optimal for predation avoidance, it is often suboptimal for forage production (Festa-Bianchet 1988; Hamel & Côté 2007). In our study, any potential negative impacts associated with constriction to escape terrain were acute and of short duration which minimises any long-term consequences to bighorn sheep health and survival. Bighorn sheep that stayed in the same pre-event areas, returned to pre-event resource selection patterns within days following shed antler hunts. Bighorn sheep that moved to another area during shed antler hunts, however, did not resume a similar pattern of resource selection. These sheep moved to higher elevations and distributed themselves along the island's central ridge. Snow periodically blankets the high ridge and spring green-up is delayed at these higher elevations. During early March, these areas likely provide suboptimal foraging opportunities. Thus, for these sheep, remaining in these areas following shed antler hunts may have longer-term consequences. A change in resource use also occurred for the bighorn sheep that moved beyond its home range (response 3) in response to shed antler hunts. The dramatic shifts into atypical sheep habitat likely increased risk of predation for this individual (Rominger 2018), increased displacement by other recreationists (Papouchis, Singer & Sloan 2001), and increased vigilance and mortality risk associated with roadways (Sproat *et al.* 2019). These shifts in resource use are based on data from a single individual, therefore, caution must be exercised in the interpretation of these results for bighorn sheep displaced from their home ranges.

CONCLUSION

Shed Antler Hunting

Antelope Island State Park offers a unique opportunity to study wildlife-human interactions (Whiting, Bowyer & Flinders 2008; Kaze *et al.* 2016; Taylor *et al.* 2020). However, because this island is a closed system, caution is needed when applying our results to other areas. Our study documents responses of mule deer and bighorn sheep to shed antler hunting, and our results provide important data to guide policy and management of these species and their habitat, especially mule deer. Currently, to protect mule deer on winter ranges, half of the state wildlife agencies in the western United States have limits on shed antler hunting. The other half have no restrictions. Where many states are open to shed antler hunting year-round, mule deer in these areas would be more susceptible to increased movement and potential displacement from home ranges. Those states that have a closed season may limit disturbance to mule deer because these ungulates may leave winter range before shed hunting is allowed. In areas where resident deer remain on winter range, these animals may experience an acute disturbance on opening day of shed antler hunts—similar to what we documented—and then be exposed to lower levels of chronic disturbance through the months that shed antler hunting persists. Future research needs to document how mule deer will respond to varying levels of shed antler hunting across different weather conditions, group sizes, and migratory patterns.

Demand for cervid antlers is growing exponentially worldwide (Kwak *et al.* 1994; Apollonio, Andersen & Putman 2010; Kuba, Landete-Castillejos & Udala 2015), and price/kg of antlers has tripled over the past decade (Koshmrl 2019). This increased demand ostensibly will continue to affect wild populations, and protection of cervids on winter range has become more difficult as shed antler hunting grows in popularity (Koshmrl 2019). Additionally, mule deer are an important species in western North America and are an integral part of the ecosystems of the western United States (Kie *et al.* 2002; Bishop *et al.* 2009; Smedley *et al.* 2019). Many populations of mule deer have declined in the past few decades (Ballard *et al.* 2001; Forrester & Wittmer 2013; Bergman *et al.* 2015). We quantified how mule deer and bighorn sheep responded to shed antler hunts, and documented changes in resource selection. Our results will help wildlife managers understand the effects of legal shed antler hunting on resource selection by mule deer and bighorn sheep and provide timely information that can help guide conservation of ungulate populations and their habitat.

LITERATURE CITED

Ager, A.A., Johnson, B.K., Kern, J.W. & Kie, J.G. (2003) Daily and seasonal movements and habitat use by female rocky mountain elk and mule deer. Journal of Mammalogy, 84, 1076-1088.

Allen, A.M., Dorey, A., Malmsten, J., Edenius, L., Ericsson, G. & Singh, N.J. (2017) Habitat–performance relationships of a large mammal on a predator-free island dominated by humans. Ecology and Evolution, 7, 305-319.

Anderson, E.D., Long, R.A., Atwood, M.P., Kie, J.G., Thomas, T.R., Zager, P. & Bowyer, R.T. (2012) Winter resource selection by female mule deer *Odocoileus hemionus*: functional response to spatio-temporal changes in habitat. Wildlife Biology, 18, 153-163.

Apollonio, M., Andersen, R. & Putman, R. (2010) European ungulates and their management in the 21st century. Cambridge University Press.

Ballard, W.B., Lutz, D., Keegan, T.W., Carpenter, L.H. & deVos Jr, J.C. (2001) Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin, 99-115.

Barton, K. (2009) MuMIn: multi-model inference, R package version 0.12. 0. http://r-forge. r-project. org/projects/mumin/.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2014) lme4: Linear mixed-effects models using Eigen and S4. R package version, 1, 1-23.

Bates, S.B., Whiting, J.C. & Larsen, R.T. (2021) Effects of shed antler hunting on ungulate movements and space use The Journal of Wildlife Management, 85, 437-448.

Bates, S.B., Whiting, J.C., McMillan, B.R., Petersen, S.L. & Larsen, R.T. (In Review) Space use and movements of individual mule deer and bighorn sheep in response to shed antler hunting.

Baxter, J.J., Baxter, R.J., Dahlgren, D.K. & Larsen, R.T. (2017) Resource selection by greater sage-grouse reveals preference for mechanically-altered habitats. Rangeland Ecology & Management, 70, 493-503.

Becker, B.H., Moi, C.M., Maguire, T.J., Atkinson, R. & Gates, N.B. (2012) Effects of hikers and boats on tule elk behavior in a national park wilderness area. Human-Wildlife Interactions, 6, 147-154.

Bergman, E.J., Doherty, P.F., White, G.C. & Holland, A.A. (2015) Density dependence in mule deer: a review of evidence. Wildlife Biology, 21, 18-29.

Bishop, C.J., White, G.C., Freddy, D.J., Watkins, B.E. & Stephenson, T.R. (2009) Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs, 1-28.

Bissonette, J.A., Kassar, C.A. & Cook, L.J. (2008) Assessment of costs associated with deer–vehicle collisions: human death and injury, vehicle damage, and deer loss. Human-Wildlife Conflicts, 2, 17-27.

Blair, R. (2004) The effects of urban sprawl on birds at multiple levels of biological organization. Ecology and Society, 9.

Bleich, V.C., Bowyer, R.T. & Wehausen, J.D. (1997) Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs, 1-50.

Bleich, V.C., Whiting, J.C., Kie, J.G. & Bowyer, R.T. (2016) Roads, routes and rams: does sexual segregation contribute to anthropogenic risk in a desert-dwelling ungulate? Wildlife Research, 43, 380-388.

Blickley, J.L. & Patricelli, G.L. (2010) Impacts of anthropogenic noise on wildlife: research priorities for the development of standards and mitigation. Journal of International Wildlife Law & Policy, 13, 274-292.

Bowyer, R.T., Van Ballenberghe, V. & Kie, J.G. (1998) Timing and synchrony of parturition in Alaskan moose: long-term versus proximal effects of climate. Journal of Mammalogy, 79, 1332-1344.

Boyce, M.S., Vernier, P.R., Nielsen, S.E. & Schmiegelow, F.K.A. (2002) Evaluating resource selection functions. Ecological Modelling, 157, 281-300.

Brookshier, J.S. & Fairbanks, W.S. (2003) The nature and consequences of mother-daughter associations in naturally and forcibly weaned bison. Canadian Journal of Zoology-Revue Canadienne De Zoologie, 81, 414-423.

