Adon Big Game Predation Study

2015 Progress Report

Campbell County Predator Management Board

May 13, 2016

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1 INTRODUCTION

The Campbell County Predator Management Board (CCPMB) recognizes the importance that the mule deer as well as other big game animals play in the local economy and ecosystem. Over the last several decades, many landowners and sportsman in northeastern Wyoming have commented on the decline of mule deer (and other games species) numbers. The CCPMB believes that this decline may have a correlation with the 1972 executive order issued by President Nixon banning the use of all toxicants for predation control measures and the high numbers of predators (coyotes, bobcats, and mountain lions) in the area.

While the Wyoming Game and Fish Department (WGFD) monitors and manages overall herd health and numbers, budget restrictions limit their ability to focus on specific sub-populations. In 2013, the CCPMB initiated a five-year study analyzing the impacts that different levels of predation control may have on big game populations including mule deer, white-tailed deer, pronghorn antelope, elk, and wild turkeys. Habitat Management, Inc. was contracted to complete the big game surveys and prepare annual reports. CCPMB completes the predator control activities and provides those data to Habitat Management. This report summarizes the methods and results of the first three years (fall 2013 – spring 2015) of this study and why it is important to continue funding for the project.

2 METHODS

The Adon Big Game Predation Study (ABGPS) is located in Campbell County, Wyoming (Figure 1). Two study areas (a Treatment Area and a Non-Treatment Area) were located by the CCPMB. The Treatment Area covers approximately 132,989 acres and the Non-Treatment Area is about 2/3 of this size at 87,694 acres.

Starting in 2013, ground and aerial surveys of game species were conducted in both areas each fall. Additionally, aerial predator control was conducted each spring (starting in the spring of 2014).

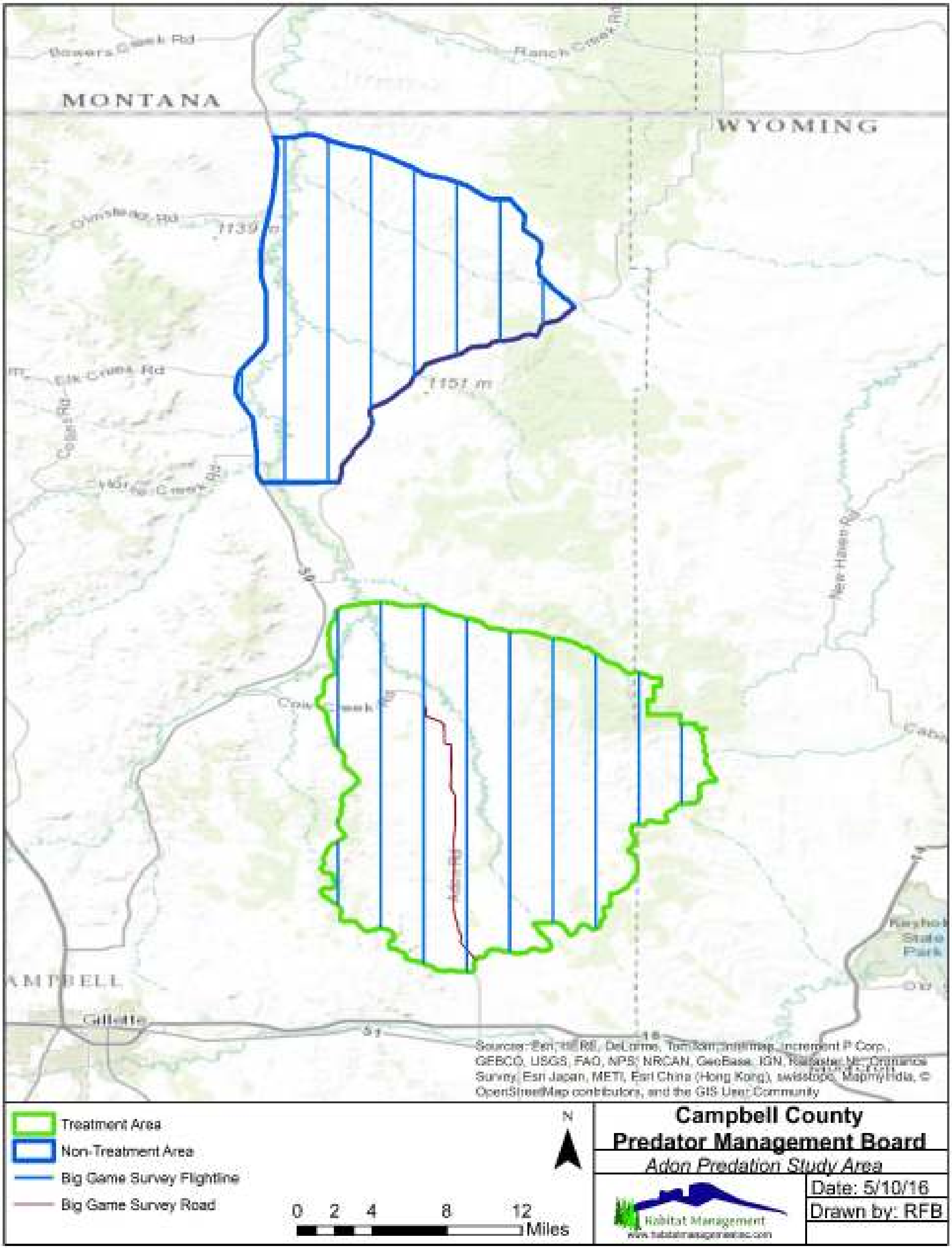
2.1 Big Game Surveys

Big game surveys were conducted by Habitat Management, Inc. in the fall of 2013, 2014 and 2015. Both ground and aerial surveys were completed in 2013 and 2014, and aerial surveys were completed in 2015.

2.1.1 Ground Surveys

Ground surveys were conducted in vehicles along county maintained roads in each study area (Figure 1). Approximately 14.4 miles of road were surveyed in each area. Counts were made only out of the driver's side of the vehicle heading from the south to the north to prevent duplicate counts. Survey were conducted during the early morning or late afternoon during favorable light conditions and with the aid of binoculars and/or spotting scopes. All game species observed were counted and classified by sex (buck/bull or doe/cow) and age (adult or fawn/calf), when possible.

Figure 1: Adon Big Game Predation Study Location Map



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

2.1.2 Aerial Surveys

Aerial line transect surveys were conducted along parallel established transects spaced approximately 1.5 miles apart (Figure 1). Nine flight line transects were established in the Treatment Area totaling approximately 125.9 miles and eight flight line transects were established in the Non-Treatment Area totaling 83.2 miles.

Surveys were conducted using a helicopter from a consistent altitude of 200 ft above ground level and during good light conditions in the early morning or late afternoon. When possible, species were classified as bucks/bulls, does/cows, or fawns/calves.

2.1.3 Estimating Density/Trend

Because conducting a census of an entire population is not feasible, a model was used for estimating big game density based on strip transect sampling. This equation was used to calculate an estimated density which allows for comparison between the two study areas of different sizes.

$$\frac{Miles\ Surveyed * 72.72}{Big\ Game\ Individuals\ Observed} = Acres\ per\ Big\ Game\ Individual$$

2.2 Predation Control

Predator control was conducted in the spring of 2014, 2015, and 2016 using aerial hunting methods. A helicopter was used to locate coyotes and their dens along with a ground crew in radio contact. Kill locations were documented with a GPS including the number of animals taken.

The CCPCB has landowner agreements for predation control in the non-treatment area, so control activities occur in both areas. However, active control is focused on the treatment area and an effort is made to take at least twice as many animals in this area.

3 RESULTS & DISCUSSION

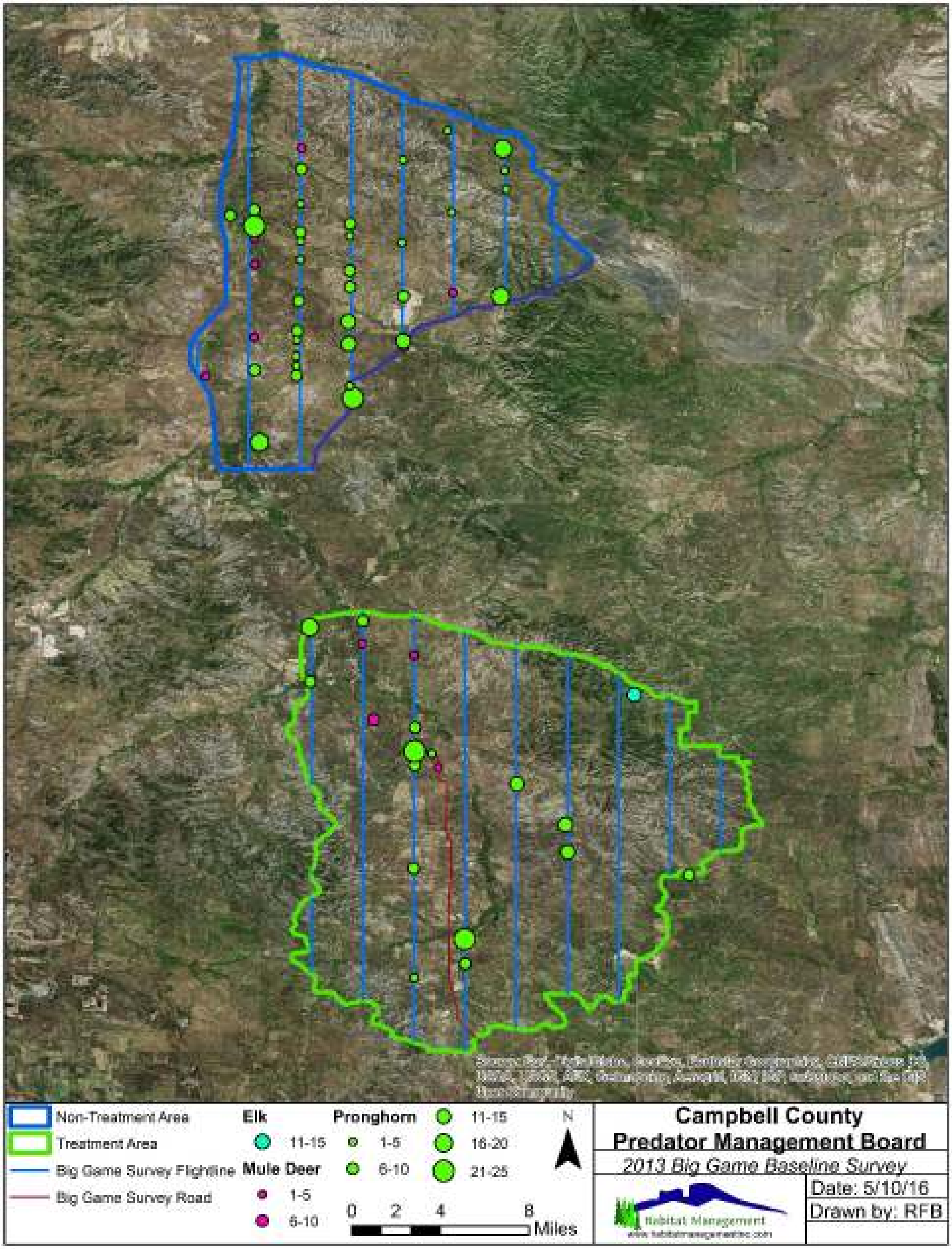
3.1 Big Game Surveys

Big game surveys were conducted in the fall of 2013, 2014 and 2015. Population estimates in the fall of 2013 serve as a baseline number before predator control activities began (Figure 2). To compare the Treatment Area to the Non-Treatment Area, the count data were converted to density estimates using the equation in Section 2.1.3. These estimates provide a number of acres per individual animal observed, thus an increase in the resulting number represents a decrease in animal density.

3.1.1 Ground Surveys

Ground surveys were conducted in the fall of 2013 and 2014. In 2013, the mule deer density was considerably higher in the Treatment Area than the Non-Treatment Area, but the pronghorn population was slightly denser in the Non-Treatment Area resulting in a relatively similar big game density in both areas (Table 1). No white-tailed deer or elk were observed in ground surveys.

Figure 2: Baseline Big Game Survey Fall 2013



In the fall of 2014, the density of mule deer in the Treatment Area was more than three times greater than that observed in 2013 while the population increase in the Non-Treatment area was only about 33% (Table 1). There was also a slight increase in pronghorn density in both areas from 2013 to 2014. Pronghorn populations increased by 55% in the Treatment Area and 31% in the Non-Treatment Area.

