

Impacts of coyote removal on space use by greater sage-grouse

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Abstract: Greater sage-grouse (*Centrocercus urophasianus*) are in decline across western North America. Identification of management strategies to enhance populations, such as predator management, may be needed to reduce further declines, but unintentional effects associated with increased human activity should also be considered. We evaluated the effect of 3 levels of predator management effort on greater sage-grouse space use. Home range size, movement rate, seasonal movement timing, and inter-seasonal distances traveled were examined as behavioral responses relative to levels of coyote removal in Bighorn Basin, Wyoming. We observed larger home range sizes during brood-rearing but overall smaller annual core (25% density kernel) sizes with higher levels of predator management. We observed higher movement rates, farther inter-seasonal distances traveled, and higher proportions of sage-grouse making inter-seasonal movements with increased predator removal effort. Our findings suggest activities like predator management may influence behavioral and spatial aspects of sage-grouse ecology. Management actions must consider the direct and indirect effects actions taken to improve a population's growth will have on behavior, habitat use, and ultimately, long-term persistence.

Key words: *Canis latrans*, *Centrocercus urophasianus*, predator control, spatial ecology, Wyoming

THE LARGEST GROUSE species in North America, greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), once occupied >1.2 million km² of sagebrush (*Artemisia* spp.) habitat across 13 western states in the United States and 3 provinces in Canada (Schroeder et al. 2004). Habitat loss and fragmentation (Braun 1998, Connelly et al. 2004), increased natural disturbances like wildfire (Connelly and Braun 1997, Connelly et al. 2000), and anthropogenic disturbances influence sagebrush communities and sage-grouse ecology (Smith et al. 2005, Walker et al. 2007, Aldridge et al. 2008, Blickley et al. 2012). As a sagebrush-obligate species, sage-grouse distribution and population density declines across western North America have been negatively affected by these factors affecting sagebrush-steppe communities (Braun et al. 2002, Knick et al. 2003, Connelly et al. 2004, Nielson et al. 2005) and now occupy only 56% of their historic range (Schroeder et al. 2004). The extent of this decline led to candidacy for listing sage-grouse under the Endangered Species Act (ESA) of 1973 as recently as 2010, with the United States Fish and Wildlife Service

(USFWS) recently ruling ESA listing of sage-grouse as unwarranted (USFWS 2015). They remain a species of conservation concern, and the ruling will be reviewed in 2020.

No single factor has led to sage-grouse population declines, but unintentional stressors and disturbance that result from anthropogenic activities have been shown to affect sage-grouse populations (Johnson et al. 2011, Blickley et al. 2012, Hess and Beck 2012b). Anthropogenic disturbance can come from a variety of long- and short-term human activities including agricultural development (Smith et al. 2005, Walker et al. 2007, Aldridge et al. 2008), historical livestock activities (Beck and Mitchell 2000, Crawford et al. 2004), urbanization (Braun 1998), energy development (Lyon and Anderson 2003, Holloran 2005, Aldridge and Boyce 2007, Doherty et al. 2008), prescribed fire (Connelly and Braun 1997, Nell et al. 2000, Hess and Beck 2012a), higher off-highway vehicle (OHV) presence or use (Blickley et al. 2012), and greater human presence for management purposes like coyote removal (Orning 2014).