Brown, C.L., Smith, J.B., Wisdom, M.J., Rowland, M.M., Spitz, D.B. & Clark, D.A. (2020) Evaluating Indirect Effects of Hunting on Mule Deer Spatial Behavior. Journal of Wildlife Management, 84, 1246-1255.

Buechner, H.K. (1960) The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs, 3-174.

Ciuti, S., Northrup, J.M., Muhly, T.B., Simi, S., Musiani, M., Pitt, J.A. & Boyce, M.S. (2012) Effects of humans on behaviour of wildlife exceed those of natural predators in a landscape of fear. PloS One, 7.

Clements, C.D. & Young, J.A. (1997) A viewpoint: rangeland health and mule deer habitat.

Coe, P.K., Clark, D.A., Nielson, R.M., Gregory, S.C., Cupples, J.B., Hedrick, M.J., Johnson, B.K. & Jackson, D.H. (2018) Multiscale models of habitat use by mule deer in winter. Journal of Wildlife Management, 82, 1285-1299.

Creel, S., Fox, J.E., Hardy, A., Sands, J., Garrott, B. & Peterson, R.O. (2002) Snowmobile activity and glucocorticoid stress responses in wolves and elk. Conservation Biology, 16, 809-814.

D'Eon, R.G. & Delparte, D. (2005) Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. Journal of Applied Ecology, 42, 383-388.

Daszak, P., Cunningham, A.A. & Hyatt, A.D. (2001) Anthropogenic environmental change and the emergence of infectious diseases in wildlife. Acta Tropica, 78, 103-116.

Dinkins, J.B., Conover, M.R., Kirol, C.P., Beck, J.L. & Frey, S.N. (2014) Greater Sage-Grouse (*Centrocercus urophasianus*) select habitat based on avian predators, landscape composition, and anthropogenic features. The Condor, 116, 629-642.

Fedy, B.C., Doherty, K.E., Aldridge, C.L., O'Donnell, M., Beck, J.L., Bedrosian, B., Gummer, D., Holloran, M.J., Johnson, G.D., Kaczor, N.W., Kirol, C.P., Mandich, C.A., Marshall, D., Mckee, G., Olson, C., Pratt, A.C., Swanson, C.C. & Walker, B.L. (2014) Habitat prioritization across large landscapes, multiple seasons, and novel areas: An example using greater sage-grouse in Wyoming. Wildlife Monographs, 190, 1-39.

Festa-Bianchet, M. (1988) Seasonal range selection in bighorn sheep - conflicts between forage quality, forage quantity, and predator avoidance. Oecologia, 75, 580-586.

Forrester, T.D., Casady, D.S. & Wittmer, H.U. (2015) Home sweet home: fitness consequences of site familiarity in female black-tailed deer. Behavioral Ecology and Sociobiology, 69, 603-612.

Forrester, T.D. & Wittmer, H.U. (2013) A review of the population dynamics of mule deer and black-tailed deer *Odocoileus hemionus* in North America. Mammal Review, 43, 292-308.

Fox, J. & Monette, G. (1992) Generalized collinearity diagnostics. Journal of the American Statistical Association, 87, 178-183.

Fox, J. & Weisberg, S. (2019) An R companion to applied regression (Third). Thousand Oaks CA: Sage.

Gaillard, J.-M., Hebblewhite, M., Loison, A., Fuller, M., Powell, R., Basille, M. & Van Moorter, B. (2010) Habitat–performance relationships: finding the right metric at a given spatial scale. Philosophical Transactions of the Royal Society B: Biological Sciences, 365, 2255-2265.

Gander, H. & Ingold, P. (1997) Reactions on male alpine chamois (*Rupicapra r. rupicapra*) to hikers, joggers and mountainbikers. Biological Conservation, 79, 107-109.

Gilbert, S.L., Hundertmark, K.J., Person, D.K., Lindberg, M.S. & Boyce, M.S. (2017) Behavioral plasticity in a variable environment: snow depth and habitat interactions drive deer movement in winter. Journal of Mammalogy, 98, 246-259.

Hair, J.F.J., Anderson, R.E., Tatham, R.L. & Black, W.C. (1995) Multivariate Data Analysis (3rd ed). Macmillan, New York.

Hamel, S. & Côté, S. (2007) Habitat use patterns in relation to escape terrain: are alpine ungulate females trading off better foraging sites for safety? Canadian Journal of Zoology, 85, 933-943.

Heffelfinger, J. (2018) Deer of the southwest: a complete guide to the natural history, biology, and management of southwestern mule deer and white-tailed deer. Texas A&M University Press.

Holloran, M.J., Fedy, B.C. & Dahlke, J. (2015) Winter habitat use of greater sage-grouse relative to activity levels at natural gas well pads. The Journal of Wildlife Management, 79, 630-640.

Hovick, T.J., Elmore, R.D., Dahlgren, D.K., Fuhlendorf, S.D. & Engle, D.M. (2014) Evidence of negative effects of anthropogenic structures on wildlife: a review of grouse survival and behaviour. Journal of Applied Ecology, 51, 1680-1689.

Huhtala, A. & Pouta, E. (2009) Benefit incidence of public recreation areas-have the winners taken almost all? Environmental & Resource Economics, 43, 63-79.

Jenness, J. (2006) Topographic Position Index (tpi_jen. avx) extension for ArcView 3. x, v. 1.3 a. Jenness Enterprises.

Jones, P.F., Jakes, A.F., Telander, A.C., Sawyer, H., Martin, B.H. & Hebblewhite, M. (2019) Fences reduce habitat for a partially migratory ungulate in the Northern Sagebrush Steppe. Ecosphere, 10.

Karsch, R.C., Cain, J.W., Rominger, E.M. & Goldstein, E.J. (2016) Desert bighorn sheep lambing habitat: parturition, nursery, and predation sites. Journal of Wildlife Management, 80, 1069-1080.

Kaze, J., Whiting, J.C., Freeman, E.D., Bates, S.B. & Larsen, R.T. (2016) Birth-site selection and timing of births in American bison: effects of habitat and proximity to anthropogenic features. Wildlife Research, 43, 418-428.

Keller, B.J. & Bender, L.C. (2007) Bighorn sheep response to road-related disturbances in Rocky Mountain National Park, Colorado. Journal of Wildlife Management, 71, 2329-2337.

Kie, J.G., Bowyer, R.T., Nicholson, M.C., Boroski, B.B. & Loft, E.R. (2002) Landscape heterogeneity at differing scales: effects on spatial distribution of mule deer. Ecology, 83, 530-544.

King, M.M. (1986) Behavioral response of desert bighorn sheep to human harassment: a comparison of disturbed and undisturbed populations. Dissertation Abstracts International B Sciences and Engineering, 46, 2516-2516.

King, M.M. & Smith, H.D. (1980) Differential habitat utilization by the sexes of the mule deer (*Odocoileus hemionus*). Great Basin Naturalist*,* 40, 273-281.

Koshmrl, M. (2019) What it takes to catch antler thieves. National Geographic.

Krausman, P.R. (1999) Some basic principles of habitat use. Grazing behavior of livestock and wildlife, 70, 85-90.

Krausman, P.R. & Bleich, V.C. (2013) Conservation and management of ungulates in North America. International journal of environmental studies, 70, 372-382.