Table 1: Big Game Ground Survey Results 2013-2014

	Treatment Area				**Non-Treatment Area**			
	Fall 2013		***Fall 2014***		***Fall 2013***		***Fall 2014***	
Species	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*
Mule Deer								
Does	3	349.1	16	65.4		0.0	3	349.1
Bucks	1	1,047.2	4	261.8	3	349.1		0.0
Fawns	7	149.6	18	58.2		0.0	1	1,047.2
Total	***11***	***95.2***	***38***	***27.6***	***3***	***349.1***	***4***	***261.8***
Pronghorn Antelope								
Does	9	116.4	6	174.5	18	58.2	16	65.4
Bucks	3	349.1	3	349.1	4	261.8	2	523.6
Fawns	2	523.6	3	349.1	2	523.6	22	47.6
Unidentified	6	174.5	19	55.1	11	95.2	6	174.5
Total	***20***	***52.4***	***31***	***33.8***	***35***	***29.9***	***46***	***22.8***
Total	**31**	**33.8**	**69**	**15.2**	**38**	**27.6**	**50**	**20.9**

3.1.2 Aerial Surveys

Aerial surveys were conducted in the fall of 2013, 2014, and 2015. The 2015 aerial surveys were completed on October 1, 2015. A total of 23 mule deer and 189 pronghorn were observed in the Treatment Area while only 2 mule deer and 23 pronghorn were observed in the Non-Treatment Area. Density estimates from aerial surveys tended to be lower than those based on ground surveys (that is each animal had a greater number of acres), but showed similar trends. In 2013, the mule deer density estimated from the aerial surveys was actually greater in the Non-Treatment Areas which was the opposite of what was observed in the ground surveys (Table 2). The population increase from 2013 to 2014 was also more pronounced in the aerial surveys with the population increasing over 9 times in the Treatment Area and 70% in the Non-Treatment Area. From 2014 to 2015 the mule deer population dropped by 65% in the Treatment Area and over 90% in the Non-Treatment Area.

Pronghorn populations in the Treatment Area have been relatively consistent in each year's aerial survey (Table 2). However, in the Non-Treatment Areas they have declined by 8% from 2013 to 2014 and by 87% from 2014 to 2015.

Some elk were observed in the Treatment Area in 2013 and 2014, but none were observed in 2015 and none were observed in the Non-Treatment Area in any year. A few white-tailed deer were observed in the Non-Treatment Area in 2013. However, given the low and inconsistent count number it is not possible to evaluate trends for these species.

Table 2: Big Game Aerial Survey Results 2013-2015

	Treatment Area						**Non-Treatment Area**					
	Fall 2013		***Fall 2014***		***Fall 2015***		***Fall 2013***		***Fall 2014***		***Fall 2015***	
Species	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*	*Count*	*Estimated Density (Ac/Animal)*
White-Tailed Deer												
Does							4	1512.6				
Bucks							1	6050.3				
Fawns												
Total	***0***	***0***	***0***	***0***	***0***	***0***	***5***	***1210.1***	***0***	***0***	***0***	***0***
Mule Deer												
Does	6	1525.9	24	381.5	18	508.6	10	605	10	605	2	3025.2
Bucks			6	1525.9	5	1831.1	2	3025.2	6	1008.4		
Fawns	1	9155.4	35	261.6			2	3025.2	8	756.3		
Total	***7***	***1307.9***	***65***	***140.9***	***23***	***398.1***	***14***	***432.2***	***24***	***252.1***	***2***	***3025.2***
Pronghorn Antelope												
Does	68	134.6	101	90.6	167	54.8	141	42.9			23	263.1
Bucks	3	3051.8			22	416.2	11	550				
Fawns							43	140.7				
Unidentified	94	97.4	104	88			47	128.7	171	35.4		
Total	***165***	***55.5***	***205***	***44.7***	***189***	***48.4***	***242***	***25***	***171***	***35.4***	***23***	***263.1***
Elk												
Cows	14	654	15	610.4		0		0		0		0
Bulls	1	9155.4		0		0		0		0		0
Calves		0		0		0		0		0		0
Total	***15***	***610.4***	***15***	***610.4***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
Total	**187**	**49**	**285**	**32.1**	**212**	**43.2**	**261**	**23.2**	**195**	**31**	**25**	**242**

3.2 Predation Control

Spring 2016 predation control was conducted on February 10th, April 11 – 13th, and April 20th, 2016. A total of 59 coyotes were killed in the Treatment Area and 36 in the Non-Treatment Area (Table 3, Figure 3). Predation control was only completed on the Treatment Area in 2014 and while predation control was completed in 2015, these data are not available at this time. However, we can note, based on the data available, that coyote population density has decreased in the Treatment Area by 36% from 2014 to 2016.

Table 3: Coyote Aerial Hunting Results 2014-2016

	Treatment Area			**Non-Treatment Area**		
Species	*Spring 2014*	*Spring 2015**	*Spring 2016*	*Spring 2014*	*Spring 2015**	*Spring 2016*
Coyotes						
Count	91		59			36
Estimated Density (Ac/Animal)	1899.8		2254.1			3694.1

* Data are unavailable.

4 TREND ANALYSIS

Overall big game density increased from 2013 to 2014 and then decreased substantially from 2014 to 2015 (Table 4). Only mule deer and pronghorn were observed consistently enough to evaluate trends. The trends appear more pronounced for mule deer than for pronghorns, but were similar for both species. Coyote densities have decreased substantially in the Treatment Area during the past three years.

Table 4: Big Game Estimated Density Summary (Ground + Aerial Surveys) 2013-2015

	Treatment Area			**Non-Treatment Area**		
	Fall 2013	***Fall 2014***	***Fall 2015***	***Fall 2013***	***Fall 2014***	***Fall 2015***
Species	*Acres/Animal*					
White-Tailed Deer				1,419.5		
Mule Deer	566.8	99.1	398.1	417.5	253.5	3025.2
Pronghorn	55.1	43.2	48.4	25.6	32.7	263.1
Elk	680.2	680.2				
Total	46.8	28.8	43.2	23.7	29.0	242

Figure 4 and Figure 5 show trends in the density of the big game and coyotes as animals/acre since this study began. While overall big game densities were greater in the Non-Treatment Area at the beginning of the project they have declined steadily in this area. In 2015, the big game density in the Non-Treatment Area was substantially lower than it was in the Treatment Area and the same was true for coyote density. The peak in big game density in 2014 and subsequent decline in 2015 may be due to predation control efforts or other factors such as regional climate fluctuations.

Figure 3: Coyote Survey Spring 2016

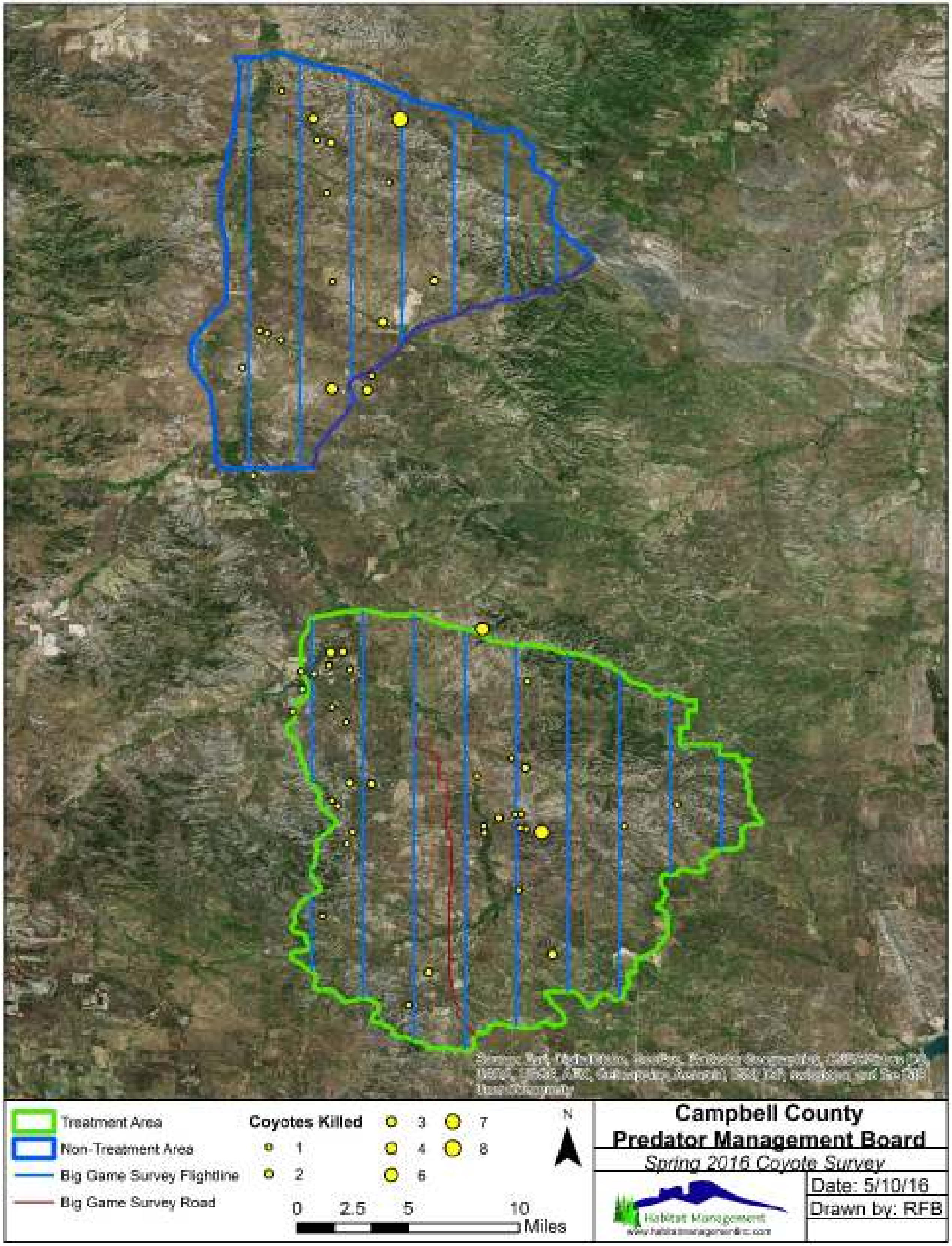
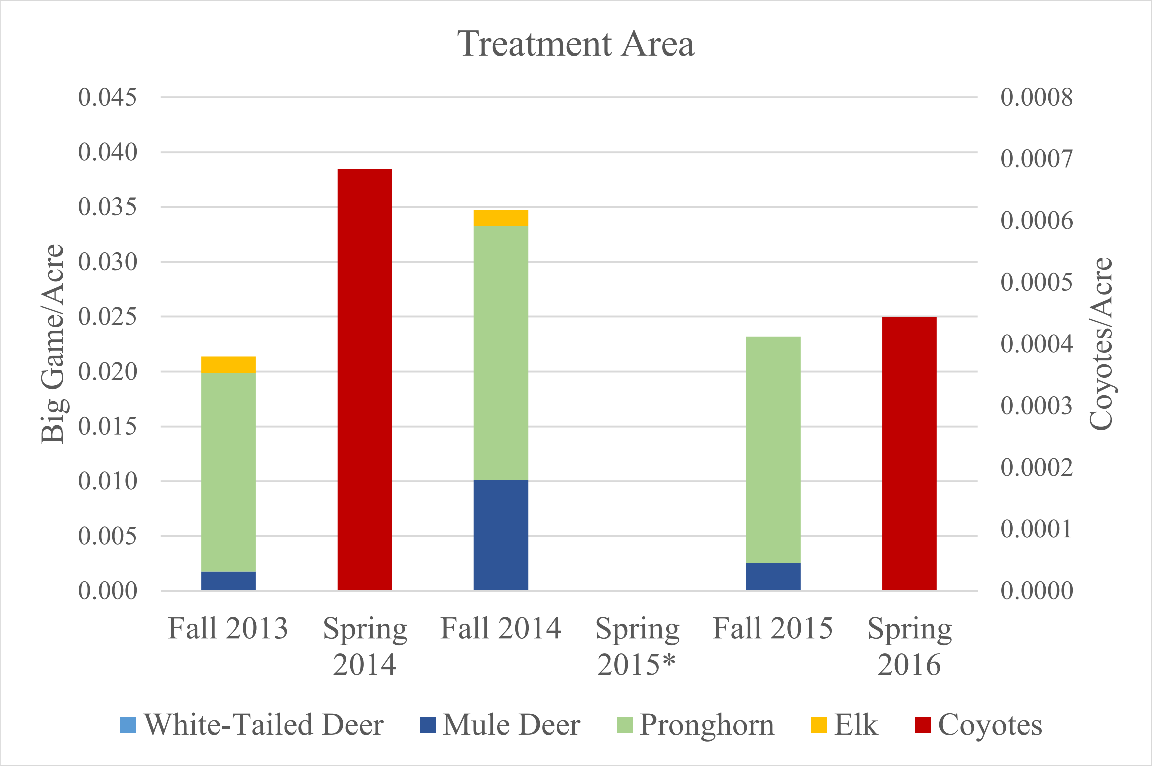
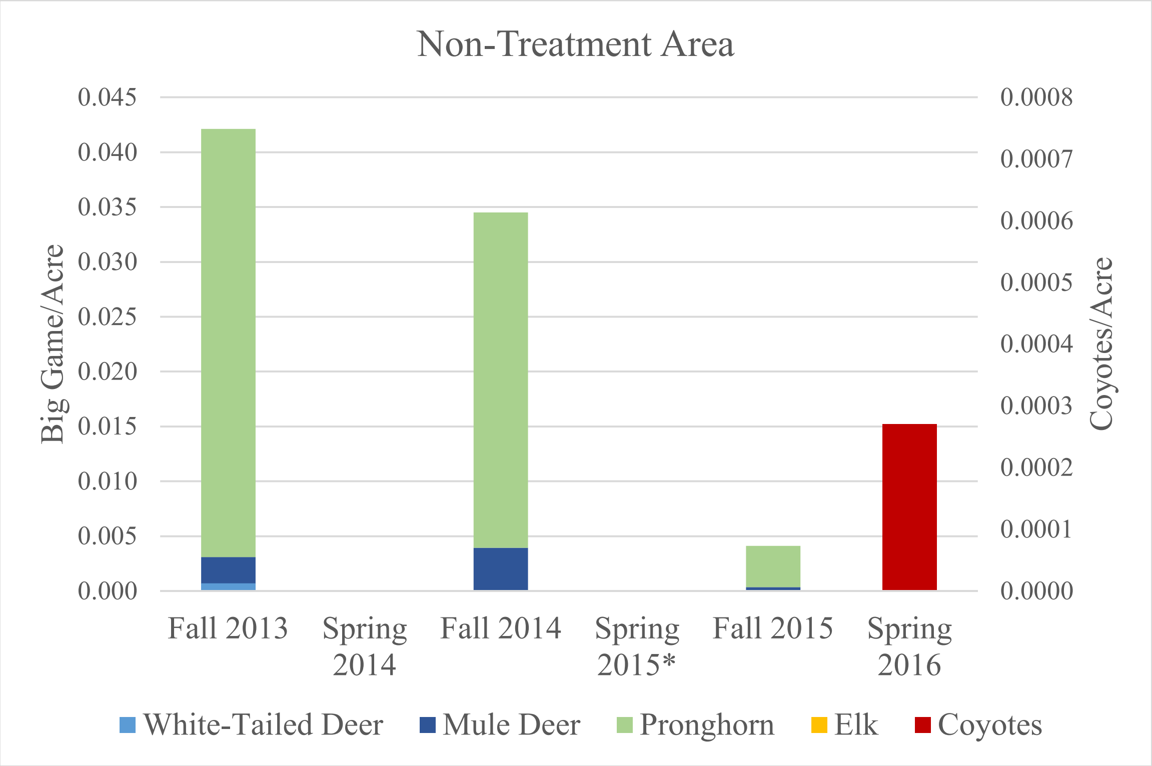