Management plans for sage-grouse often

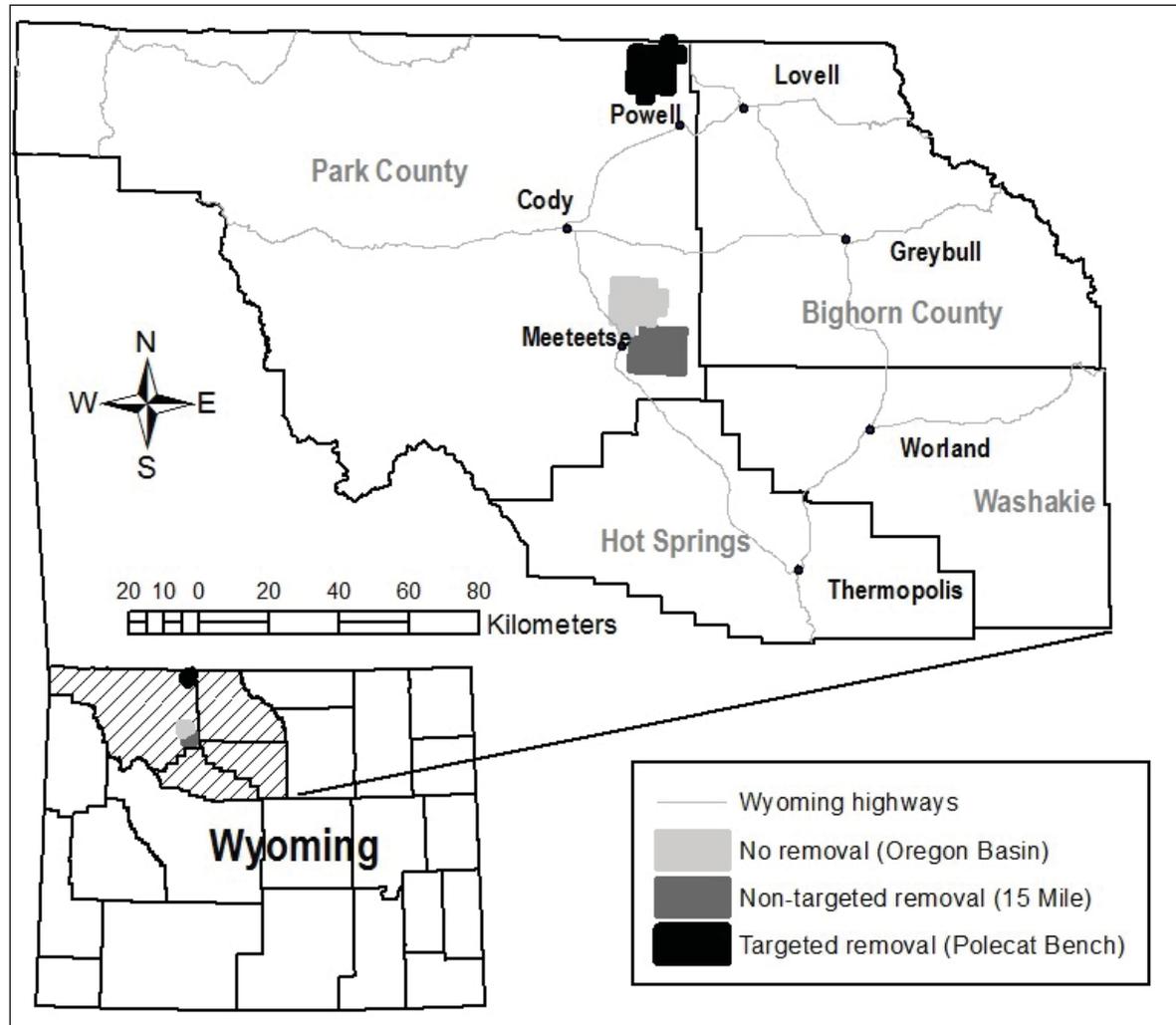


Figure 1. Location of our study of anthropogenic effects on greater sage-grouse (*Centrocercus urophasianus*) space use and movement patterns in Bighorn Basin, Wyoming, USA, 2011–2013. We compared the effects of anthropogenic activity related to different levels of predator management at 3 sites with no (Oregon Basin), non-targeted (15 Mile), and targeted (Polecat Bench) predator removal levels (Orning 2014).

focus on habitat restoration as the primary means to mitigate reductions in habitat quality and quantity as well as to minimize predator effects (Braun 1998, Connelly et al. 2000, Coates and Delahanty 2004, Connelly et al. 2004). These efforts provide only limited success if anthropogenic factors operating at larger spatial scales are not considered (Coates and Delahanty 2004, Manzer and Hannon 2005, Mezquida et al. 2006). Human interference may influence sage-grouse population declines by affecting the dynamics of predator–prey systems (i.e., altering predator community structure, densities, or distribution) or by disturbing sage-grouse space use (e.g., habitat selection, home range, or seasonal movement patterns) during critical life stages of breeding (lek attendance and nesting), brood rearing, or overwinter periods. Behavioral changes could

subsequently increase predation rates on birds and their nests (Greenwood et al. 1995) or alter causes of mortality (Sedinger et al. 2009) and nest loss (Ellis-Felege et al. 2012).

Protection and restoration of crucial breeding and brood-rearing areas have been the primary focus for managers across their range as they are strongly linked to specific, known habitat requirements for sage-grouse (Connelly et al. 2000, Holloran and Anderson 2005, Hagen et al. 2007). Efforts to understand sage-grouse space use, habitat selection, and habitat availability throughout all life stages have become increasingly important to conservation and management objectives (Homer et al. 1993; Bruce et al. 2011; Fedy and Aldridge 2011; Dzialak et al. 2011, 2013). Home range is a commonly used measure of animal space use across multiple taxa, including sage-grouse

(Musil et al. 1993, Drut et al. 1994, Connelly et al. 2000), allowing the evaluation of changes in use over temporal and spatial scales (White and Garrott 1990).

We sought to evaluate the influence of predation and predator management on sage-grouse space use and movement patterns. Our objective was to quantify sage-grouse home range size and movement patterns between sites with differing levels of prescribed coyote removal (Orning 2014), while controlling for other factors known to influence sage-grouse. We hypothesized sage-grouse home range, movement rates, and timing of seasonal movements change relative to predator management, with more variation in areas with greater human activity related to predator management. Understanding the trade-offs that anthropogenic activities like predator management can have on sage-grouse space use will provide managers and conservationists with information to enhance decisions about sage-grouse management.