Kuba, J., Landete-Castillejos, T. & Udala, J. (2015) Red deer farming: breeding practice, trends and potential in Poland- a review. Annals of Animal Science, 15, 591-599.

Kwak, W., Kim, K., Kim, C., Jeon, B. & Lee, S. (1994) Deer farming in Korea: on-farm survey in Kyung-Kee and Chung-Buk provinces. Asian-Australasian Journal of Animal Sciences, 7, 347-355.

Lendrum, P.E., Anderson, C.R., Long, R.A., Kie, J.G. & Bowyer, R.T. (2012) Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. Ecosphere, 3.

Lendrum, P.E., Anderson, C.R., Monteith, K.L., Jenks, J.A. & Bowyer, R.T. (2013) Migrating mule deer: effects of anthropogenically altered landscapes. PloS One, 8.

Long, R.A., Muir, J.D., Rachlow, J.L. & Kie, J.G. (2009) A Comparison of Two Modeling Approaches for Evaluating Wildlife-Habitat Relationships. The Journal of Wildlife Management, 73, 294-302.

Longcore, T. & Rich, C. (2004) Ecological light pollution. Frontiers in Ecology and the Environment, 2, 191-198.

Lowrey, C. & Longshore, K.M. (2017) Tolerance to disturbance regulated by attractiveness of resources: A case study of desert bighorn sheep within the River Mountains, Nevada. Western North American Naturalist, 77, 82-98.

Lynch, E., Northrup, J.M., McKenna, M.F., Anderson, C.R., Angeloni, L. & Wittemyer, G. (2015) Landscape and anthropogenic features influence the use of auditory vigilance by mule deer. Behavioral Ecology, 26, 75-82.

Macarthur, R.A., Geist, V. & Johnston, R.H. (1982) Cardiac and behavioral responses of mountain sheep (Ovis canadensis canadensis) to human disturbance. Journal of Wildlife Management, 46, 351-358.

Manly, B., McDonald, L., Thomas, D.L., McDonald, T.L. & Erickson, W.P. (2007) Resource selection by animals: statistical design and analysis for field studies. Springer Science & Business Media.

Mazerolle, M.J. & Mazerolle, M.M.J. (2017) Package ‘AIC$_c$modavg’. R package.

Mimiaga, J. (2018) New regulation limits growing practice of antler collection. The Journal. The Journal: Ballantine Communications, Inc, The Journal, Ballantine Communications, Cortez, Colorado, USA.

Nicholson, M.C., Bowyer, R.T. & Kie, J.G. (1997) Habitat selection and survival of mule deer: tradeoffs associated with migration. Journal of Mammalogy, 78, 483-504.

Nix, J.H., Howell, R.G., Hall, L.K. & McMillan, B.R. (2018) The influence of periodic increases of human activity on crepuscular and nocturnal mammals: Testing the weekend effect. Behavioural Processes, 146, 16-21.

Olson, D.D., Bissonette, J.A., Cramer, P.C., Bunnell, K.D., Coster, D.C. & Jackson, P.J. (2015) How does variation in winter weather affect deer—vehicle collision rates? Wildlife Biology, 21, 80-87.

Papouchis, C.M., Singer, F.J. & Sloan, W.B. (2001) Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management, 65, 573-582.

Peignier, M., Webber, Q.M., Koen, E.L., Laforge, M.P., Robitaille, A.L. & Vander Wal, E. (2019) Space use and social association in a gregarious ungulate: testing the conspecific attraction and resource dispersion hypotheses. Ecology and Evolution, 9, 5133-5145.

Pelletier, F. (2006) Effects of tourist activities on ungulate behaviour in a mountain protected area. Ibex Journal of Mountain Ecology, 8, 15-19.

Ramirez, P. & Mosley, S.B. (2015) Oil and Gas Wells and Pipelines on US Wildlife Refuges: Challenges for Managers. PloS One, 10.

Reinking, A.K., Smith, K.T., Mong, T.W., Read, M.J. & Beck, J.L. (2019) Across scales, pronghorn select sagebrush, avoid fences, and show negative responses to anthropogenic features in winter. Ecosphere, 10.

Robinson, R.W., Whiting, J.C., Shannon, J.M., Olson, D.D., Flinders, J.T., Smith, T.S. & Bowyer, R.T. (2019) Habitat use and social mixing between groups of resident and augmented bighorn sheep. Scientific Reports, 9.

Rodgers, P.A., Sawyer, H., Mong, T.W., Stephens, S. & Kauffman, M.J. (2021) Sex-specific migratory behaviors in a temperate ungulate. Ecosphere, 12, e03424.

Rogerson, J.D., Fairbanks, W.S. & Cornicelli, L. (2008) Ecology of gastropod and bighorn sheep hosts of lungworm on isolated, semiarid mountain ranges in Utah, USA. Journal of Wildlife Diseases, 44, 28-44.

Rominger, E.M. (2018) The Gordian knot of mountain lion predation and bighorn sheep. Journal of Wildlife Management, 82, 19-31.

Rouse, J., Haas, R., Schell, J. & Deering, D. (1974) Monitoring vegetation systems in the Great Plains with ERTS. NASA special publication, 351, 309.

Sappington, J.M., Longshore, K.M. & Thompson, D.B. (2007) Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. The Journal of Wildlife Management, 71, 1419-1426.

Sawyer, H., Nielson, R.M., Lindzey, F. & McDONALD, L.L. (2006) Winter habitat selection of mule deer before and during development of a natural gas field. The Journal of Wildlife Management, 70, 396-403.

Schroeder, C.A., Bowyer, R.T., Bleich, V.C. & Stephenson, T.R. (2010) Sexual segregation in Sierra Nevada bighorn sheep, *Ovis canadensis sierrae*: ramifications for conservation. Arctic Antarctic and Alpine Research, 42, 476-489.

Sikes, R.S., Thompson, T.A. & Bryan, J.A., II (2019) American Society of Mammalogists: raising the standards for ethical and appropriate oversight of wildlife research. Journal of Mammalogy, 100, 763-773.

Singer, F.J., Papouchis, C.M. & Symonds, K.K. (2000) Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology, 8, 6-13.

Smedley, D.C., van de Kerk, M., McMillan, B.R., Hersey, K.R., Whiting, J.C. & Larsen, R.T. (2019) Movements, space use and site fidelity of translocated and resident mule deer (*Odocoileus hemionus*). Wildlife Research, 46, 509-517.

Smith, K.T., Taylor, K.L., Albeke, S.E. & Beck, J.L. (2020) Pronghorn Winter Resource Selection Before and After Wind Energy Development in South-Central Wyoming. Rangeland Ecology & Management, 73, 227-233.

Smith, T.S., Flinders, J.T. & Winn, D.S. (1991) A habitat evaluation procedure for Rocky Mountain bighorn sheep in the intermountain west. Great Basin Naturalist, 51, 205-225.

Sproat, K.K., Martinez, N.R., Smith, T.S., Sloan, W.B., Flinders, J.T. & Bates, J.W. (2019) Desert bighorn sheep responses to human activity in southeastern Utah. Wildlife Research, 47, 9.

Straka, T.M., Fritze, M. & Voigt, C.C. (2020) The human dimensions of a green-green-dilemma: Lessons learned from the wind energy - wildlife conflict in Germany. Energy Reports, 6, 1768-1777.

Taylor, A.R. & Knight, R.L. (2003) Wildlife responses to recreation and associated visitor perceptions. Ecological Applications, 13, 951-963.