Figure 4: Treatment Area Big Game & Coyote Density Trends 2013-2016



* Data are unavailable.

Figure 5: Non-Treatment Area Big Game & Coyote Density Trends 2013-2016



* Data are unavailable.

5 RECOMMENDATIONS

With three years of data, it is possible to suggest that some trends are developing. These early results suggest that the predation control efforts may be resulting in the desired increase in big game populations within the Treatment Area. It is recommended that this project be continued to complete the full five-year planned schedule to allow for more detailed analysis of trends. In order to complete the project CCPCB asks for continued funding. Currently CCPCB looks to use continued funding for predator control as defined in section 6.2 and big game surveys as defined in section 6.3 to further enhance the current treatment area and provide proper statistical data to show the importance of the project. Without continued funding the project lacks credible statistical data to correlate predator control and the prevention of big game population decline.

6 PROJECT DESIGN

The CCPMB is anticipating a 2 year project implementation timeline to finish the 5 year project goal. The project has been broken down into 2 tasks detailed below.

6.1 Phase 1 – Predation Control

Lethal control methods are required to stop coyote depredation or to reduce the coyote population in an area. Various lethal control options are available, including traps, snares, shooting, denning and toxicants. The effectiveness, selectivity, and specificity of each method will be considered before being utilized. Each method requires varying degrees of skill and experience to be made effective. Usually a combination of control methods is most effective. (Dorsett, 2013)

All of our predator controls methods will be done by qualified and professional trappers. All locations of predators removed from the treatment area will be documented via GPS location. The CCPMB still has landowner agreements for predation control in the non-treatment area, therefore, control will continue in that area. However, for the treatment area, the amount of active control will be twice as much, and we will use the following methods as the non-treatment area.

Currently the CCPMB administers predation control on approximately 1.8 million acres of land. As a part of the declining big game population in the area, the project design is to increase the amount of predation control on the treatment area compared to the non-treatment control area. The various treatments are listed below.

6.1.1.1 4.1.1 Leg hold Traps

The steel leg hold trap is a mechanical capture device that is a versatile tool for coyote control. Traps can be set to work in various situations. A No. 3 or No. 4 trap size is recommended for coyotes.

6.1.1.2 4.1.2 Snares

The snare is a mechanical device consisting of flexible wire cable loop and locking device that tightens around the coyote's body as it passes through the loop. Snares are made of flexible cable, usually 1/16 to 3/32 inches in diameter. The length of a snare varies, but they usually are between 32 and 48 inches long. (Dorsett, 2013)

6.1.1.3 4.1.3 Calling and Shooting

Hunting coyotes by attracting them within shooting range with predator calls can be effective in some cases. Calling coyotes during daylight, especially in the early morning hours, is best. Calling and shooting is a selective tool, but requires some skill. Calling success improves in areas of high coyote populations. To be successful in areas of low coyote density, it is critical to be in the right place at the right time when you call. (Dorsett, 2013)

6.1.1.4 4.1.4 Denning

Denning is the practice of removing coyote pups and/or the parent coyote from the den during whelping season, from April through June. The primary purpose of denning is to reduce or stop predation by adult coyotes that are killing large mammals to feed their pups. Normally if the pups are removed the predation by the coyote will stop (Crosby and Wade, 1978). Denning is a highly selective technique, however, tracking skills and knowledge of coyote behavior is required for the den hunter to be consistently successful.

Aerial hunting is also a good method for locating coyote dens. A ground crew with radio contact with the aircraft should be used in conjunction with the aerial den hunting. The ground crew can check out possible den sites located by the aircraft. Aircraft are especially useful for den hunting in areas where tracking is difficult such as in rocky terrain. Areas where dens have been found previously should be checked out each season, often coyotes may den in the same area if not in the same den site. (Dorsett, 2013)

6.1.1.5 4.1.5 Hunting with Dogs

Sight-hunting dogs can be used to hunt coyotes in open, flat country with good visibility and limited fencing. Trail hounds can also be used for coyote hunting, and are especially effective if used in conjunction with aerial hunting. The trail hounds can be used to move coyotes out of rough or heavily-vegetated terrain for aerial hunters. (Dorsett, 2013)

6.1.1.6 4.1.6 Aerial Hunting

Aircraft, either fixed-wing or helicopter, are often the tool of choice to try to get immediate relief from coyote predation, or to quickly reduce a high coyote population. Aerial hunting is highly selective for coyotes, and can be used to take specific depredating coyotes. (Dorsett, 2013)

Lethal control methods are required to stop coyote depredation or to reduce the coyote population in an area. Various lethal control options are available, including traps, snares, shooting, denning and toxicants. The effectiveness, selectivity, and specificity of each method will be considered before being utilized. Each method requires varying degrees of skill and experience to be made effective. Usually a combination of control methods is most effective. (Dorsett, 2013)

6.2 Phase 2 Aerial Surveys, Mapping and Reporting

Habitat Management Inc will conduct fall aerial surveys to continue data collection for reporting and mapping. These reports will provide statistical data presenting the results of the aerial

Aerial line transect surveys will be conducted along parallel established transects spaced approximately 1.5 miles apart (Figure 1). Nine flight line transects were established in the Treatment Area totaling approximately 125.9 miles and eight flight line transects were established in the Non-Treatment Area totaling 83.2 miles.

Surveys were conducted using a helicopter from a consistent altitude of 200 ft. above ground level and during good light conditions in the early morning or late afternoon. When possible, species were classified as bucks/bulls, does/cows, or fawns/calves.

6.2.1 Estimating Density/Trend

Because conducting a census of an entire population is not feasible, a model was used for estimating big game density based on strip transect sampling. This equation was used to calculate an estimated density which allows for comparison between the two study areas of different sizes.

7 CURRENT CONTRIUBUTERS

Currently, the CCPMB has several donations, and are very appreciative of those who have supported. Below is a listing of the current project contributions and amounts. We are confident that additional contributors will participate in the project.

Table 1: Current Funding

2015 Contributing Party	Amount
ADMB	$18,055.00
Wyoming Sportsman's Group	$10,500.00
Habitat Management, Inc.*	$1,000.00
Total Funding	$29,555.00
Remaining Budget	**$10,495.88**

8 ESTIMATED COST

In a short time we have had generous support for the project proposed by the Campbell County Predator Management Board. The local sportsman and wildlife enthusiasts understand how valuable the efforts are. In this area of northeast Wyoming, public land is a premium. Much of the population depends on the relative small amount of public land in the area to recreate. This table depicts the funding needed to continue the project throughout the next year.

Table 2: Estimated Project Cost

Phase 1 Tasks	**Estimated Cost**
Task 1 – Define Scope of Work, Develop Monitoring Protocols, Build Maps	$500.00
Task 2 – Help Secure Funding For Project*	In Kind
Task 3 – 2015/16 Predation Control (36 Plane flight hours, gunner, trapper)	$31,060.00
Phase 1 Total	$31,560.00
Phase 2 Tasks	**Estimated Cost**
Aerial Survey	$2,100.00
Reporting and Mapping	$2,500.00
Phase 2 Total	$4,600.00
Estimated Total of Project	**$36,160.00**
Additional Funding Needed	**$25,644.12**

*In Kind services by Habitat Management, Inc. Up to $1,000.00

Monitoring causes of mortality, predation rates, and space use of greater sage-grouse in the Bighorn Basin

Final Report to the Meeteetse Conservation District

Prepared By:

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USDA APHIS Wildlife Services

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Monitoring causes of mortality, predation rates, and space use of greater sage-grouse in the Bighorn Basin.

Greater sage-grouse (hereafter sage-grouse) are a species requiring large expanses of native sagebrush rangelands to persist. Wyoming is one of 11 western states and 2 Canadian provinces where sage-grouse currently occupy. Wyoming contains a large contiguous expanse of native sagebrush rangelands and 37% of the overall sage-grouse population representing 64% of the eastern population of sage-grouse. Therefore, understanding sage-grouse population dynamics and population growth rates in Wyoming is important for the conservation of the species.

Observed population declines in sage-grouse have led to concern for the persistence of populations throughout the currently occupied range. In 2010, the U. S. Fish and Wildlife Service determined that listing the range-wide sage-grouse population is warranted but precluded by higher priority actions. In 2011, Meeteetse Conservation District (MCD) entered into a cooperative service agreement with the National Wildlife Research Center (NWRC) to investigate the effects of predators on sage-grouse in the Bighorn Basin of northwestern Wyoming. Originally, study sites were chosen based on expected levels of predator control by Wildlife Services for livestock and big game protection; however, subsequent analysis revealed that predator control by hectare (i.e., size of study sites) did not differ statistically. Thus, predator management for livestock and big game continued as necessary and was considered equal across sage-grouse study areas. From 2011-2015, we captured and marked 288 breeding female sage-grouse with either VHF radio or GPS transmitters across 5 study sites (Figure 1). We used standard statistical analysis techniques to estimate rates of female survival, female cause-specific mortality, nest survival, and chick survival. We used motion-activated cameras at nests to identify specific nest predators and estimate cause-specific mortality rates of nests.

A full report from 2011-2014 is attached as an addendum to this report. It was previously submitted to MCD and Wyoming Wildlife and Natural Resources Trust. Data from 2015 were not able to be incorporated into the entire dataset due to insufficient data points. A key contributing factor was the large amount of rain received in Bighorn Basin in the spring of 2015. We captured 93 females on 6 leks across 5 study sites between March 28 and April 4, 2015 (Table 1). We deployed 82 VHF and 6 GPS transmitters on 88 of these hens. Frequent and heavy rains that persisted following capture made ranch roads inaccessible for long periods of time. Thus, we likely missed several nest attempts, and were often prohibited from checking on adults and nests for fear of causing property damage to cooperating landowners. A total of 29 nests were identified between 4/14/15 and 6/18/15, and number of nests found per study site ranged from 2 on Bud Kimball to 10 on Major Basin. Of the 29 nests, known fates and fate dates (i.e., hatch or fail) were found for 15 nests. Of those, 6 hatched and 9 failed. As in previous years, nest fates included egg destruction by coyote, badger, and common raven. If nest abandonment or nest failure due to hen mortality occurred in 2015, we were not able to detect it.

Estimates of chick survival require hatch date and 3 or more scheduled flushes with the brood hen. Of nests with known success fate, we had 3 flushes with 2 brood hens. Two other brood hens had 1 flush each, and 8 radio-marked hens were incidentally flushed with chicks but their nests were never found.

Hen survival and cause-specific mortality also could not be calculated for 2015 due to gaps between last know signal and transmitter recovery. In many cases, scavenging, decomposition, and missing carcasses were noted when transmitters were recovered.

Although the 2015 could not be joined with the previous years' data, our results from 2011-2014 remain informative and have not changed since the last repot. In summary, adult hen survival differed between breeding season and winter but did not differ across site, year, or by bird age. Hen survival in breeding seasons was 0.62 (SE = 0.03) and over-winter survival was 0.92 (SE = 0.03). Golden eagles and coyotes were known predators of adult hens, although cause-specific mortality rates for breeding females did not differ during the breeding season. Nest survival differed across study sites but did not differ across years or by bird age. Site-specific nest survival rates were, from highest to lowest, 0.56 (SE = 0.05) at Fifteen Mile, 0.45 (SE = 0.03) at Oregon Basin, 0.35 (SE = 0.05) at Bud Kimball, 0.33 (SE = 0.03) at Major Basin, and 0.20 (SE = 0.01) at Polecat Bench. The greatest cause of nest failures at Fifteen Mile, Oregon Basin, and Polecat Bench was due to coyote depredation, although nest loss to ravens almost equaled loss to coyotes at Polecat Bench. The greatest cause of nest failure at Major Basin was due to badger depredation. The greatest cause of nest failure at Bud Kimball was due to abandonment. Chick survival rate for 2011-2014 was 0.54 (SE = 0.03).