Study area

We examined space use by sage-grouse over the duration of quasi-experimental predator removal (Orning 2014) from 2011 to 2013 in the northwest portion of Bighorn Basin, Wyoming (Figure 1). Bighorn Basin is a semi-arid, intermontane basin located on the north-central Wyoming plateau, which encompasses 32,000 km² of Bighorn, Hot Springs, Park, and Washakie counties. The study area included 513 km² of Bighorn Basin and was carried out at 3 lek complexes: Oregon Basin (44° 22.45 N, 108° 48.17 W), 15 Mile (44° 10.89 N, 108° 44.38 W), and Polecat Bench (44° 57.00 N, 108° 45.54 W). Each site was defined as a 171-km² area with ≥1 active lek and surrounding nesting areas used by sage-grouse. Average valley elevation was 1,524 m, and the area was composed of badland topography, intermittent buttes, and big sagebrush communities. Average maximum and minimum temperature during the study period (March to September) was 25.7°C and -0.4°C, respectively in 2011 and 29.7°C and 0.1°C in 2012. Total precipitation during the study period was 14.7 cm in 2011 and 19.5 cm in 2012 (Fales Fock, WY, USA; <<http://www.raws.dri.edu>>). Bighorn Basin is composed of mostly public land managed by

the U.S. Bureau of Land Management (40%), U.S. Forest Service (25%), state (5%), and other federal agencies (>1%; Bureau of Reclamation, National Park Service, Department of Defense), as well as some private land (25%; Sage-grouse Conservation Plan for the Bighorn Basin, WY 2007). Land uses in sagebrush areas included livestock grazing, wildlife habitat, dry land and irrigated crop production, recreation, bentonite mining, and oil and gas extraction. Common plants included shrubs, such as Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), basin big sagebrush (*A. t. tridentata*), greasewood (*Sarcobatus vermiculatus*), and rabbitbrush (*Chrysothamnus viscidiflorus* and *Ericameria nauseosa*); forbs such as globemallow (*Sphaeralcea* spp.), milkvetch (*Astragalus* spp.), fringed sagewort (*A. frigida*), phlox (*Phlox* spp.), and pepperweed (*Lepidium virginicum*). Perennial grasses included bluebunch wheatgrass (*Pseudoroegneria spicata*), blue grama (*Bouteloua gracilis*), and needle and thread (*Hesperostipa comata*), and invasive species such as cheatgrass (*Bromus tectorum*), knapweed (*Centaurea* spp.), and toadflax (*Linaria* spp.). Detailed descriptions of vegetative characteristics for Bighorn Basin can be found in Hess and Beck (2012a).

Methods

Animal handling and location data

In 2011–2012, we captured female sage-grouse under Wyoming Chapter 33 Permit #802 using rocket nets on 3 lek complexes (6 leks) in March and April and hoop net and spotlight techniques in post-brood flock areas in September 2011 (Giesen et al. 1982). Leks were targeted for capture based on sufficient grouse lek attendance to minimize rocket use ≤2 launches per lek (i.e., 10–20 hens in attendance). Hens were fitted with either very high frequency (VHF) necklace-style transmitters (Advanced Telemetry Systems Inc., Isanti, MN, USA) or ARGOS/GPS solar PTT packs (PTT-100, Microwave Telemetry, Columbia, MD, USA) using a rump mount (Dzialak et al. 2012). Hens were weighed and classified as a yearling (first breeding season) or adult (≥ second breeding season) based on the shape of primary feathers (Eng 1955, Dalke et al. 1963, Beck et al. 1975). Global Positioning System (GPS) transmitters weighed 30 g and were fitted to hens weighing