Taylor, J.C., Bates, S.B., Whiting, J.C., McMillan, B.R. & Larsen, R.T. (2020) Optimizing deployment time of remote cameras to estimate abundance of female bighorn sheep. Wildlife Research.

Utah State Parks. (2001) Antelope Island State Park: wildlife management plan update. Utah Division of Parks and Recreation, Utah Department of Natural Resources, Salt Lake City, USA.

Utah State Parks. (2018) Park visitation records. (ed. N. Resources). Utah Department of Natural Resources, Salt Lake City, USA.

Wang, M. & Schreiber, A. (2001) The impact of habitat fragmentation and social structure on the population genetics of roe deer (*Capreolus capreolus* L.) in Central Europe. Heredity, 86, 703-715.

Westover, M., Baxter, J., Baxter, R., Day, C., Jensen, R., Petersen, S. & Larsen, R. (2016) Assessing Greater sage-grouse selection of brood-rearing habitat using remotely-sensed imagery: can readily available high-resolution imagery be used to identify brood-rearing habitat across a broad landscape? PLOS ONE, 11, e0156290.

Whiting, J.C., Bowyer, R.T. & Flinders, J.T. (2008) Young bighorn (*Ovis canadensis*) males: can they successfully woo females? Ethology, 114, 32-41.

Whiting, J.C., Bowyer, R.T. & Flinders, J.T. (2009a) Annual use of water sources by reintroduced Rocky Mountain bighorn sheep *Ovis canadensis canadensis*: effects of season and drought. Acta Theriologica, 54, 127-136.

Whiting, J.C., Bowyer, R.T. & Flinders, J.T. (2009b) Diel use of water by reintroduced bighorn sheep. Western North American Naturalist, 69, 407-412.

Wiedmann, B.P. & Bleich, V.C. (2014) Demographic responses of bighorn sheep to recreational activities: a trial of a trail. Wildlife Society Bulletin, 38, 773-782.

Wisdom, M.J., Ager, A.A., Preisler, H.K., Cimon, N.J. & Johnson, B.K. (2004) Effects of off-road recreation on mule deer and elk. In: Transactions of the 69th North American Wildlife and Natural Resources Conference: 531-550

Wolfe, M.L. & Kimball, J.F. (1989) Comparison of bison population estimates with a total count. Journal of Wildlife Management, 53, 593-596.

Wyckoff, T.B., Sawyer, H., Albeke, S.E., Garman, S.L. & Kauffman, M.J. (2018) Evaluating the influence of energy and residential development on the migratory behavior of mule deer. Ecosphere, 9, e02113.

Xu, W.J., Dejid, N., Herrmann, V., Sawyer, H. & Middleton, A.D. (2021) Barrier Behaviour Analysis (BaBA) reveals extensive effects of fencing on wide-ranging ungulates. Journal of Applied Ecology.

FIGURES

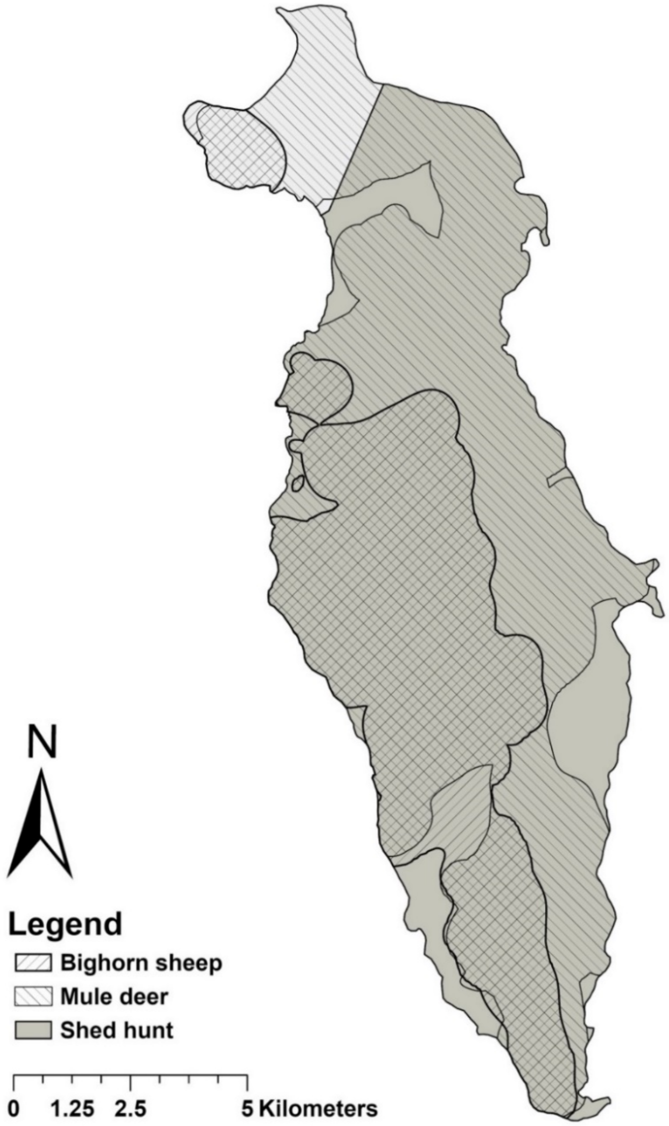

Figure 3-1. Antelope Island State Park, Utah, USA, where we documented resource selection in late-winter of individual mule deer and bighorn sheep during shed antler hunts during March 2012–2015. Stippled polygons represent annual home ranges of 31 collared mule deer and 36 collared bighorn sheep (Bates, Whiting & Larsen 2021).