We used Population Viability Analysis (PVA) models to estimate population growth rates for 4 of 5 study sites, and full details are described in the previous report (attached). According to our estimates, sage-grouse populations at Fifteen Mile, Oregon Basin, and Major Basin are increasing, while the population at Polecat Bench is decreasing. Under these circumstances the mean time until extinction was greater than 50 years at Fifteen Mile, Oregon Basin, and Major Basin and 20 years (SE = 0.10) at Polecat Bench.

Near the completion of this study, the US Fish and Wildlife Service found that the greater sage-grouse remains relatively abundant and well distributed throughout the species' range and does not face the risk of extinction now or in the foreseeable future. We compared or demographic parameter estimated to other documented estimates from across the sage-grouse range. We found that, in general, our estimates were within the average reported range for specific demographic parameter. Our estimates often were near the upper reported average estimate and sometimes exceeded documented estimates from other studies, suggesting that current land-use practices do not have a negative impact on sage-grouse populations across most of the Bighorn Basin.

While the species is not viewed at risk of extinction, risk remains for local sub-populations and further research is necessary. The nest survival estimate at Polecat Bench was very low when compared to other sites within this study and documented from other parts of the sage-grouse range. Our PVA modelling suggested that a reduction in nest loss to common ravens could affect an increase in population growth as long as raven depredation of sage-grouse nests is additive rather than compensatory. Thus, our exploratory analyses for this site suggest management effective at controlling the raven population could result in a turnaround for this population.

This study was conducted in conjunction with Meeteetse Conservation District and was supported in part by USDA APHIS Wildlife Services Wyoming, the Bighorn Basin Conservation Districts, the Bighorn Basin Predator Management Districts, WYO-BEN, BreitBurn Operating LP, Marathon Oil Company, Fidelity Oil Company, Wyoming Animal Damage Management Board, V Ranch, Belden Ranch, Park County Farm Bureau, Wyoming Game and Fish Department, U. S. Bureau of Land Management, the Shoshone National Forest, and Wyoming Wildlife and Natural Resources Trust. In-kind support through land access was provided by numerous landowners in northwestern Wyoming. This was a very large undertaking and failure to mention any cooperator or stakeholder is unintentional.

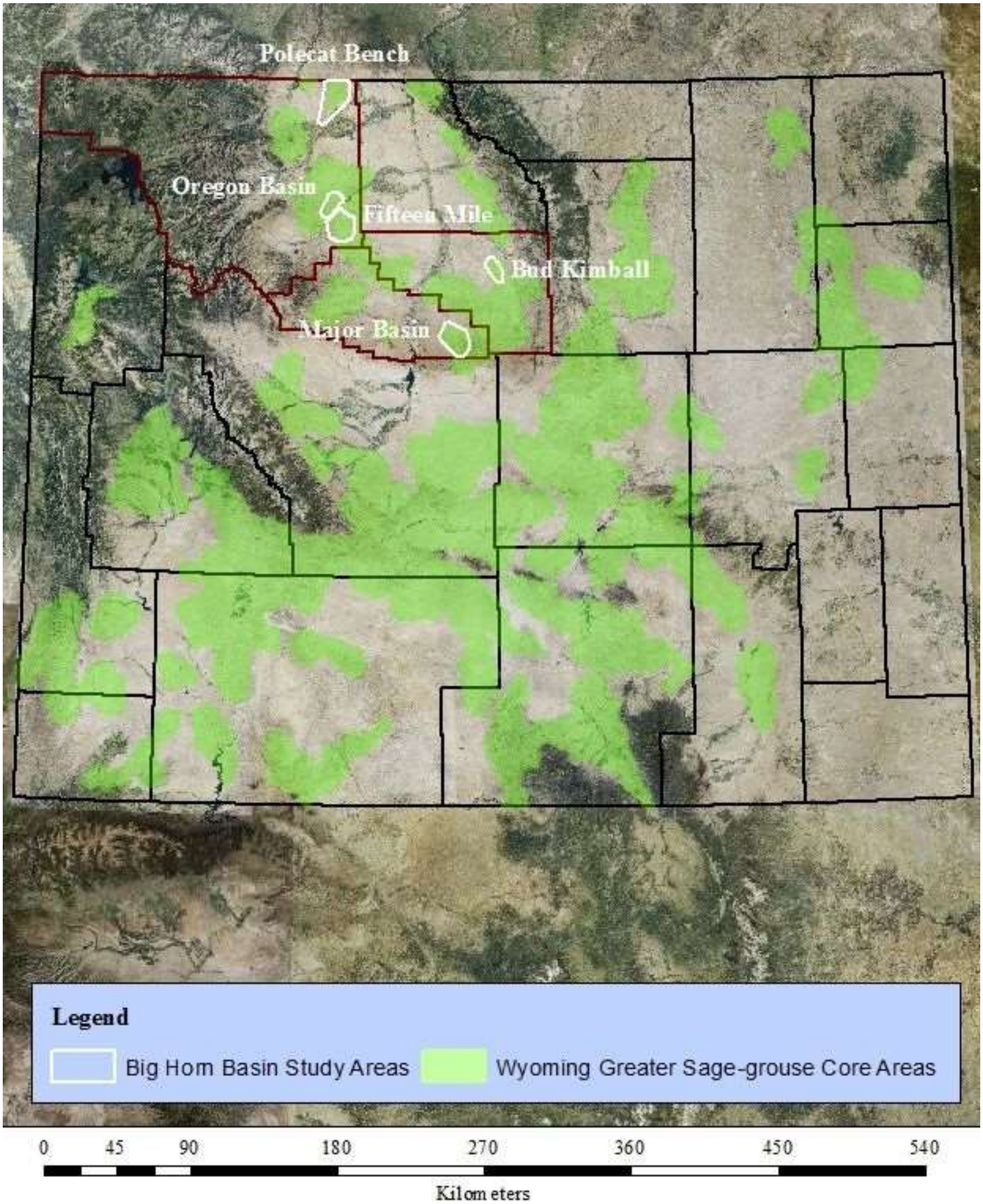

Figure 1. Sage-grouse study sites in the Bighorn Basin, Wyoming where demographic data were collected from marked females, 2011-2015.

Table 1. Number of individual female sage-grouse captured on study sites across the Bighorn Basin, Wyoming by study site and year 2011-2015.

Study Site	Year					TOTAL
	2011	2012	2013	2014	2015	
Polecat Bench	14	14	12	10	23	73
Oregon Basin	19	13	18	6	20	76
Major Basin	N/A	13	15	12	13	53
Fifteen Mile	N/A	17	14	10	22	63
Bud Kimball	N/A	N/A	N/A	15	15	30
TOTAL	33	57	59	53	93	295

Project Title: Coyote control targeted on mule deer fawning areas at Cedar Mountain
Brief Description of Project: Program of targeted predator control on key fawning ranges when it is most effective for the benefit of mule deer in the Uinta mule deer herd unit. Work targeted using data from the radio collar study
Submitted By / Affiliation: Jeff Short / Wyoming Game and Fish Department

The project area is located within Uinta and Sweetwater Counties in deer hunt area 132. This is within the Uinta mule deer herd unit and is commonly referred to as the Cedar Mountain area. The project commenced May 1, 2012 and will run through July 2015.

The Uinta/Cedar Mountain deer herd has not been able to fully recover from a severe population crash that occurred in the early 1990's. Manipulations of hunting season strategies alone have not improved overall herd numbers. Fawn recruitment continues to suffer and post season fawn ratios are not adequate to grow this herd to our objectives.

Several studies have found that the vast majority of coyote caused mortalities on mule deer occur in the first two months of their lives. This predation is usually by a select number of coyotes occupying specific fawning ranges. It is often intensified during times of low availability of alternate prey, depressed deer populations and where fawns are vulnerable due to habitat limitations. This may be the case at the present time since mule deer numbers are depressed and deer in the area are experiencing low fawn recruitment. It has been found that coyote control done to benefit mule deer is far more effective if done in high intensity on specific fawning ranges immediately before, during and right after the fawning and done to specifically target coyotes active in those areas.

From our recent mule deer study funded in part by ADMB we have gained valuable information on the mule deer population in the area. We found that 98% of captured does were pregnant in the winter. This high pregnancy rate is typical for mule deer. We followed those radio collared does in June and found that at least 80% of pregnant does had a minimum of one fawn at side. During the following December we flew extensive classification surveys in those areas and found a fawn:doe ratio of only 46:100. That means on average only 46% of does still had a single fawn surviving to 6 months of age. This is a very low figure indicating a very dire situation for the mule deer herd. Doe survival was very high from the previous winter at 96% and doe condition appeared to be at or above normal. Mule deer fawning habitats are very limited in this area and the amount of quality habitat is most likely restricting the ability to grow fawns to 6 months old. Coyote predation on fawns is exacerbated by the small areas available for mule deer fawning habitat. A coyote can be very effective at hunting fawns when there are small patches of quality fawning habitat to hunt. The identified fawning habitats had not received predator control treatment in the past. A multiple year intensive coyote removal effort was advised. The Muley Fanatic Foundation of Wyoming (MFF) funded year one of this work in 2012. ADMB and the MFF jointly funded year two and three of the project in 2013 and 2014. After treatments we can look at post treatment faw:doe ratios to determine the effectiveness of our efforts.

The Uinta County Predator Board provides personnel, support, ground work and local expertise in the coyote removal efforts. They contract with a competent vendor to complete the aerial gunning operations. The funding allows for approximately 12-15 hours per year of helicopter coyote removal. This is time specific on identified mule deer fawning ranges. Maps of key identified fawning ranges are provided to the Unita County Predator Board. Those maps have been updated yearly as new data is analyzed. Coyote removal is conducted immediately prior to, during or within two months of mule deer fawning. This typically occurs in early June in this area. This maximizes the benefit to mule deer.

ADMB budget expenditures

helicopter coyote removal	$ 9,998.63

HAUB SCHOOL OF ENVIRONMENT AND NATURAL RESOURCES

Wyoming Range Mule Deer Project

Summer 2017 Update

MONTEITH SHOP

HAUB SCHOOL OF ENVIRONMENT & NATURAL RESOURCES

WYOMING COOPERATIVE FISH & WILDLIFE RESEARCH UNIT

UW UNIVERSITY OF WYOMING

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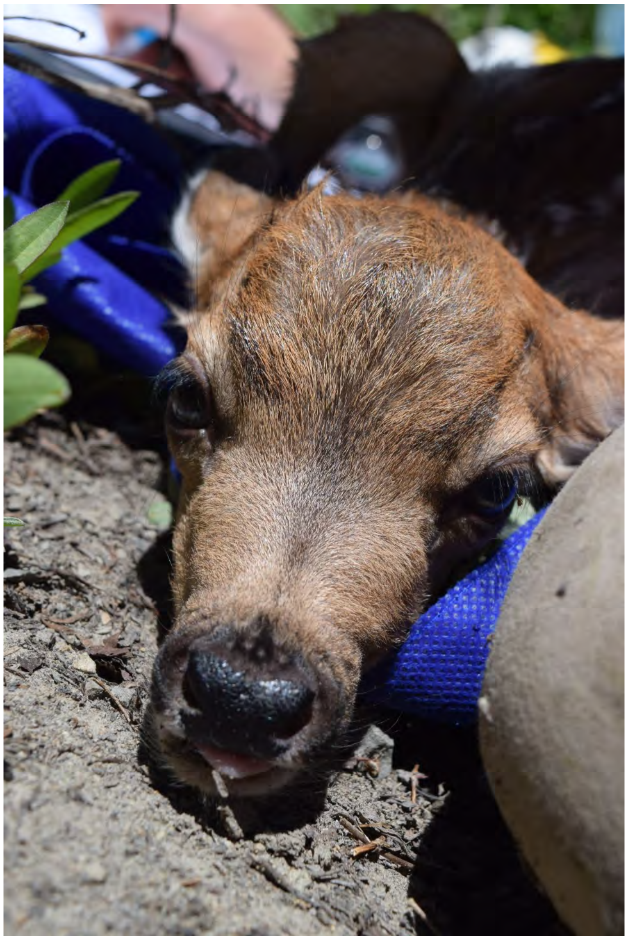
PROJECT BACKGROUND

The Wyoming Range Mule Deer Project was initiated in March 2013. The overarching goal of the project is to investigate the nutritional relationships among habitat conditions, climate, and behavior to understand how these factors interact to regulate population performance. Since the initiation of the project, we have tracked and monitored the survival, behaviors, reproduction, and habitat conditions of 164 female, adult mule deer of the Wyoming Range. In March 2015, we expanded our research efforts to include evaluation of survival and cause-specific mortality of fawns belonging to our collared mule deer. This component of the project is aimed at unraveling the relative contributions of habitat, maternal nutrition, and predation on survival of young mule deer—a study that is the first of it’s kind in Wyoming. This update will report on some of our accomplishments and preliminary findings of adult survival and reproduction and will highlight the breadth of factors that contribute to fawn mortality in western Wyoming. So far, our research has gleaned invaluable insight into what regulates population performance of this iconic population, and we aim to further refine our understanding of the factors that affect the population with continued, robust data collection on various aspects of mule deer ecology, including nutrition and habitat contributions, predation, migration, reproduction, and survival.