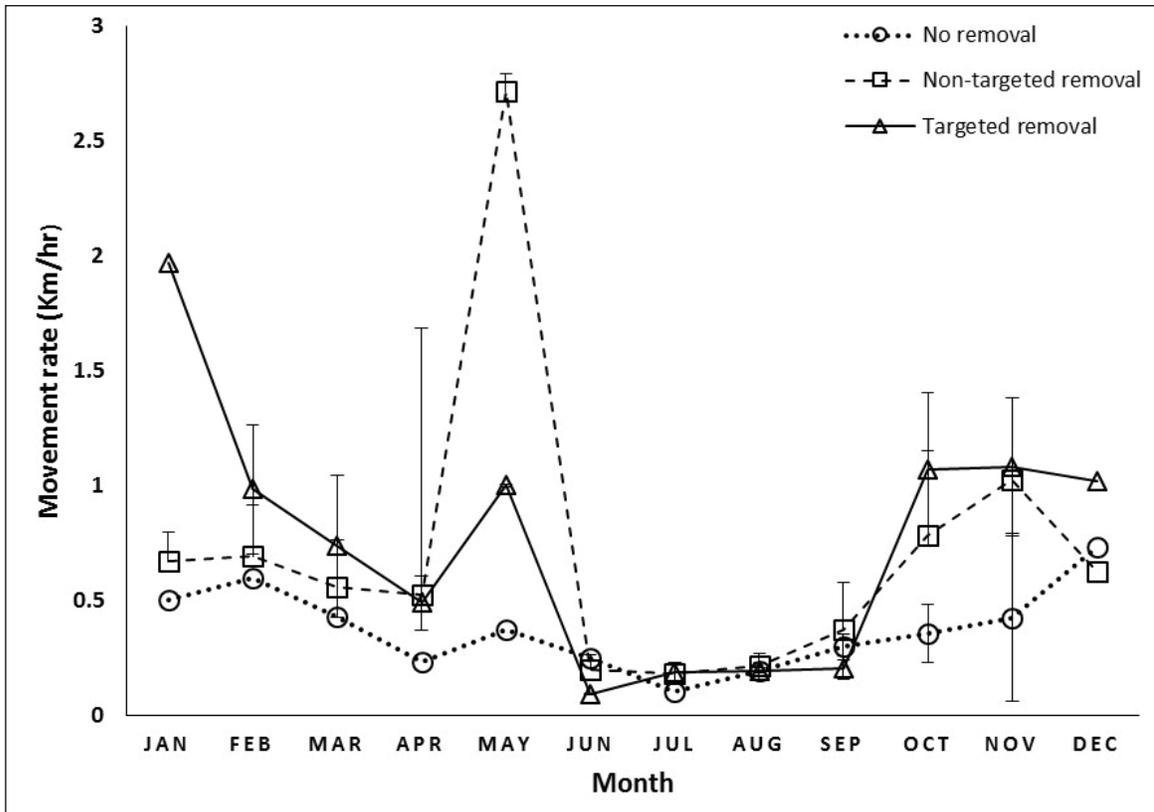


Figure 2. Mean monthly movement rates of sage-grouse hens ($n = 11$) at 3 sites with differing predator management levels in Bighorn Basin, Wyoming, USA, 2011–2013. Management levels were based on the intensity of predator removal efforts by USDA, APHIS, Wildlife Services, with no, non-targeted, and targeted coyote removal occurring between March 14 and June 15, 2012. Error bars show standard error (SE).

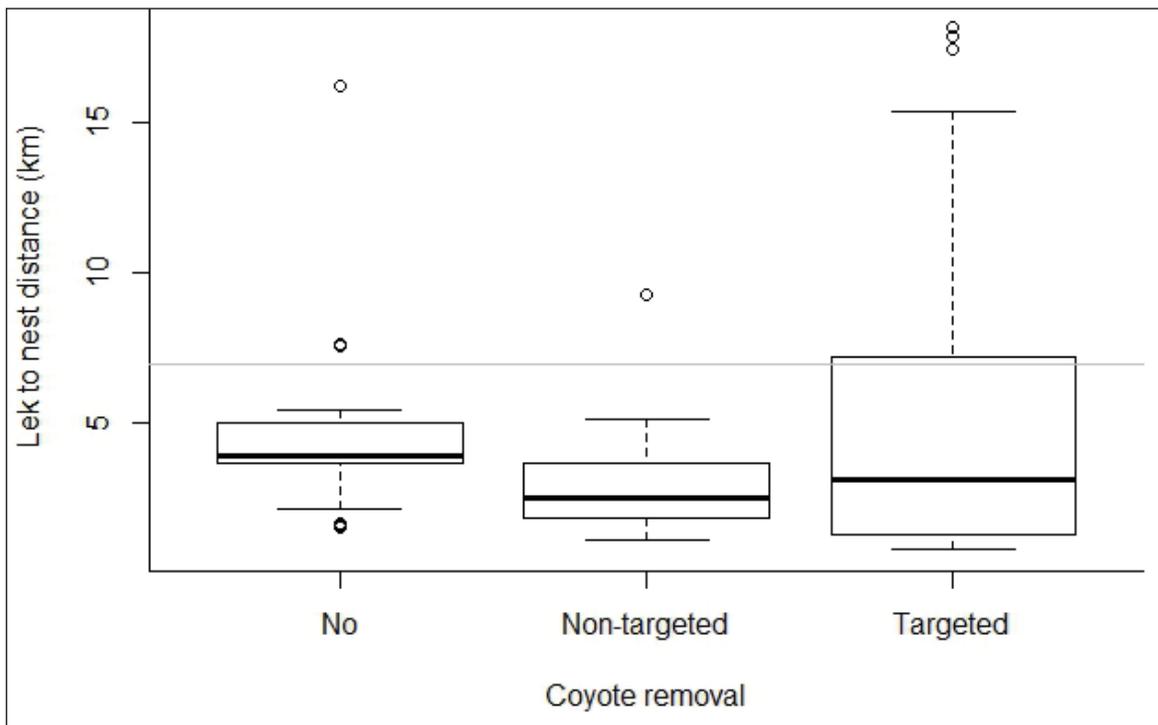


Figure 3. Average lek-to-nest distances (km) for radio-tagged sage-grouse ($n = 59$) at 3 sites with varying levels of predator management in Bighorn Basin, Wyoming, USA, 2011–2013. Management levels were based on the intensity of predator removal efforts by USDA, APHIS, Wildlife Services, with no, non-targeted, and targeted coyote removal occurring between March 14 and June 15, 2012. Gray line shows literature reported average sage-grouse lek-to-nest distance (7 km).