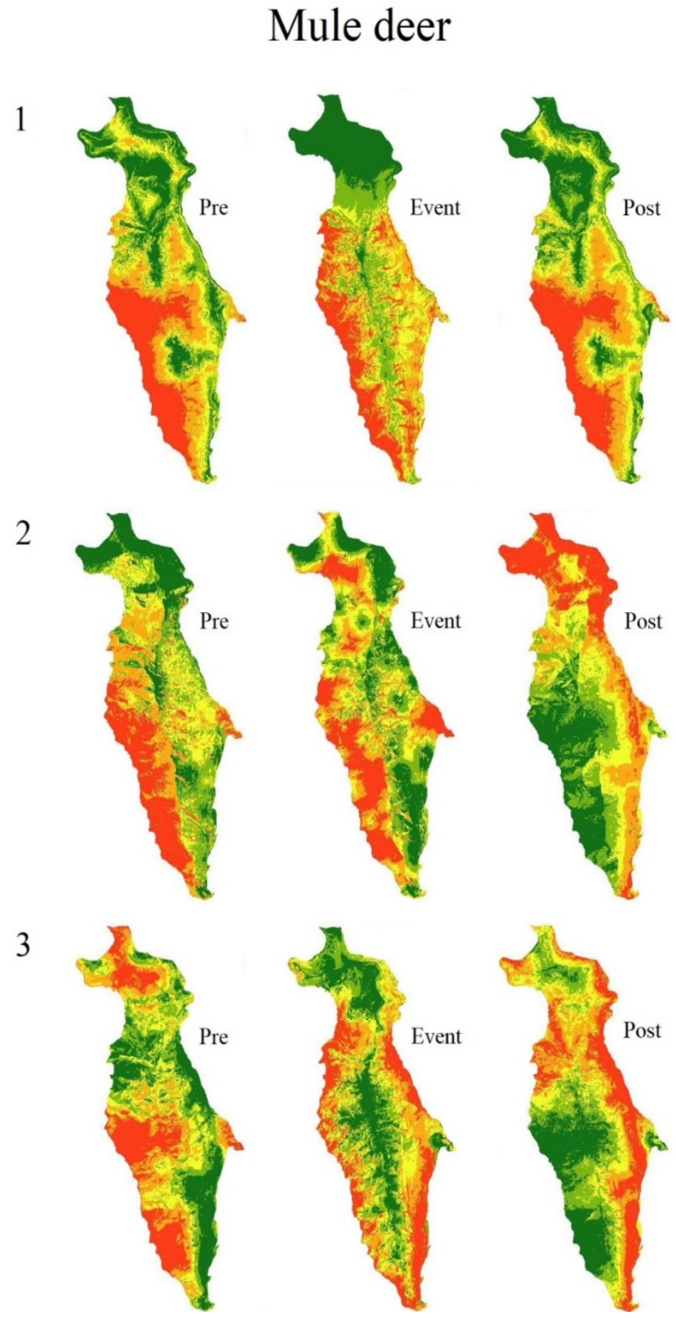

Figure 3-2. Change in resource selection by 27 mule deer during late winter in response to shed antler hunts held in March on Antelope Island State Park, Utah, USA (2012-2015). Mule deer responded by 1) remaining in approximate pre-event location, 2) moving to another location within their annual home range, or 3) moving beyond the boundary of their annual home range but re-entering their home range boundaries within seven days post event.

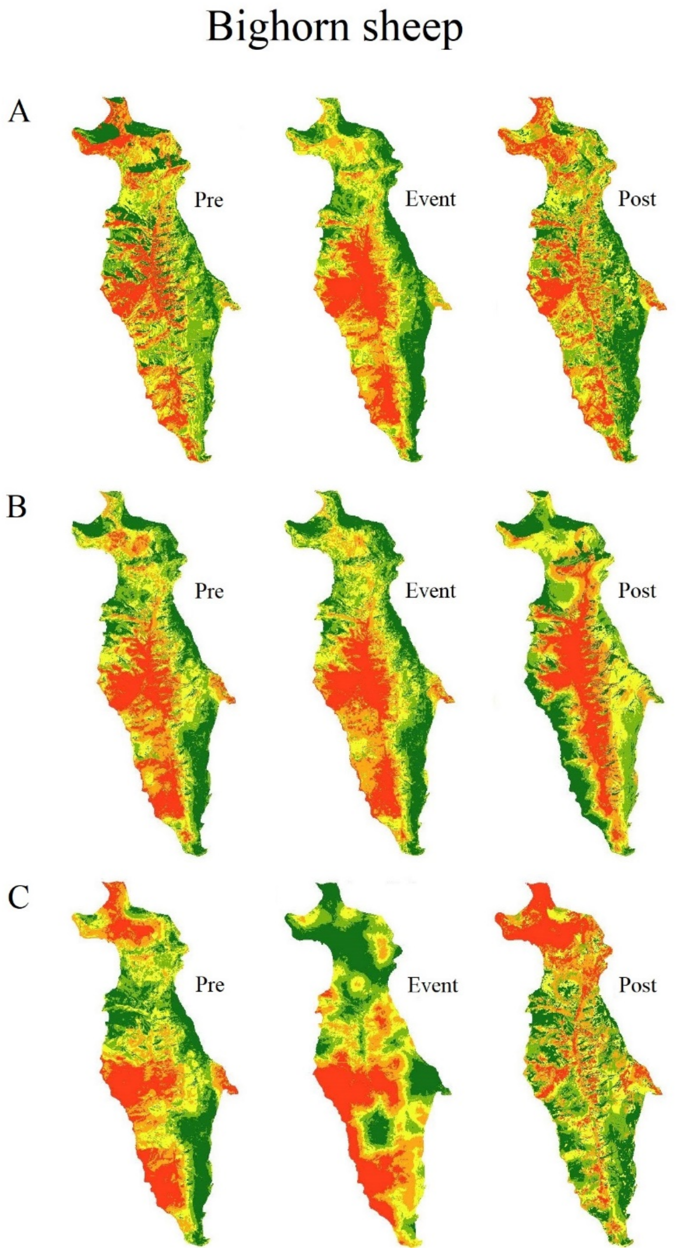

Figure 3-3. Change in resource selection by 29 bighorn sheep during late winter in response to shed antler hunts held in March on Antelope Island State Park, Utah, USA (2012-2015). Bighorn sheep responded by 1) remaining in approximate pre-event location, 2) moving to another location within their annual home range, or 3) moving beyond the boundary of their annual home range but re-entering their home range boundaries within seven days post event.