WINTER 2016/2017

Adult Survival

This last winter of 2016/2017 proved to be a tough one for mule deer. Conditions on winter ranges for Wyoming Range mule deer were severe with snowpack levels exceeding 200% and numerous days of sub-zero weather. These harsh winter conditions strongly affected winter survival and only 63% of our collared adults survived from November until summer 2017 (compared with >90% in years past). Older animals and animals that entered winter in poor condition were more susceptible to succumbing to winter exposure (Figure 1).

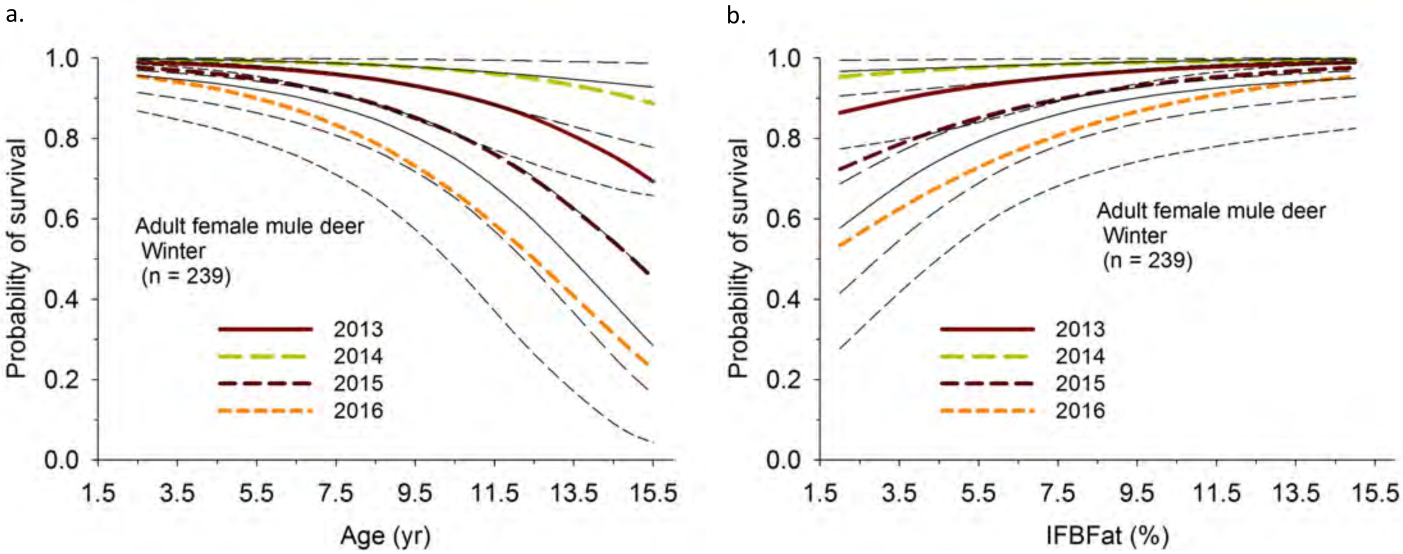


Figure 1. The effects of age (a) and December body fat (IFBFat %; b) on the probability of survival overwinter. Probability of survival decreases as animals get older and as the % body fat (IFBFat %) in December decreases.

Fawn Survival

Winter conditions tend to have the greatest effect on survival of fawns and this winter was no exception. We observed 100% mortality of the fawns we collared in summer 2016 and had survived to the beginning of winter. Mortality rates of that caliber can have substantial repercussions on population dynamics because the majority of an entire cohort of deer is gone. Although these numbers are staggering, winter die-offs like the one observed this winter do occasionally occur and populations do eventually rebound. We have now found ourselves with a unique opportunity to evaluate how mule deer populations rebound from harsh winters.

We retrieved all remains of mortalities of collared fawns. Whole carcasses were submitted to the Wyoming State Veterinary Lab and WGFD Wildlife Health Laboratory for necropsy.

MARCH 2017 ADULT CAPTURES

Since March 2013, we have recaptured collared mule deer as they enter winter ranges in December and before they leave winter ranges in March. This has allowed us to track changes in nutritional condition and reproductive status of animals.

We use ultrasonography to measure % body fat and evaluate pregnancy of collared mule deer.

Nutritional Condition

Nutritional condition in March 2017, measured as % body fat, was the lowest we have observed in our research (averaging 1.8% ± 0.25; Figure 2). Although it is rare to see animals in this poor of condition, it was expected given the severity of the winter.

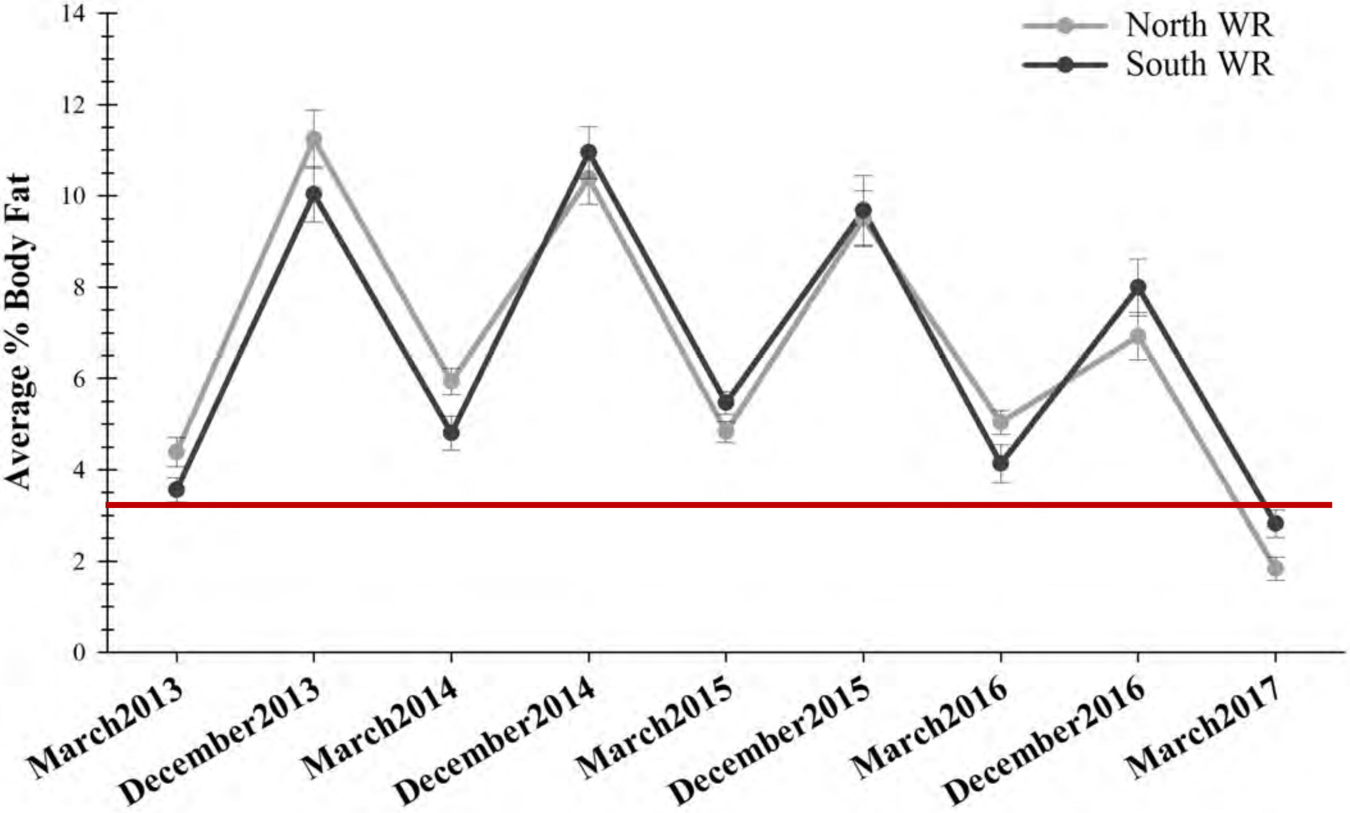


Figure 2. Average % body fat of adult, female mule deer on North (near Big Piney,WY) and South (near Cokeville and Evanston, WY) winter ranges for Wyoming Range mule deer. Deer were in significantly poorer shape in March 2017 than any other year.

Pregnancy

Despite extremely poor nutritional condition of animals this March, fetal rates among winter ranges were comparable to the preceding 4 years (Figure 3) and pregnancy rates remained high. Interestingly, average eye diameter of fetuses was lower in March 2017 (14.0 ± 0.18) than in previous years (15.3 ± 0.11; Figure 4). Fetal eye diameter is a measure of fetal development and is often used to estimate the timing of birth.

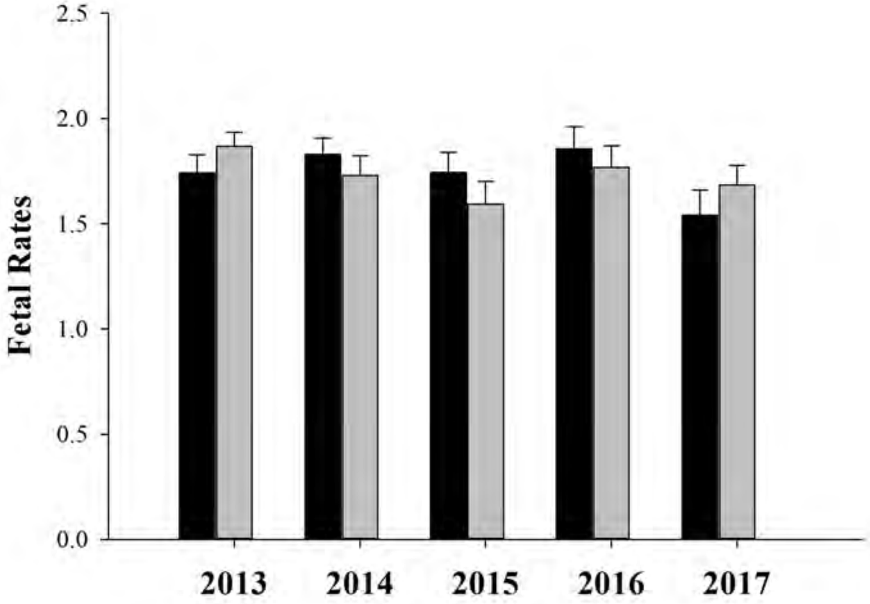


Figure 3. Fetal rates (average number of fetuses per pregnant animal) did not differ among years—despite severe winter conditions.

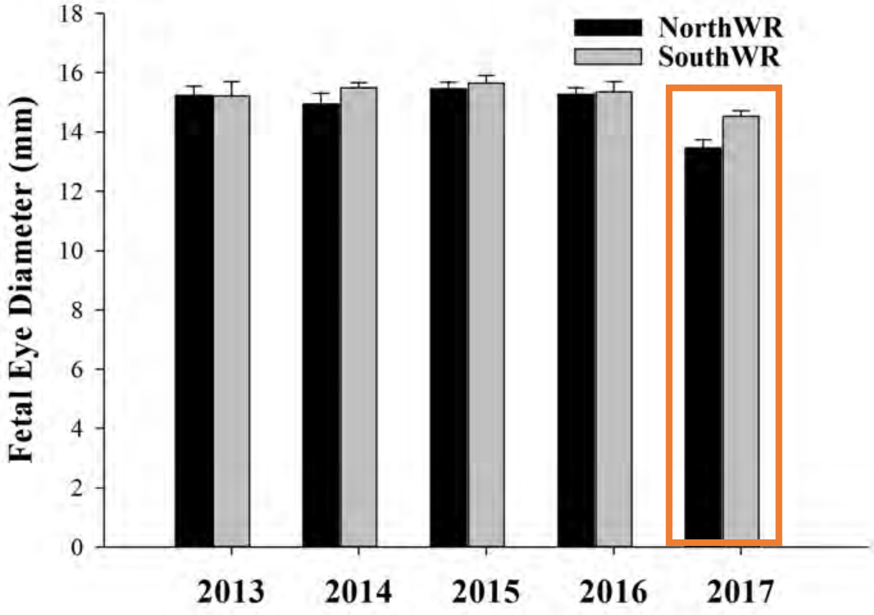
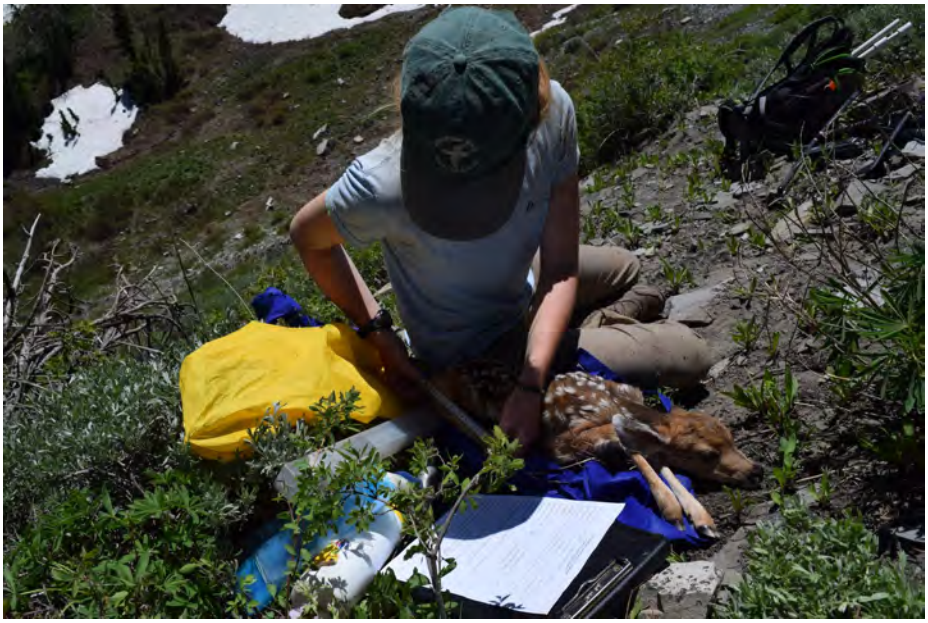


Figure 4. Average fetal eye diameter measured in March of each year. Fetal eye diameter was significantly smaller in March 2017 compared with any other year.