>1,300 g. GPS transmitters were programmed to record 3 locations per day during fall and spring at 1200, 1500, and 1800 hours (September 15 to November 15, March 22 to April 30), 2 locations per day during winter at 1300 and 1700 hours (November 15 to January 2), and 7 locations per day (every hour from 1200–1800 hours) during the nest, brood, and inter-seasonal periods (May 1 to September 14). The VHF transmitters weighed 22 g and had a battery life expectancy of 869 days. We monitored VHF radio-tagged hens using hand-held receivers and vehicle-mounted whip or Yagi antennas every 48–72 hours from the time of capture through the end of the brood-rearing season (August) to identify nest sites and track seasonal movement timing. We obtained ≥ 3 sequential bearings within 15 minutes for each triangulation of a hen and collected locations twice per week. Opportunistic visuals and homing to within 50 m of radio-tagged animals were also used as part of the VHF dataset. We obtained location estimates for VHF triangulation data from program LOCATE III (version 3.34, Pacer Computing, Tatamagouche, NS, Canada) using maximum likelihood estimation (MLE).

Predator removal

Coyote (*Canis latrans*) were removed by USDA, APHIS, Wildlife Services to test the effects of no (Oregon Basin), non-targeted (15 Mile), and targeted (Polecat Bench) coyote removal on hen survival and nest success (Figure 1; Orning 2014). We were unable to randomly assign treatments but were able to randomly assign which of the two sites already receiving treatments became the targeted removal site. Thus, the study represents a quasi-experiment. Methods of removal included aerial gunning, snare and leg-hold trapping, den gassing, and opportunistic shooting. Year-round coyote removal occurred at the targeted removal site for domestic livestock depredation and agriculture damage. We call this site the targeted removal site because additional lethal removals of coyotes were carried out in sage-grouse nesting habitat from March 14 to June 15, 2012. Coyote removals at the non-targeted removal site were applied for mule deer (*Odocoileus hemionus*) fawn production with no additional targeted coyote removal for sage-grouse. No coyote removal occurred at the no

removal site in either year of the study and it served as the experimental control. The study was approved by the USDA National Wildlife Research Center's Institutional Animal Care and Use Committee (IACUC) under protocol QA-1860.

Movement rate and home range estimation

Although the experimental unit is each study area where different levels of treatment were applied, we evaluated sage-grouse movement and home range sizes within each treatment site for analysis. We generated movement step lengths for GPS-marked birds to calculate mean monthly movement rates (km between 2 consecutive sites divided by the elapsed time [hours] between when the data were collected). We defined seasonal ranges for sage-grouse biologically (i.e., a general time frame and adjusted depending on individual bird movement patterns) as breeding (March to May), brood (June to August), and winter (September to November) seasons (Connelly et al. 2011b, Fedy et al. 2012). We classified the occurrence of inter-seasonal movements to winter ranges if either of 2 criteria were met: 1) ≥ 5 km movement occurred, or 2) identifiable shifts in location area habitat features occurred (e.g., a hen moved from a sagebrush bench down in elevation to a riparian/agriculture habitat). Seasonal kernel density estimates (KDE) ranges were generated for birds that showed seasonal movement behavior. We calculated the movement distances for GPS-marked birds as the distance between core area centroid points and report averaged distances within each site. We used analysis of variance (ANOVA) to evaluate differences in home range size and distances traveled.

Minimum convex polygon (MCP) is the most common method used to report sage-grouse home range (Drut et al. 1994, Sveum et al. 1998, Connelly et al. 2000, Dzialak et al. 2012, Aldridge and Boyce 2007), but identifying fine-scale changes in space use could be problematic (Garshelis 2000). Powell (2000) advocated KDE as the best estimator available for home range estimation, and this technique is well represented in the home range estimation of other taxa (Seaman 1993, Stahlecker and Smith 1993, Nielsen and Woolf 2001, Hebblewhite

Table 1. Average distances traveled across all seasonal movements (seasonal) and between breeding, brood-rearing, and winter use areas for GPS-marked sage-grouse hens ($n = 12$) in Bighorn Basin, Wyoming, USA, 2011–2013. Management levels were based on the intensity of predator removal efforts by USDA, APHIS, Wildlife Services at 3 sites with no, non-targeted, and targeted coyote removal occurring between March 14 and June 15, 2012.