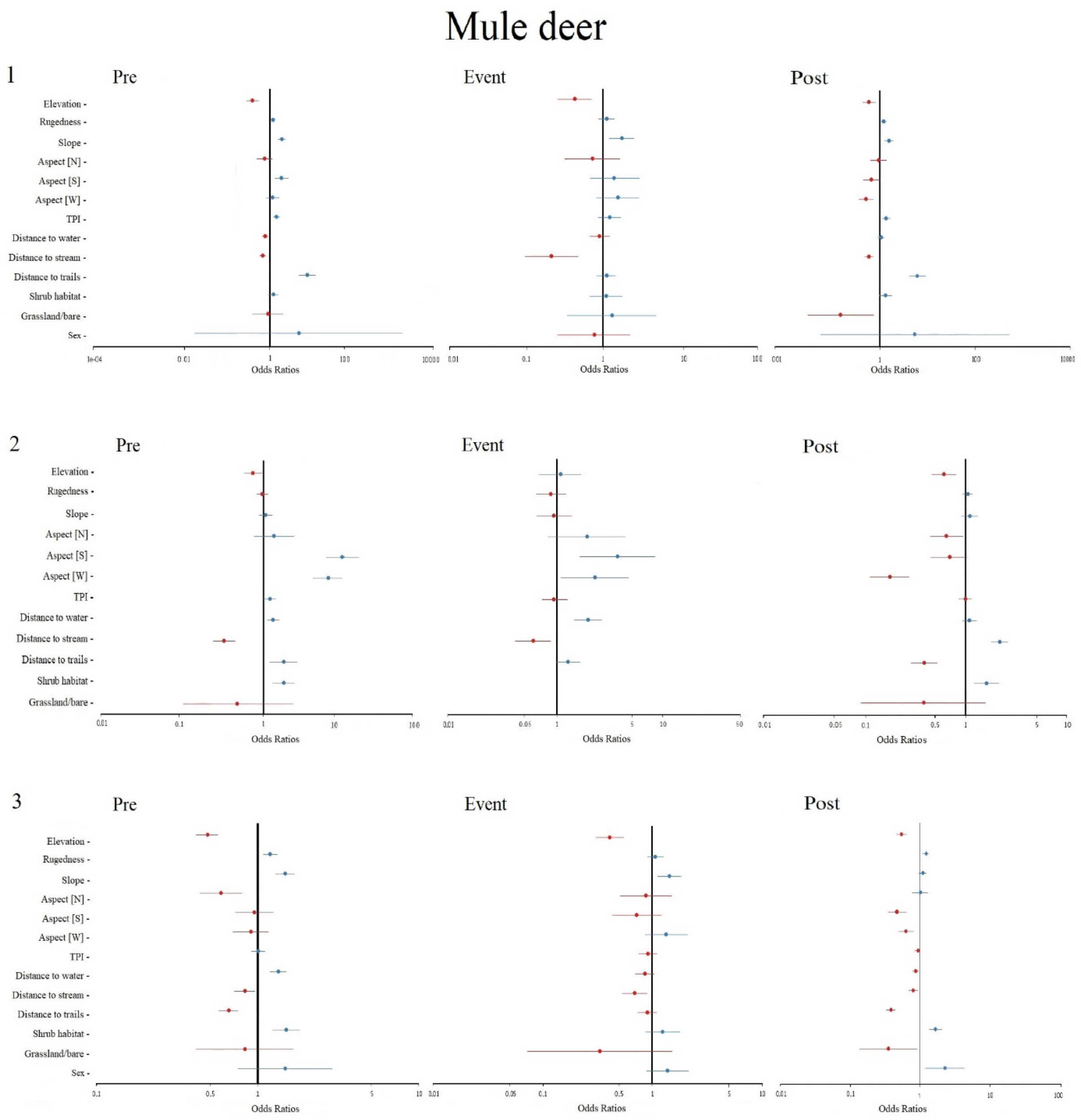

Figure 3-4. Odds ratios for use of topographic, abiotic, and biotic habitat features by 27 mule deer 7 days prior to (Pre), during (Event), and 7 days following (Post) shed antler hunts held in March on Antelope Island State Park, Utah, USA (2012-2015). Odds ratios are presented for mule deer that 1) remained in approximate pre-event location, 2) moved to another location within their annual home range, or 3) moved beyond the boundary of their annual home range but re-entered their home range boundaries within 7 days post-event.

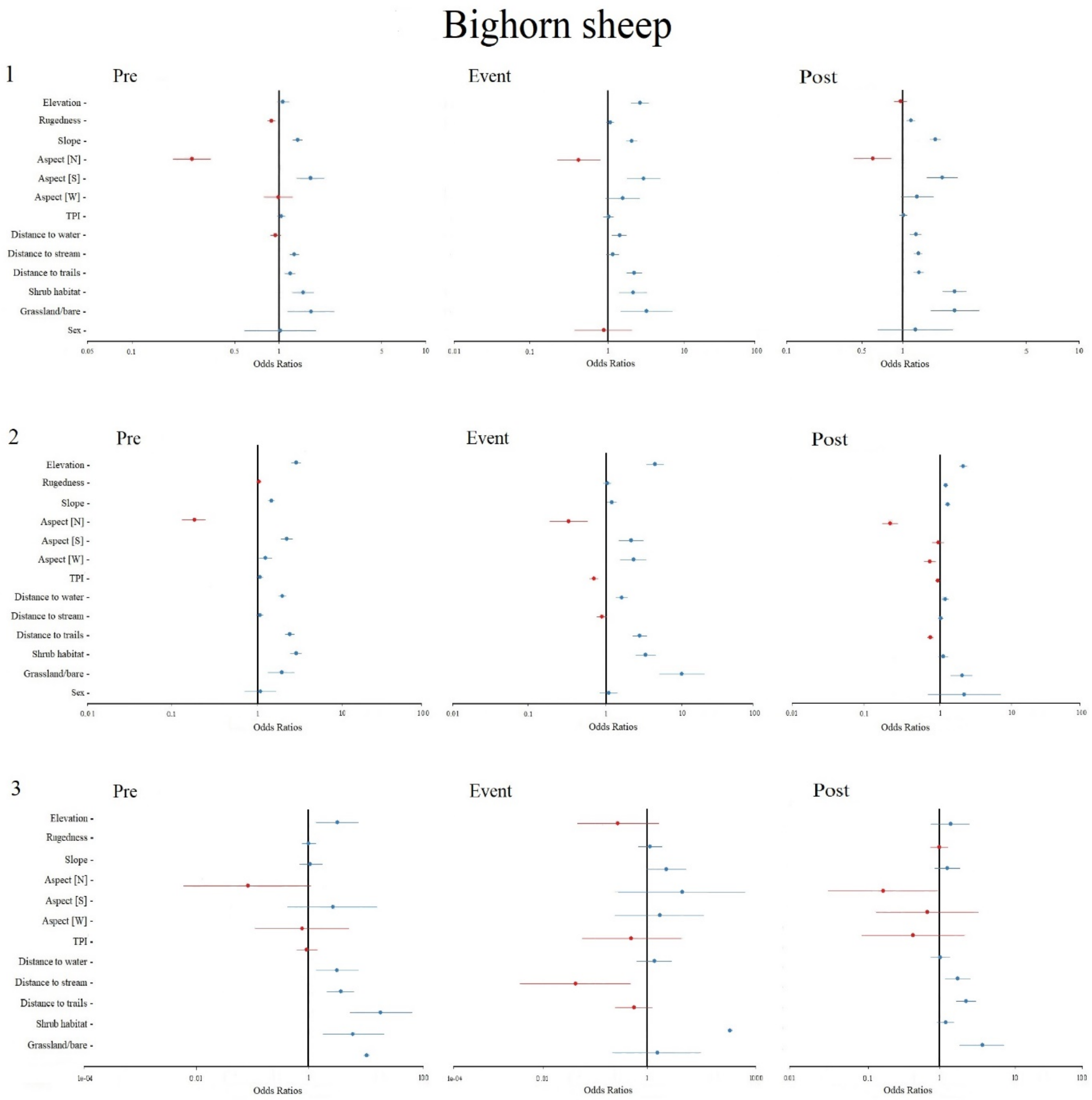

Figure 3-5. Odds ratios for use of topographic, abiotic, and biotic habitat features by 29 bighorn sheep 7 days prior to (Pre), during (Event), and 7 days following (Post) shed antler hunts held in March on Antelope Island State Park, Utah, USA (2012-2015). Odds ratios are presented for bighorn sheep that 1) remained in approximate pre-event location, 2) moved to another location within their annual home range, or 3) moved beyond the boundary of their annual home range but re-entered their home range boundaries within 7 days post-event.

TABLES

Table 3-1. Response of 27 mule deer (9 males, 18 females) and 29 bighorn sheep (13 males, 16 females) to shed antler hunts (1, 2, or 3), number of pre-shed antler hunt use locations, number of use locations during shed antler hunts, number of post-shed antler hunt use locations, and the number of individuals providing sample locations in our study during late winter (March) on Antelope Island State Park, Utah, USA (2012-2015). An equivalent number of random locations were generated for each species (mule deer, bighorn sheep), response (1, 2, 3) and event phase (Pre, Event, Post) for resource selection analyses.