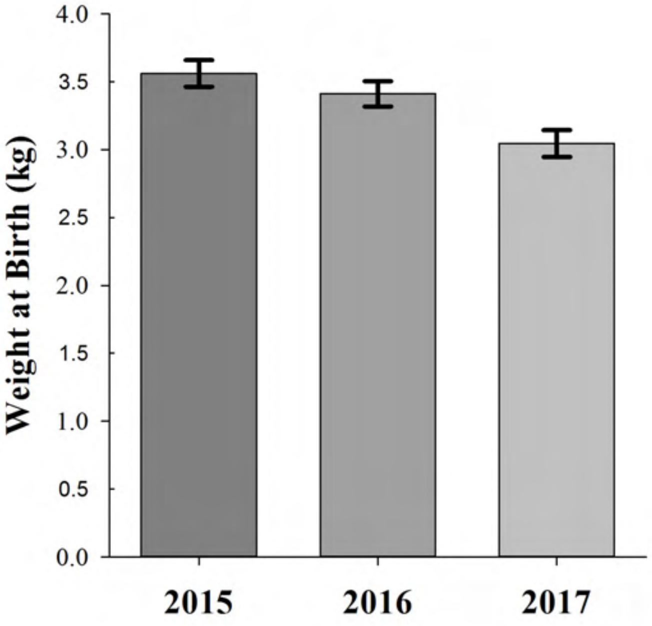
FAWN SURVIVAL

Fawn Capture and Collaring



Since March 2015, we have been capturing and collaring fawns of our collared adults to evaluate what factor most influence fawn survival. Fawns are located using a vaginal implanted transmitter (VIT) deployed in pregnant females that is expelled at birth. Once fawns are located, we then capture, radio-collare, and collecte a suite physical data (e.g., body weight). We then monitored daily survival of collared fawns. Over the three summers, we have tracked the survival of 194 mule deer fawns throughout the Wyoming Range.

	2015	2016	2017 - So Far
Number of Fawns Tracked	58	70	66
Summer Mortality	45%	56%	44%
Median Birthdate	June 10	June 13	June 16
Average Weight at Birth	3.56 (± 0.098)	3.41 (±0.093)	3.04 (±0.099)



Newborn fawns caught in 2017 were significantly lighter than newborn fawns caught in previous years (Figure 5). This was of little surprise because of the overall poor nutritional condition of pregnant females and the smaller eye diameter of fetuses measured in March 2017. With this information, we are now in a position to better evaluate the influence of birth weight and maternal condition on summer survival of fawns.

Figure 5. Average weight of fawns captured <48hours from birth. Fawns were significantly lighter in 2017 compared with the previous two years.

Cause-Specific Mortality of Fawns

To evaluate cause-specific mortality of fawns, we track daily survival of all fawns captured over the course of the summer. When a mortality is detected, we immediately investigate the event to ensure an accurate assessment of the cause of mortality. There is a breadth of various causes for fawn mortality including predation, disease, malnutrition, drowning, hypothermia, vehicle-collision, and just getting caught up in vegetation. The proportion of fawns that die because of the aforementioned causes varies from year to year (Figure 6).

So far, in summer 2017, 30% of mortalities were because fawns were stillborn. Currently, this is leading cause of death for fawns in 2017, but that will inevitably change as the summer progresses and more fawns die of other causes such as disease and predation.

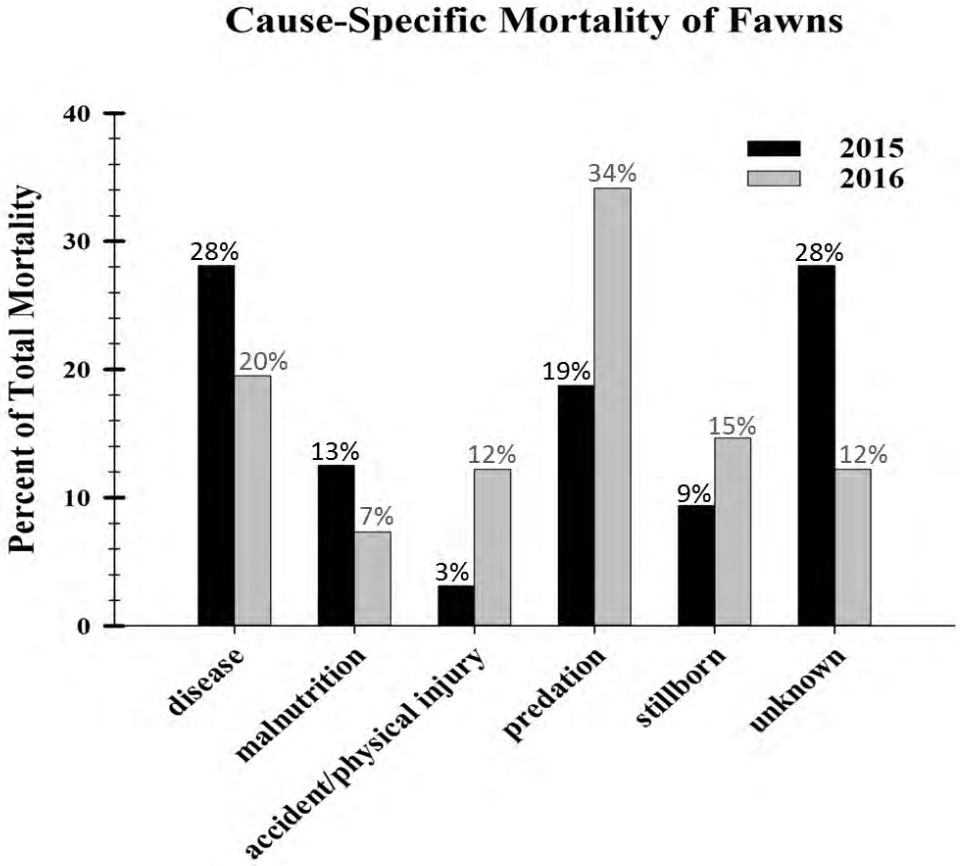


Figure 6. The relative occurrences of various causes of mortality for mule deer fawns.

Cause of Mortality: Malnutrition

Cause of Mortality: Predation

Habitat and Maternal Conditions

The condition of a female and the habitat conditions she experiences in the summer may be very important in predicting and understanding fawn survival – especially in understanding the influence of malnutrition and disease on fawn survival. Therefore, we are evaluating forage and habitat conditions within summer home ranges of collared deer. Specifically, we are measuring habitat structure and forage availability of known locations of use by collared adults that gave birth to fawns. We will then couple these data with information on maternal condition (i.e., nutritional condition) and evaluate the influence on fawn survival.

FUTURE RESEARCH EFFORTS

Throughout summer and winter of 2017, we will continue our research efforts aimed at elucidating the relative influence of predation, climate, and habitat conditions on fawn survival in the Wyoming Range. The severe winter conditions of 2017 will provide us with a unique opportunity to evaluate how severe winter weather may influence the ability of females to subsequently rear young, and thus, provide valuable insight into the factors that regulate population growth and examine the prospects for recovery of this cherished herd.

Project Partners and Funders

The Wyoming Range Deer Project is a collaborative partnership in inception, development, operations, and funding. Without all the active partners, this work would not be possible. Funds have been provided by the Wyoming Game and Fish Department, Wyoming Game and Fish Commission, Wyoming Wildlife and Natural Resource Trust, Muley Fanatic Foundation, Bureau of Land Management, Knobloch Family Foundation, U.S. Geological Survey, National Science Foundation, Wyoming Governor's Big Game License Coalition, Boone and Crockett Club, Animal Damage Management Board, Ridgeline Energy Atlantic Power, Bowhunters of Wyoming, and the Wyoming Outfitters and Guides Association. Special thanks to the Wyoming Game and Fish Department, Bureau of Land Management, and Wyoming State Veterinary Lab for assistance with logistics, lab analyses, and fieldwork. Also, thanks to the Cokeville Meadows National Wildlife Refuge and U.S. Forest Service for providing field housing.

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Assessing and Reducing Common Raven Impacts on Greater Sage-grouse Nesting Ecology

Final statistical analysis and report – November 20, 2017

prepared by

HWA Wildlife Consulting
2308 South 8th St. - Laramie, Wyoming - 82070

EXECUTIVE SUMMARY

This report describes the field activities, statistical analysis, and results of the Meeteetse Conservation District research project titled ‘Assessing and reducing common raven impacts on greater sage-grouse nesting ecology’. Field methods included capturing and attaching GPS units to greater sage-grouse hens (*Centrocercus urophasianus*) and breeding and nonbreeding common ravens (*Corvus corax*). We established two field sites in the Bighorn Basin, Wyoming (Polecat Bench and YU Bench), to explicitly incorporate some geographic variability in measured avian metrics and in response to treatments. We monitored nesting success and movement activity of sage-grouse and ravens in 2016 and 2017. We also conducted a field experiment by destroying all discoverable raven nests within 4.0 km of a GPS-tagged sage-grouse nest within half of each study area and monitored breeding raven movement patterns and sage-grouse nest success in response to raven nest treatments. The total dataset from this study contains a total of 62,922 GPS-tagged raven locations, 55,667 GPS-tagged sage-grouse locations, 24 active raven nests located, 16 raven nests treated, and 43 monitored sage-grouse nests. We found that spatio-temporal use of the landscape was fundamentally different for breeding ravens and nonbreeding ravens, with breeding ravens showing diurnal variation in movement and rapid travel and nonbreeding ravens showing minimual diurnal variation in their slow and steady travel rates. We found that treating raven nests resulted in a significant change in how treated breeding ravens used the landscape, causing them to range widely, similar to nonbreeding ravens. We also found higher sage-grouse nest success in treated compared to untreated areas in the Polecat Bench study area but not in the YU Bench study area. Together, these results suggest that treating raven nests may be an effective way to improve sage-grouse nest success, but only in landscapes where ravens are a primary nest predator.

INTRODUCTION

In 2016, with funding support for a sixth consecutive year from the Animal Damage Management Board (ADMB), the Meeteetse Conservation District (MCD) continued with an agreement with Laramie-based HWA Wildlife Consultants, LLC (HWA, formerly Hayden-Wing Associates, LLC) to continue the joint research project on raven impacts on greater sage-grouse in the Bighorn Basin. This research project was a new phase of an ongoing project initially begun by MCD and the National Wildlife Research Center in Logan, UT and Corvallis, OR in 2011. Beginning in the 2016 field season, the ongoing study shifted from *Evaluation of causes of mortality and predation rates of sage-grouse in the Big Horn Basin* to *Assessing and reducing common raven impacts on greater sage-grouse nesting ecology.* We tested a novel approach to reducing raven impacts on sage-grouse and evaluated it effectiveness, including the mechanism by which it worked.

BRIEF DESCRIPTION OF PROJECT

Current raven management usually involves lethal bait, which often kills nonbreeding ravens that frequent landfills (Coates 2007). However this method of control has had either spatially-dependent or no detectable effect on sage-grouse nesting success in the larger surrounding landscape (Coates 2007, Bui et al. 2010, Dinkins 2013). This is likely because breeding ravens usually forage exclusively within a few kilometers of the nest and rarely visit poison bait stations (Rösner and Selva 2005, HWA unpublished data). Further, as-yet unpublished data from GPS-tagged ravens in southcentral Wyoming suggests that breeding raven pairs whose nests failed for natural reasons switched to a spatially wide-ranging behavioral pattern whereas nesting and post-successful nesting pairs continued to intensively use the landscape surrounding the nest site (HWA *manuscript in prep*). Together these studies suggest that an alternative nest-focused breeding raven control method, where breeding ravens are induced to switch behavioral and space-use patterns, and reduce energetic demands to those of nonbreeding ravens, may prove successful in improving greater sage-grouse nest success.

In 2016 we began a new study to better understand raven ecology, greater sage-grouse nesting ecology, and interactions between the two. Study components included:

1) <u>Determine spatial use of the landscape by breeding and nonbreeding ravens</u> – Determining how ravens use the landscape equivalently or differently depending on breeding status will provide information on how specific management actions are likely to impact different components of the raven population.