Coyote removal	Inter-seasonal travel distance (km)						Seasonal travel distance (km)			
	Breed – Brood		Breed – Winter		Brood – Winter		\bar{x}	SD	Min	Max
	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD				
No	12.2 ^a	-	4.4 ^a	-	5.9	1.2	7.1	3.5	4.4	12.2
Non-targeted	35.8	24.6	30.5	8.4	15.8	5.7	28.6	17.4	10.5	59.6
Targeted	16.3	3.9	14.6	1.6	3.9	2.6	12.5	7.3	2.0	21.8

^aFrom 1 individual

and Merrill 2007, Berger et al. 2008), yet seldom used to evaluate sage-grouse or other tetronid home-ranges (see Burnett 2012 and Whitaker et al. 2007 for exceptions). Thus, we report both KDE estimates and mean MCP ranges for comparison with other sage-grouse populations.

We obtained home ranges for radio-marked sage-grouse using Geospatial Modelling Environment (GME version 7.2.0; Beyer 2012) in program R (R Development Core Team 2008). Home ranges were generated for GPS ($n = 11$) and VHF ($n = 48$) marked birds with ≥ 5 locations over annual ($n = 32$) and seasonal periods ($n = 24$). We excluded birds from KDE home range estimation when this criterion was not met. We generated KDEs using a 30-m cell size and the PLUGIN bandwidth (smoothing factor). We report total home ranges as the 99% density kernel areas that represent the maximum range used by a given bird. We deviated from the norm or reporting 95% density kernel utilization because the potential for predation risk is not diminished by excluding potential “exploratory” movement, and the trade-offs associated with foraging over the entirety of an animal’s range was critical to our assessment of a behavioral response (Mysterud and Ims 1998, Garshelis 2000, Powell 2000). We defined core use areas by the 25% density kernel contour (i.e., higher density of use like nesting).

Results

We obtained 6,309 GPS locations (September 2011 to March 2013) and 550 VHF locations (April to August 2011, 2012) from 59 sage-grouse in Bighorn Basin. Location points per

site were relatively equal for GPS-tagged hens ($n_{\text{no}} = 1,906$, $n_{\text{non-targeted}} = 2,167$, $n_{\text{targeted}} = 2,234$), but biased towards the 2 sites that had radio-tagged hens in both years for the VHF dataset ($n_{\text{no}} = 301$, $n_{\text{non-targeted}} = 39$, $n_{\text{targeted}} = 186$).

Movement rates and dispersal timing

Mean monthly movement rates fluctuated more and were higher at sites with predator removal (Figure 2). Mean annual movement rates for sage grouse hens were 1.8 times higher at the site with non-targeted removals and 2.4 times higher at the site with targeted predator removals (no = 0.36, SD = 0.16; non-targeted = 0.64, SD = 0.36; targeted = 0.87, SD = 0.35). Average distances traveled across all seasonal movements were 4 times longer at the site with non-targeted removal and 1.8 times longer at the site with targeted removal (Table 1). Nest distances were on average within 6 km of leks for all 3 sites (Figure 3), similar to but lower than average distances reported for other sage-grouse populations (7 km; Connelly et al. 2000, Holloran and Anderson 2005). We observed a higher proportion of hens nesting >7 km from capture leks in the targeted removal site (no = 16%, non-targeted = 10%, targeted = 29%), but no differences in lek-to-nest distance were detected across sites ($F = 1.12$, $df = 2$, $P = 0.33$). While 1 hen from the no predator removal site nested 16.9 km from the capture lek, the targeted predator removal site had the longest lek-to-nesting distance observed in the study, 18.2 km. Further, an additional 4 hens from the targeted predator removal site nested >10 km from their respective capture leks.

Average distances sage-grouse hens traveled over summer breeding, brood, and

Table 2. Average kernel density estimation (KDE) home ranges (km²) for GPS (*n* = 11) and VHF (*n* = 48) radio-tagged sage-grouse hens at 3 sites with varying levels of predator management in Bighorn Basin, Wyoming, USA, 2011–2013. Management levels were based on the intensity of predator removal efforts by USDA, APHIS, Wildlife Services at sites with no, non-targeted, and targeted coyote removal occurring between March 14 and June 15, 2012.