Species	Response	Pre	Event	Post	Individuals
Mule deer	1	671	180	641	6
Mule deer	2	560	159	560	7
Mule deer	3	1,344	382	1,340	14
Bighorn sheep	1	2,656	768	2,684	17
Bighorn sheep	2	3,340	960	3,356	11
Bighorn sheep	3	224	64	224	1

Table 3-2. Description of GIS explanatory variables and fixed variables tested for influencing resource selection by mule deer and bighorn sheep in response to shed antler hunting during late winter (March) on Antelope Island State Park, Utah, USA, 2012–2015. VRM, TPI, and decay functions used in this analysis (Jenness 2006; Sappington, Longshore & Thompson 2007; Fedy *et al.* 2014; Westover *et al.* 2016)

Variable	Description
Topographic	
Elevation	Elevation (10m DEM)
Aspect	Aspect (10m DEM), binned in 4 cardinal directions (1 = N, 2 = E, 3 = S, 4 = W)
Slope	Percent Slope (10m DEM)
Ruggedness	Vector Ruggedness Measure (VRM) with a 3-cell window
TPI_100	Topographic Position Index (TPI) with a 100-cell window
Anthropogenic	
Buildings	Distance to buildings with 560 m decay function
All roads	Distance to any road with 560 m decay function
Public roads	Distance to roads open to visitors with 560 m decay function
Trails	Distance to maintained trails with 560 m decay function
Abiotic	
All water sources	Distance to open water with 560 m decay function
Streams	Distance to streams with 560 m decay function
Springs	Distance to springs with 560 m decay function
Biotic	
Shrub vegetation	Distance to change in vegetation type with 560 m decay function
Sparse vegetation	Distance to change in vegetation height with 560 m decay function
Fixed	
Year	Random 2012-2015 (Random factor)
Animal identification	Random Collar ID number (Random factor)
Species	Categorical 1 (bighorn sheep) or 0 (mule deer)
Sex	Categorical 1 (male) or 0 (female)
Use	Categorical 1 (animal location) or 0 (random location)

Table 3-3. Mule deer selection of habitat resources during late winter (March) on Antelope Island, Utah, USA from 2012 to 2015 in response to shed antler hunting during pre, event and post phases, listed by response type (1, 2, or 3) as compared to random locations (*n* = 5,837). Response type is defined by individuals 1) remaining in approximate pre-event location, 2) moving to another location within their annual home range, or 3) moving beyond the boundary of their annual home range but re-entering their home range boundaries within seven days post event. Estimates, standard errors (SE), z statistics, and probabilities are reported for elevation, ruggedness, slope, aspect, tpi (topographic position index), distance to a water source, distance to a stream, distance to a recreational trail, and vegetation type (shrub or open).

	Pre				Event				Post			
Response 1	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)
(Intercept)	-2.908	2.702	-1.076	0.282	-1.770	1.189	-1.489	0.136	-1.941	2.284	-0.850	0.396
Elevation	-0.940	0.174	-5.405	<0.001	-0.840	0.257	-3.264	0.001	-0.544	0.157	-3.474	<0.001
Ruggedness	0.188	0.073	2.589	<0.011	0.115	0.124	0.932	0.351	0.152	0.071	2.151	0.031
Slope	0.677	0.110	6.140	<0.001	0.565	0.195	2.892	0.004	0.438	0.103	4.260	<0.001
Aspect_north	-0.284	0.224	-1.268	0.205	-0.320	0.420	-0.761	0.447	-0.065	0.206	-0.318	0.751
Aspect_south	0.646	0.203	3.178	0.001	0.354	0.377	0.939	0.348	-0.425	0.213	-1.996	0.046
Aspect_west	0.162	0.188	0.865	0.387	0.450	0.320	1.404	0.160	-0.685	0.191	-3.583	<0.001
TPI_100	0.364	0.090	4.064	<0.001	0.195	0.175	1.116	0.264	0.284	0.095	3.003	0.003
Dist(m) to water	-0.249	0.086	-2.908	0.004	-0.102	0.152	-0.672	0.502	0.041	0.085	0.487	0.626
Dist(m) to stream	-0.379	0.092	-4.114	<0.001	-1.534	0.407	-3.770	<0.001	-0.517	0.109	-4.754	<0.001
Dist(m) to trails	2.063	0.233	8.843	<0.001	0.114	0.140	0.816	0.415	1.812	0.206	8.809	<0.001
Shrub vegetation	0.195	0.141	1.387	0.166	0.099	0.252	0.394	0.694	0.251	0.144	1.750	0.080
Sparse vegetation	-0.086	0.446	-0.193	0.847	0.261	0.673	0.388	0.698	-1.915	0.821	-2.333	0.020
Sex	1.605	2.930	0.548	0.584	-0.257	0.550	-0.467	0.640	1.680	2.341	0.718	0.473
Response 2	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)
(Intercept)	-3.780	1.769	-2.137	0.033	-2.050	1.126	-1.821	0.069	-0.093	0.925	-0.100	0.920
Elevation	-0.301	0.140	-2.149	0.032	0.103	0.226	0.455	0.649	-0.487	0.142	-3.433	<0.001
Ruggedness	-0.028	0.081	-0.344	0.731	-0.118	0.163	-0.723	0.470	0.050	0.069	0.724	0.469

Slope	0.077	0.111	0.695	0.487	-0.065	0.191	-0.343	0.732	0.098	0.095	1.034	0.301
Aspect_north	0.319	0.301	1.060	0.289	0.661	0.428	1.545	0.122	-0.433	0.192	-2.257	0.024
Aspect_south	2.339	0.249	9.406	<0.001	1.249	0.410	3.046	0.002	-0.369	0.207	-1.777	0.076
Aspect_west	1.911	0.234	8.157	<0.001	0.805	0.374	2.149	0.032	-1.727	0.220	-7.866	<0.001
TPI_100	0.184	0.089	2.065	0.039	-0.102	0.135	-0.759	0.448	-0.004	0.077	-0.050	0.960
Dist(m) to water	0.286	0.086	3.323	<0.001	0.675	0.156	4.330	<0.001	0.093	0.085	1.104	0.269
Dist(m) to stream	-1.165	0.164	-7.084	<0.001	-0.498	0.194	-2.561	0.010	0.780	0.102	7.672	<0.001
Dist(m) to trails	0.591	0.212	2.786	0.005	0.246	0.133	1.844	0.065	-0.954	0.156	-6.118	<0.001
Shrub vegetation	0.604	0.165	3.672	<0.001	0.228	0.260	0.877	0.380	0.477	0.148	3.217	0.001
Sparse vegetation	-0.768	0.839	-0.915	0.360	NA	NA	NA	NA	-0.962	0.725	-1.328	0.184
Response 3	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)
(Intercept)	-2.552	2.667	-0.957	0.339	-2.138	2.023	-1.057	0.291	-2.640	2.648	-0.997	0.319
Elevation	-0.720	0.083	-8.684	<0.001	-0.879	0.149	-5.901	<0.001	-0.612	0.080	-7.624	<0.001
Ruggedness	0.180	0.050	3.578	<0.001	0.082	0.089	0.924	0.356	0.192	0.052	3.708	<0.001
Slope	0.393	0.066	5.991	<0.001	0.378	0.125	3.021	0.003	0.088	0.065	1.347	0.178
Aspect_north	-0.524	0.152	-3.455	<0.001	-0.123	0.278	-0.441	0.659	0.008	0.142	0.056	0.955
Aspect_south	-0.043	0.140	-0.306	0.760	-0.314	0.270	-1.162	0.245	-0.756	0.153	-4.932	<0.001
Aspect_west	-0.099	0.131	-0.754	0.451	0.308	0.230	1.342	0.180	-0.460	0.131	-3.502	<0.001
TPI_100	0.010	0.049	0.208	0.835	-0.075	0.100	-0.754	0.451	-0.076	0.052	-1.457	0.145
Dist(m) to water	0.291	0.056	5.161	<0.001	-0.144	0.100	-1.435	0.151	-0.155	0.057	-2.719	0.007
Dist(m) to stream	-0.181	0.075	-2.423	0.015	-0.356	0.136	-2.615	0.009	-0.230	0.079	-2.891	0.004
Dist(m) to trails	-0.411	0.071	-5.806	<0.001	-0.092	0.103	-0.894	0.371	-0.968	0.082	-11.769	<0.001
Shrub vegetation	0.411	0.100	4.127	<0.001	0.235	0.186	1.260	0.208	0.508	0.101	5.039	<0.001
Sparse vegetation	-0.182	0.357	-0.508	0.611	-1.087	0.779	-1.395	0.163	-1.043	0.491	-2.125	0.034
Sex	0.393	0.343	1.147	0.251	0.339	0.228	1.487	0.137	0.815	0.334	2.442	0.015