2) <u>Evaluate a targeted lethal/non-lethal method for reducing raven impacts on sage-grouse nesting success</u> – We proposed a combination non-lethal (raven nest removal) and lethal (raven egg removal) treatment method for two reasons. First, broadly-applied lethal control of juvenile and adult ravens largely impacts transient individuals and has minimal impact on nesting pairs, but nesting raven pairs appear to be the raven population component that has the largest impact on sage-grouse nest success (Bui et al. 2010, Dinkins 2013). Second, targeted lethal control of nesting pairs involves permit complications, locating and killing two mobile birds (rather than destroying the stationary nest), and results in an open nesting territory that can be immediately occupied by another pair of breeding ravens. A targeted non-lethal/lethal option has the potential to effectively improve sage-grouse nest success while also being feasible to apply over large landscapes. Expected outcomes include an assessment of whether destroying raven nests alters raven space use and whether this alteration in space-use is associated with improved greater sage-grouse nest success.

Due to time and budget constraints, additional research objectives have not been analyzed and are therefore not discussed in this report. This report contains statistical analyses pertaining to movement behavior of nonbreeding ravens, breeding ravens, and sage-grouse, raven space-use responses to raven nest treatment, and sage-grouse nest fate in response to raven nest treatments.

STUDY AREA AND FIELD METHODS

We used two study areas in northwest Wyoming (Figure 1) in 2016 and 2017. The Polecat Bench (PB) study area is located just north of Powell, Wyoming, and the YU Bench (formerly known as Sheets Flat) study area is located just east of Meeteese, Wyoming. Each study area was split into a treatment and non-treatment side for the targeted raven nest removals. Due to difficulty in accessing raven nests in rugged terrain in the southern half of the YU study area, this portion was removed from the study in 2017.

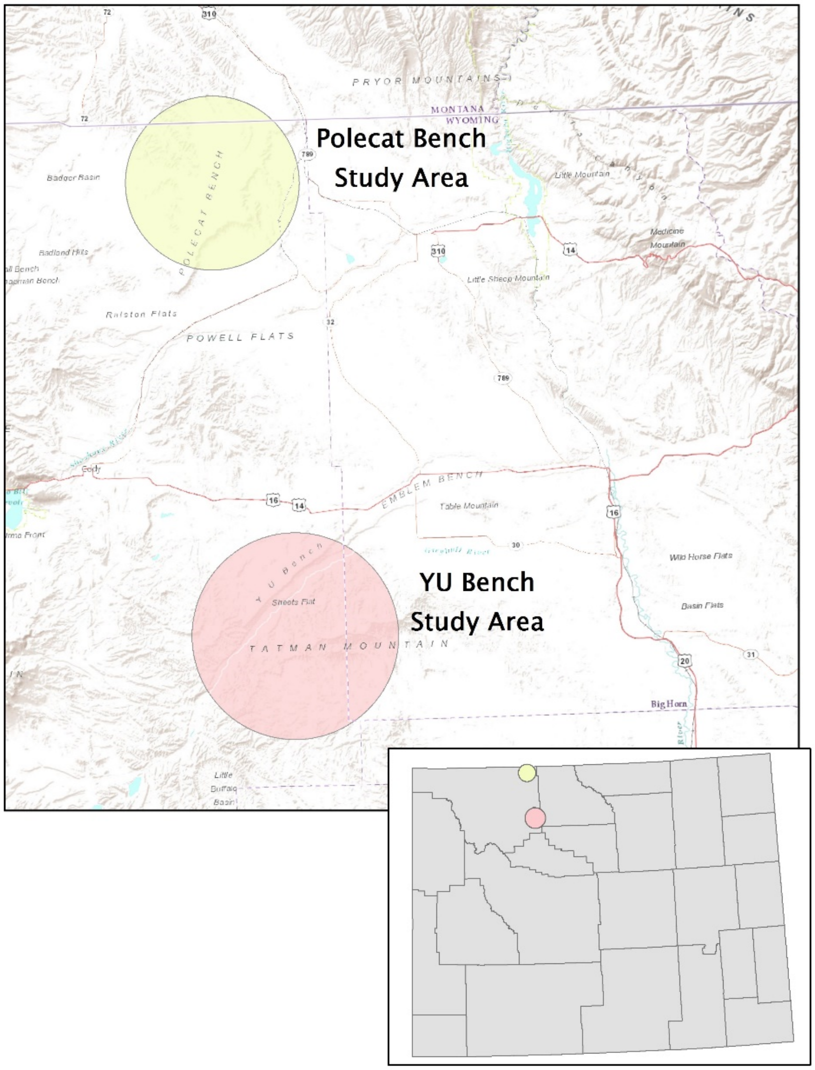


Figure 1. Study areas for raven and greater sage-grouse capture and nesting locations that were part of the study. The southern half of the YU Bench study area was dropped after 2016 due to difficulty in accessing raven nests in rugged terrain. All capture locations and nests were within these study areas, although individual ravens and greater sage-grouse traveled outside of these areas. Study area boundaries include data from 2016 and 2017.

Based on previous field studies by HWA in Wamsutter, WY, we noted that ravens forage within 2 miles of their nests, most heavily within 1.5 miles of their nests (Rösner and Selva 2005, HWA *manuscript in prep*). The majority of greater sage-grouse tend to nest within 3 miles of known leks (Holloran and Anderson 2005, HWA unpublished data). Following this knowledge, we focused raven capture within 4 miles of sage-grouse leks. We then established 4 km boundaries around GPS-tagged sage-grouse nests within the treatment side of each study area within which to conduct raven nest treatments. We altered the official delineation of each study area's boundaries where necessary to ensure that the treatment and non-treatment sides of each study area encompassed the associated GPS-tagged sage-grouse.

For the treatment side of each study area, MCD employees conducted the treatment actions. This included extensive searches for raven nests. Once located, raven nests and/or associated eggs or chicks were removed or destroyed as approved by the Wyoming Game and Fish Department (permit ID: 1056) and the

U.S. Fish and Wildlife Service (permit # MB85114B-0). Treatment of raven nests took place throughout the overlap between the sage-grouse and raven nesting seasons within the treatment side of each study area. All known discoverable raven nests in treatment portions were treated regardless of whether or not a member of the breeding pair was GPS-tagged. On the non-treatment portions of each study area, we did not treat raven nests to allow for comparison of treatment to non-treatment.

In 2016, a variety of trapping methods were tried for capturing ravens, including: padded leg-hold traps, net-launchers, and hoop-netting at night. Padded leg-hold traps were the only trapping method employed during 2017 for ravens. Unfortunately, very difficult field conditions prevented successful captures of new ravens in 2017. Several ravens captured and GPS-tagged in 2016 were still active and contributed GPS locations. Ravens captured in 2016 were outfitted with 30-gram solar powered CTT-1000-BT3 Series GPS-GSM transmitters (Cellular Tracking Technologies). These transmitters allowed for much faster sampling intervals and allowed us to measure raven movement patterns more accurately during the grouse nesting season. Raven transmitters were set to record GPS-quality (±3 meters) locations at 30 minute time intervals when stationary and 5 minute time intervals when flying during the greater sage-grouse nesting season (April 1 – June 30). The high frequency location fixes were only activated when birds were inside the study areas; hence the study areas were used as geofences and the programming defaulted to the 30 minute intervals when birds were outside the pre-programmed study area boundaries. After the nesting season, we increased the time interval to a static 30 minute interval independent of geofences in order to save battery power (July 1 – August 31). During the fall, winter, and early spring (September 1 – March 31), the transmitters were programmed to record locations every 3 hours. All raven programming was for daylight hours only and GPS locations from the raven CTT transmitters were downloaded via cellular technology. CTT transmitters were fitted to ravens using standard backpack harnesses constructed with ¼" Teflon ribbon (Bally Ribbon).

Greater sage-grouse captured in 2016 were captured almost exclusively on leks using rocket-nets, although one grouse was captured opportunistically using spot-lighting and a hoop-net during the 2016 field season. In 2017, all sage-grouse were captured using the spot-lighting and hoop-net method. Because sage-grouse were more stationary during the nesting season, we outfitted hens with 30-gram solar-powered GPS/ARGOS PTT transmitters (Microwave Telemetry, Inc.). Transmitters were programed to record 5-15 GPS-quality (±18 meters) locations per day for each grouse hen, depending on the time of year. The programming varied slightly among transmitters, but generally transmitters were programmed to record 16 GPS locations per day between April 15 and June 30, and 6 GPS locations per day the remainder of the year (July 1 – April 14). The greater sage-grouse ARGOS PTT location data were received via the ARGOS satellite system (CLS America, Inc.) every three days. ARGOS PTT transmitters were fitted to sage-grouse using rump-mounted harnesses constructed with ¼" Teflon ribbon (Bally Ribbon).

Sage-grouse nest success was monitored from GPS-outfitted hens by MCD staff. Nest locations were determined by identifying clusters of GPS locations once nesting activity was detected (i.e., movement patterns indicative of incubation). We estimated the incubation date using the GPS data then forecast the hatch date using an average incubation period of 27 days. A hen departing from a nest >2 days prior to the expected hatch data indicated a nest failure. Nests were checked immediately after hens departed the area to confirm nest fate. Nests were considered successful if hens incubated for $\geq$24 days and a ground visit verified $\geq$1 egg hatched. Hatched eggs were identified by hatching pattern (i.e., eggs split into halves) and detached membranes. Nests were classified as unsuccessful if hens vacated the nest >3 days prior to the expected hatch date and a ground visit confirmed a nest failure.

RESULTS

RAW DATA

Greater sage-grouse

Three sage-grouse hens had working GPS units that were attached in earlier years of this study and were subsumed into this study's sample of hens. Seventeen sage-grouse hens were captured in late March / early April, 2016, and outfitted with ARGOS GPS units. Eleven greater sage-grouse hens captured and outfitted in 2016 were still alive and had functioning units in 2017. We captured five additional hens in April 2017 to re-deploy GPS units recovered from hen mortalities in 2016. The 20 captures in 2016 were equally split between the two study areas. Three of the 2017 captures were in PB, two captures were in YU Bench.

As of July 12, 2017 (the end of data collection for this analysis), we had collected 55,667 GPS locations from tagged sage-grouse. The mean number of locations per individual hen was 1,104.4 (SD 562.4) with a minimum of 78 locations and a maximum of 1,934 locations per hen.

In the PB study area, 3 of 11 nests and 4 of 12 nests were successful in 2016 and 2017, respectively. In YU Bench, 2 of 12 nests and 1 of 7 nests were successful in 2016 and 2017, respectively.

Six hen carcasses were recovered in 2016 and three in 2017. One transmitter was recovered in 2016 without evidence of a carcass. Four additional hens did not transmit locations in the two weeks prior to July 12, 2017 (the end of data collection for this analysis) and may have died, dropped the GPS unit, or had GPS unit malfunction.

Common raven

Twelve ravens were captured in 2016, three males and three females in each study area. Raven capture efforts were unsuccessful in 2017 due to poor weather and field logistics. However, six ravens captured and GPS-tagged in 2016 were still alive with active CTT units in 2017, providing additional GPS location and movement data.

As of July 12, 2017 (the end of data collection for this analysis), we had collected 62,922 GPS locations from tagged ravens. The mean number of locations per individual raven was 5,243.5 (SD 3,863.0) with a minimum of 255 locations and a maximum of 11,633 locations per raven.

Six of the 12 ravens were active breeders in 2016. Four of these breeders were in the non-treatment side of the two study areas; two breeders were in treatment sections. In 2017, only one of the six surviving and tagged ravens was a breeder and it was in the treatment section of YU Bench. An additional nine raven nests were located in treatment areas and one additional raven nest was located in the non-treatment areas in 2016. Nine raven nests from untagged ravens were located and treated and five untagged raven nests were located and not treated in 2017.