Coyote removal	Annual KDE			Breeding KDE			Brood KDE			Migration KDE				
	Core (25%)	Total (99%)	SE	Core (25%)	Total (99%)	SE	Core (25%)	Total (99%)	SE	Core (25%)	Total (99%)	SE		
	×	×	×	×	×	×	×	×	×	×	×	×		
No	2.2	54.8	16.8	0.1	0.04	0.1	0.4	0.3	7.6	4.7	0.3	0.1	6.1	1.9
Non-targeted	3.6	82.0	34.1	1.2	0.5	32.3	2.0	1.1	28.9	15.9	2.0	1.3	47.9	32.9
Targeted	5.0	101.6	21.7	1.2	0.6	23.2	0.1	0.04	3.2	1.2	6.5	1.8	130.3	12.4

winter use areas were longer in both the non-targeted and targeted predator management sites compared to the no removal site (Table 1; $F = 7.28$, $df = 2$, $P = 0.01$). We lacked sufficient sample sizes to formally test for differences among seasons, but movements from breeding to brood ranges were shorter in the no removal site compared to the non-targeted and targeted removal sites. Similarly, distances were also shorter from breeding to winter ranges (i.e., some birds transitioned directly to winter

areas during nesting periods, after failed nest attempts) between the no and non-targeted removal sites. However, the average distances traveled were shortest in the targeted removal site when birds were moving from brood to winter ranges (Table 1).

Seasonal movement occurred between June 24 and July 30 in 2011 (median dispersal date = July 12), and between May 8 and July 9 in 2012 (median dispersal date = June 13). Timing of movement to brood and inter-seasonal use areas (>5 km from nesting) varied between years by almost a month with sage-grouse moving on average 24 days earlier in 2012 than was observed in 2011 ($n = 8$, $SD = 9.17$, range 8–34 days). Sage-grouse moved on average 21 days earlier in the no removal site and on average 29 days earlier in the targeted predator removal site in 2012. Data were not available for 2011 in the non-targeted removal site for comparison.

Home range size

We observed no differences in annual home range size between sites (Table 2; $F_{core} = 1.60$, $df = 2$, $P_{core} = 0.22$; $F_{total} = 1.24$, $df = 2$, $P_{total} = 0.30$ for 25% core and 99% total use areas, respectively). Home range sizes used over the nesting period were marginally different between sites ($F_{core} = 2.88$, $df = 2$, $P_{core} = 0.10$; $F_{total} = 2.12$, $df = 2$, $P_{total} = 0.16$), where core nesting range sizes were 10 times larger at sites with coyote removal, and total nesting range sizes were 2–3 times larger. Range sizes used by sage-grouse appeared to be negatively associated with predator removal over the inter-seasonal (winter) period at both the core ($F = 16.15$, $df = 2$, $P = 0.004$) and total ($F = 26.12$, $df = 2$, $P = 0.001$) range use levels (Table 2). There were no differences in core or total range sizes used during the brood period between the no removal site and the targeted and non-targeted predator removal sites ($F_{core} = 0.71$, $df = 2$, $P = 0.52$; $F_{total} = 0.66$, $df = 2$, $P = 0.54$). We observed annual MCPs to be marginally different between sites ($F = 2.45$, $df = 2$, $P = 0.10$), with larger MCPs associated with increased predator removal levels (no = 18.7 km², non-targeted = 401.1 km², targeted = 240.5 km²).

Discussion

The increased movement rates and longer distances traveled between sites we observed may suggest a behavioral response relative to predator management. Most sage-grouse

hens reduced movement over the nest and brood periods (April to August), as would be expected during nest incubation and chick care time periods (Berry and Eng 1985, Connelly et al. 2011a, Dzialak et al. 2011). At all 3 sites, the lowest movement rates were observed in June, July, and August, which coincides with brooding and the presence of chicks. Although we did not directly collect nest and brood information for our GPS-tagged birds, we know of no other events or life-history traits that could result in consistently low rates of movement for female sage-grouse. We believe the spike in movement observed in May at the 2 predator removal sites to be the result of nest loss and subsequent early dispersal to winter range. The travel distances we observed may provide further support to the manifestation of a potentially negative association with predator removal effort. Though we could not examine travel distances relative to predator management within seasons, average movement distance between ranges over all seasons was higher at sites with non-targeted and targeted coyote removal. However, we believe the higher proportion of sage-grouse hens nesting above average distances from leks at the targeted removal site may be the result of additional stressors beyond predator management. The lack of response in sage-grouse hen survival and lower nest success relative to coyote removal effort observed at the targeted removal site further support likely additional factors influencing populations at that specific site (Orning 2014).

Variation in sage-grouse movements and space use could also be a behavioral response to predator disturbance. Because effort was prescribed to address sage-grouse predation, it is unclear if the mechanism for the response we observed was due to increased human activity associated with removal effort or from the absence of predators that were removed. Predator control efforts were pre-defined in our study sites, so we could only use a quasi-experimental design (i.e., randomly assign targeted treatment but other treatment levels were pre-defined). An experiment that could use a complete random design to assign treatment levels, and repeat treatments across multiple sites to avoid issues of pseudo-replication, would help tease apart these 2

potential causes. While we acknowledge a large amount of variation at all 3 sites due to our small sample sizes, the general trend appeared to support higher movement rates and further distances traveled with increased predator management efforts. This could have energetic costs and long-term fitness implications for sage-grouse. Energetic costs from increased movement and point-to-point travel distances could manifest as reduced forage time and greater energy expenditures associated with flushing or movement away from disturbing activity, which could influence overwinter survival or reproductive capability (Vehrencamp et al. 1989, Beck et al. 2006). Further, overall increased movement due to disturbance may secondarily increase exposure and risk of predation (Dzialak et al. 2011).