Table 3-4. Bighorn sheep selection of habitat resources during late winter (March) on Antelope Island, Utah, USA from 2012 to 2015 in response to shed antler hunting during pre, event and post phases, listed by response type (1, 2, or 3) as compared to random locations (*n* = 14,276). Response type is defined by individuals 1) remaining in approximate pre-event location, 2) moving to another location within their annual home range, or 3) moving beyond the boundary of their annual home range but re-entering their home range boundaries within seven days post event. Estimates, standard errors (SE), z statistics, and probabilities are reported for elevation, ruggedness, slope, aspect, tpi (topographic position index), distance to a water source, distance to a stream, distance to a recreational trail, and vegetation type (shrub or open).

Table 3–4. Bighorn sheep selection of habitat resources during late winter (March) on Antelope Island, Utah, USA from 2012 to 2015 in response to shed antler hunting during pre, event and post phases, listed by response type (1, 2, or 3) as compared to random

	Pre				Event				Post			
Response 1	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)
(Intercept)	-2.425	2.171	-1.117	0.264	-3.046	1.714	-1.777	0.076	-3.173	2.224	-1.427	0.154
Elevation	0.067	0.051	1.315	0.189	0.875	0.124	7.072	<0.001	-0.026	0.054	-0.480	0.631
Ruggedness	-0.112	0.031	-3.572	<0.001	0.063	0.055	1.157	0.247	0.138	0.033	4.149	<0.001
Slope	0.297	0.039	7.675	<0.001	0.651	0.080	8.173	<0.001	0.502	0.041	12.245	<0.001
Aspect_north	-1.360	0.151	-9.026	<0.001	-0.781	0.299	-2.611	0.009	-0.454	0.146	-3.103	0.002
Aspect_south	0.496	0.111	4.460	<0.001	0.975	0.228	4.271	<0.001	0.607	0.121	5.024	<0.001
Aspect_west	-0.006	0.115	-0.057	0.955	0.403	0.243	1.658	0.097	0.226	0.126	1.797	0.072
TPI_100	0.042	0.032	1.304	0.192	0.019	0.074	0.262	0.793	0.017	0.033	0.511	0.609
Dist(m) to water	-0.050	0.043	-1.165	0.244	0.319	0.111	2.884	0.004	0.205	0.045	4.542	<0.001
Dist(m) to stream	0.245	0.037	6.549	<0.001	0.135	0.089	1.516	0.129	0.236	0.038	6.185	<0.001
Dist(m) to trails	0.177	0.042	4.206	<0.001	0.717	0.106	6.790	<0.001	0.245	0.042	5.849	<0.001
Shrub vegetation	0.384	0.086	4.489	<0.001	0.684	0.192	3.558	<0.001	0.804	0.092	8.734	<0.001
Sparse vegetation	0.506	0.187	2.710	0.007	1.055	0.364	2.897	0.004	0.800	0.187	4.276	<0.001
Sex	0.025	0.287	0.088	0.930	-0.115	0.397	-0.289	0.773	0.201	0.293	0.685	0.493
Response 2	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)
(Intercept)	-3.545	2.557	-1.387	0.166	-3.596	2.132	-1.686	0.092	-2.660	2.698	-0.986	0.324
Elevation	1.021	0.069	14.751	<0.001	1.350	0.122	11.060	<0.001	0.658	0.053	12.311	<0.001

Ruggedness	-0.001	0.030	-0.040	0.968	0.054	0.055	0.983	0.326	0.161	0.030	5.364	<0.001
Slope	0.315	0.037	8.581	<0.001	0.173	0.069	2.522	0.012	0.215	0.032	6.643	<0.001
Aspect_north	-1.820	0.174	-10.442	<0.001	-1.002	0.265	-3.776	<0.001	-1.423	0.109	-13.058	<0.001
Aspect_south	0.754	0.091	8.308	<0.001	0.698	0.173	4.044	<0.001	-0.058	0.082	-0.712	0.477
Aspect_west	0.161	0.100	1.605	0.109	0.760	0.183	4.151	<0.001	-0.290	0.085	-3.423	<0.001
TPI_100	0.021	0.033	0.631	0.528	-0.314	0.064	-4.943	<0.001	-0.070	0.031	-2.275	0.023
Dist(m) to water	0.633	0.052	12.204	<0.001	0.441	0.085	5.177	<0.001	0.139	0.042	3.315	<0.001
Dist(m) to stream	0.029	0.037	0.766	0.443	-0.097	0.068	-1.420	0.156	0.011	0.036	0.309	0.758
Dist(m) to trails	0.846	0.060	14.092	<0.001	0.928	0.101	9.168	<0.001	-0.273	0.044	-6.232	<0.001
Shrub vegetation	1.015	0.078	12.948	<0.001	1.096	0.143	7.682	<0.001	0.094	0.066	1.424	0.154
Sparse vegetation	0.606	0.187	3.242	0.001	2.081	0.313	6.653	<0.001	0.626	0.167	3.743	<0.001
Sex	0.041	0.224	0.186	0.853	0.095	0.125	0.762	0.446	0.689	0.525	1.312	0.190
Response 3	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)	Estimate	se	z value	Pr(>|z|)
(Intercept)	-6.279	3.441	-1.825	0.068	-8.858	3.183	-2.783	0.005	-3.159	3.321	-0.951	0.341
Elevation	1.148	0.450	2.551	0.011	-1.941	1.365	-1.422	0.155	0.328	0.291	1.130	0.259
Ruggedness	0.007	0.159	0.041	0.967	0.148	0.403	0.366	0.714	-0.015	0.134	-0.114	0.910
Slope	0.085	0.239	0.357	0.721	1.226	0.650	1.886	0.059	0.224	0.196	1.146	0.252
Aspect_north	-2.477	1.327	-1.867	0.062	2.233	2.110	1.059	0.290	-1.731	0.863	-2.007	0.045
Aspect_south	0.972	0.928	1.048	0.295	0.787	1.479	0.532	0.595	-0.393	0.797	-0.493	0.622
Aspect_west	-0.261	0.971	-0.269	0.788	-1.076	1.646	-0.654	0.513	-0.815	0.808	-1.009	0.313
TPI_100	-0.090	0.209	-0.430	0.667	0.440	0.589	0.746	0.455	0.015	0.143	0.107	0.915
Dist(m) to water	1.122	0.461	2.434	0.015	-4.740	1.843	-2.572	0.010	0.534	0.200	2.666	0.008
Dist(m) to stream	1.296	0.279	4.648	<0.001	-0.901	0.607	-1.484	0.138	0.802	0.151	5.309	<0.001
Dist(m) to trails	2.928	0.635	4.613	<0.001	5.364	1.908	2.811	0.005	0.161	0.135	1.188	0.235
Shrub vegetation	1.793	0.627	2.859	0.004	0.604	1.454	0.415	0.678	1.273	0.349	3.648	<0.001
Sparse vegetation	2.359	1.203	1.962	0.050	NA	NA	NA	NA	NA	NA	NA	NA