While we observed a clear shift in the timing of inter-seasonal movements between years, we lacked sufficient multi-year data within each site to evaluate if the observed shift was in response to higher short-term management or a response to natural climate and environmental variation (i.e., drought response; Fischer and Reese 1996). For instance, the spring of 2011 was colder, had more rainfall, and had longer persisting snow, whereas the spring of 2012 had little remaining snow from winter, warmer temperatures, and less rainfall, drying out nest and brood areas earlier. This annual weather variation between the years might account for some of the differences in the timing of seasonal movements we observed. However, sage-grouse habitat use is influenced by landscape-scale factors (Doherty et al. 2008), and disturbance from human activity has been linked to avoidance of wintering habitats (Doherty et al. 2008), longer nest distances from leks (Lyon and Anderson 2003), and lek abandonment (Holloran 2005, Blickley et al. 2012, Hess and Beck 2012b). These demonstrated sensitivities to human use suggest the alterations in the timing of inter-seasonal movements and space use we observed could also be in response to predator management activities.

Altered behavioral patterns during critical life stages, like nesting, may suggest a response to long- and short-term anthropogenic features. We observed sage-grouse in Bighorn Basin to have larger home range sizes during nesting and overwinter periods relative to predator

management effort. Our results also suggest sage-grouse may be restricting their range use in response to anthropogenic features while simultaneously requiring larger areas to meet specific life-stage requirements (e.g., human use and poor quality habitat or habitat fragmentation). Large amounts of variation resulting from our sample size limited our ability to detect differences over several scales for sage-grouse home range sizes in Bighorn Basin. Higher samples of GPS-marked sage-grouse, monitored for longer periods, would reduce variation and enhance understanding of sage-grouse range use in response to human activities. Though further examination is needed to clarify the association between specific human stressors and sage-grouse space use, our findings parallel emerging evidence on the disturbance effects of anthropogenic features (Crawford et al. 2004, Blickley et al. 2012, Hess and Beck 2012b) and may suggest activities like predator management can influence behavioral and spatial aspects of sage-grouse ecology.

We observed a negative association between annual home range size and predator management. Congruently, Whitaker et al. (2007) identified home range reductions when human disturbance was reduced (hunting closure) for ruffed grouse (*Bonasa umbellus*), suggesting that alterations in home range size can be relative to human factors beyond just resource availability or limitation. We also observed substantively less variation in brood range size in the targeted removal site compared to the relatively equal variation in both the non-targeted and no removal sites. Alternative to expected inverse relationships to resource availability, it is possible the observed smaller ranges and high variability were indicative of disturbing activity restricting habitat availability. It follows that the identification of factors associated with variation in home range size could help identify resource limitations or disruptive activity (Whitaker et al. 2007).

Increasing natural and anthropogenic disturbances leading to continued habitat loss and fragmentation affect not only sagebrush-steppe communities, but the behavior and ecology of sagebrush-dependent species like sage-grouse (Connelly and Braun 1997, Connelly et al. 2004, Walker et al. 2007, Aldridge et al. 2008). We quantified home range size of sage-grouse and movement in Bighorn Basin at 2 spatial

scales by examining overall and core range size over annual (landscape scale) and seasonal (patch scale) time periods. By conducting our study in Bighorn Basin, we could examine the question of whether intensifications in predator management may influence sage-grouse behavior (home range, movement patterns, and seasonal movement).

Sage-grouse declines invariably include a multitude of complex interactions (Crawford et al. 2004, Moss et al. 2010, Hagen 2011). Thus, identifying changes in behavior as they relate to human activities is imperative to test and understand to propagate the most effective management for a specific population's system. Management actions must consider crucial habitat for important seasonal life stages (i.e., nesting), as well as the direct and indirect effects that actions taken to improve a population's growth (i.e., predator removal) will have on behavior, habitat use, and ultimately, long-term persistence.

Management implications

The current study was conducted at a local scale of Bighorn Basin, Wyoming. We were unable to repeat treatments across sites due to logistical limitations associated with the size of the study area. Future studies should implement a complete random experimental design, repeat treatments across sites, and focus on broad-scale patterns to better understand the effects of human activity associated with management actions on sage-grouse populations. However, our findings suggest more attention is needed on the tradeoff between management activity aimed to mitigate factors that have negative effects and the impacts the added human activity required to conduct such actions may have on sage-grouse. Managers should consider whether proposed actions will have a large enough positive effect to counter the cost imposed by the disturbance necessary to implement the action. Therefore, how and if predator removal is prescribed to improve vital rates of sage-grouse will need to be considered on a population-level basis, as it will be critical to consider the magnitude of positive and negative effects to both demographic and behavioral responses.

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