STATISTICAL ANALYSES

Temporal movement patterns of ravens and sage-grouse

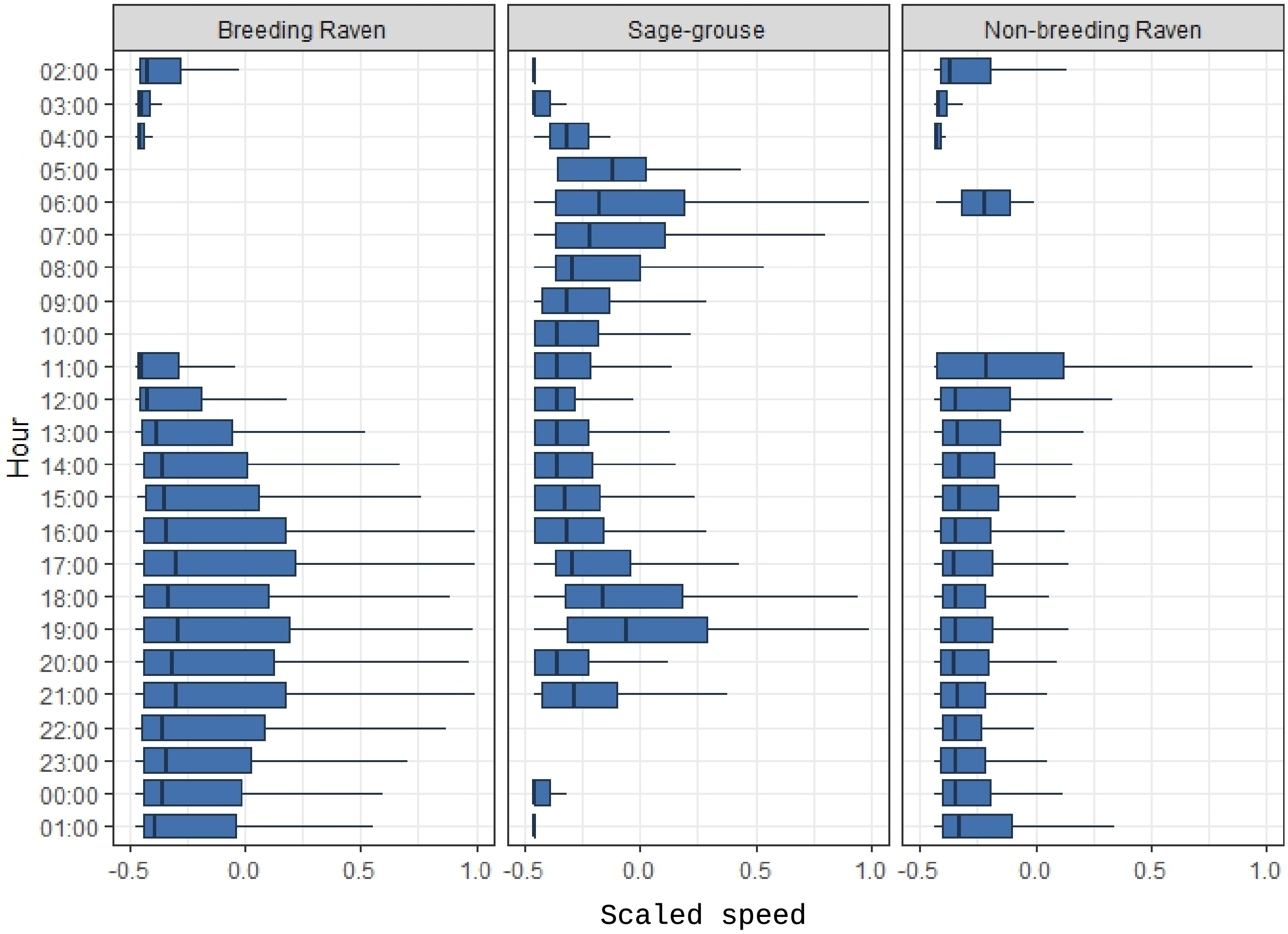
Understanding how different groups of animals use the same space is crucial to understanding when and where individuals from those groups interact. For ravens and sage-grouse this means identifying how they use the landscape in a spatiotemporal context to identify times or places of interaction, particularly during sage-grouse nesting. Of further interest is comparing and contrasting how breeding versus nonbreeding ravens use space as part of this study's goal of establishing a baseline for how breeding ravens use the landscape and whether they use the landscape different than nonbreeding ravens.

To achieve this comparison among nonbreeding ravens, breeding ravens, and breeding sage-grouse during the breeding season, we focused on diurnal patterns of movement rates. For diurnal patterns we wanted to see if there are periods of peak activity when a raven is more likely to encounter a sage-grouse, whether breeding ravens had the same activity patterns as nonbreeding ravens, and whether sage-grouse had times of peak activity when they most often left the nest temporarily unattended. We defined the sage-grouse breeding season as April 1st through June 15th, which was approximately one week prior to the earliest sage-grouse nest initiation date (April 7th) and approximately one week later than the latest nest hatch date and nest failure date (both June 10th). We restricted this analysis to only include raven and sage-grouse movement metrics from within this window.

The GPS units for ravens and sage-grouse were from different manufacturers and therefore had fundamentally different location recording schedules. As detailed in the Methods section above, raven locations were recorded every 5 minutes while actively moving and every 30 minutes when stationary. Sage-grouse GPS units generally recorded ~16 locations per day (hourly, during daytime) during breeding. Distances between successive locations within an individual raven or sage-grouse were not directly comparable because longer time periods between successive locations can also result in longer (or shorter) distances recorded traveled (e.g., an incubating hen may leave the nest to forage briefly, then return, and be recorded as having traveled a distance of 0 m during the encompassing GPS location recording interval). Further, GPS units on both ravens and sage-grouse sometimes temporarily malfunctioned or failed to achieve sufficient satellite coverage and could not record a location. To deal with unequal intervals between successive GPS locations, we calculated rate of movement (km/hr) between successive locations as a standardized metric across individuals. Then, to accommodate dramatically different calculated rates of movement between ravens and sage-grouse, we scaled movement rates within each group: breeding ravens, nonbreeding ravens, and sage-grouse hens. After scaling, each group has mean = 0 and standard deviation = 1. Finally, we rounded movement rate timestamps to the nearest hour for plotting and analysis purposes. Statistical analysis was a generalized linear model using a quasipoisson distribution. The first simple model was simply a fixed effect of Group (i.e., breeding raven, nonbreeding raven, etc.) and BirdID as a nuisance variable to account for each individual bird's inherent behavioral pattern. The second full model also included Hour and Hour*Group to test for temporal differences in movement rates among groups.

We found that both breeding ravens and sage-grouse showed strong cyclical patterns in movement rates throughout the 24-hour period (Figure 2). Sage-grouse showed prominent increases in movement rate early in the morning and in the evening, peaking at 06:00 and 19:00. Breeding ravens were missing data from early in the morning, but showed a gradual increase and then decrease in movement rates over the day, with a gentle peak between ~17:00 – 21:00. Nonbreeding ravens were also missing morning data, but at first location showed the highest movement rates at 11:00, suggesting the possibility of unobserved high movement rates earlier in the morning. During the remainder of the day nonbreeding ravens showed consistent low movement rates. The simple statistical model found that breeding ravens had significantly higher movement rates than nonbreeding ravens ($p<0.001$) or sage-grouse ($p<0.001$) across all hours combined. Breeding ravens on average traveled 1.40 times faster than nonbreeding ravens and 1.22 time faster than sage-grouse hens. The full statistical model looking for hourly differences in movement rates among groups found no difference in scaled movement rates between sage-grouse and breeding ravens at any time (all p-values > 0.307). However, breeding ravens showed significantly lower movement rates than nonbreeding ravens at 01:00, 02:00, 04:00, and 12:00 and significantly higher movement rates than nonbreeding ravens at each hour from 14:00 to 23:00 (all p-values <0.05).

Figure 2. Boxplots of movement rates for breeding ravens, sage-grouse, and nonbreeding ravens in Bighorn Basin, WY, USA during sage-grouse breeding season in 2016-2017. X-axis (speed.grp.scale) is movement rate in km / hr scaled for each group. Some time periods were completely missing observations due to GPS unit scheduling and/or failure to record location due to GPS unit or satellite issues (e.g., too few satellites, power failures, physical barrier between GPS unit and satellites, etc.).



Together, Figure 2 and the statistical analyses suggest that breeding ravens and sage-grouse have strong crepuscular patterns of movement, with longer and faster movements in early morning and early evening. In contrast, nonbreeding ravens showed no evening spike in activity but rather constant movement rates. In light of breeding ecology, the differences in raven movement make sense. Breeding ravens need to forage to sustain energy for incubation and feeding, but need to balance foraging food with attending the nest and therefore would move quickly when they foraged. Engel and Young (1992) also observed that during spring, breeding ravens increase the proportion of time spent moving or flying in the afternoon and evening compared to morning. In contrast, without a nest to attend, nonbreeding ravens are free to forage at a steady pace over a wide area (Heinrich et al. 1994, Webb et al. 2012, Loretto et al. 2016). In terms of interactions between breeding ravens and sage-grouse, ravens may be leveraging hen foraging periods to find unattended sage-grouse nests. While few published data are available to inform timing of raven nest depredation, Coates (2007) found that eight out of nine video-recorded raven depredations of sage-grouse nests occurred between ~6:30-9:30 and 18:00-19:00, the peak periods of sage-grouse off-nest movement in our study.

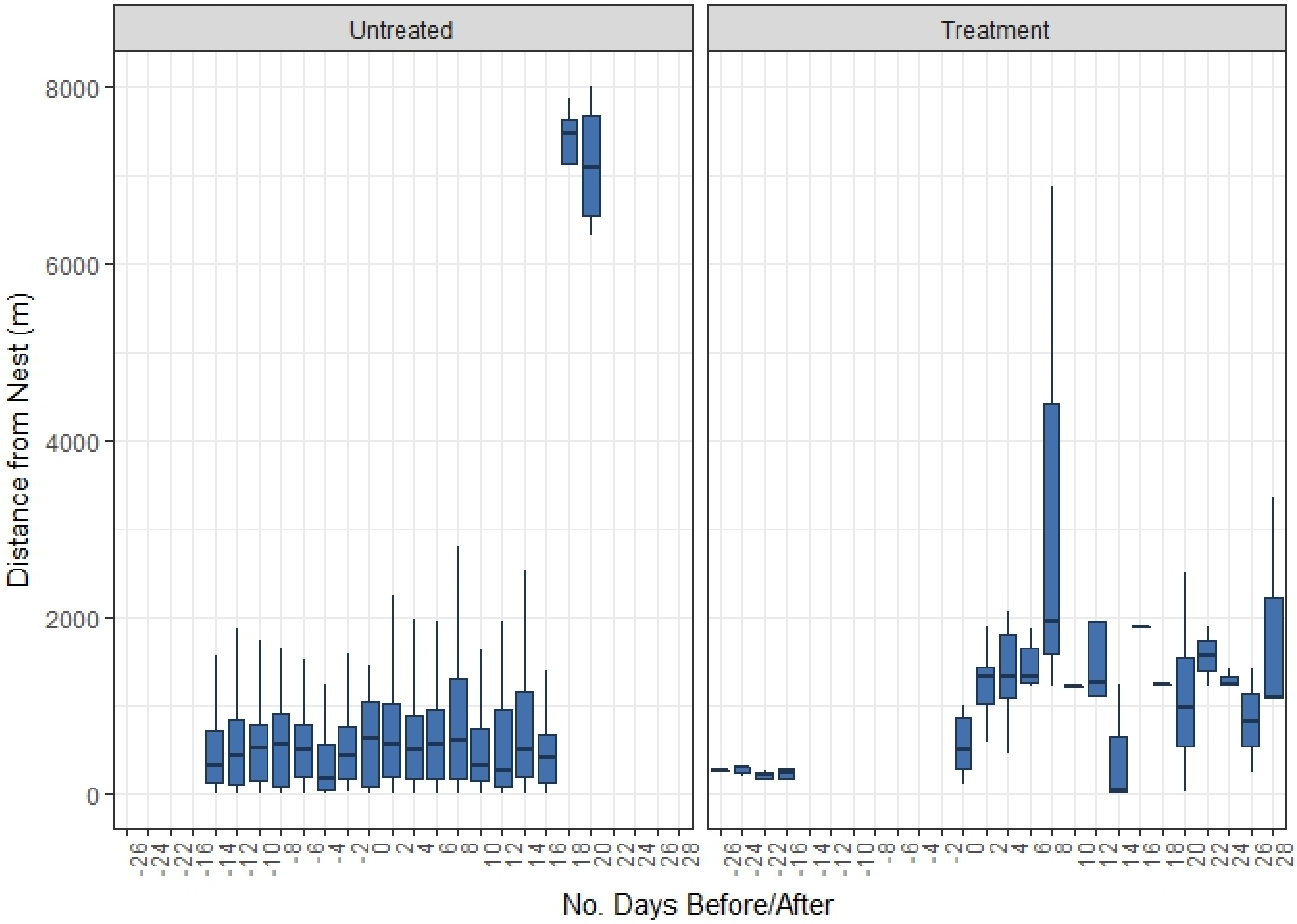
Raven space-use response to nest treatment

The notion that ravens would alter space use when incubating a nest and tending to young is logical and widely supported by field data. Breeding ravens often stay within 2 km of the nest (Rösner and Selva 2005). They establish non-shared territories to defend local food opportunities (Webb et al. 2012). Even after the raven chicks fledge, the adults and chicks can occupy the same territory for up to six weeks while the adults teach the chicks how to forage (Stiehl 1985). Given that the act of attending a nest alters raven space use, it stands to reason that removing the need to attend a nest (e.g., destroy the nest) would induce a behavioral shift back to that of nonbreeding ravens. For example, in southcentral Wyoming, ravens whose nests failed due to natural causes quickly switched to a space use pattern similar to nonbreeding ravens, traveling significantly further between successive locations and ranging over much larger portions of the landscape than breeding ravens or than breeding ravens who successfully hatched (HWA *manuscript in prep*).

In this study we treated active raven nests and then monitored the space use response of GPS-tagged ravens in those nests. Sample size was small, given the difficulty in capturing known breeding ravens and the fact that treated and untreated portions of the landscape were largely determined by the spatial distribution of our GPS-tagged sage-grouse. Nonetheless, we were able to monitor space use of three GPS-tagged ravens whose nests were treated and four GPS-tagged ravens whose nests were untreated. Treatment consisted of regular nest searches in treated areas. When a nest was located, it was destroyed along with any eggs. Follow-up surveys were conducted by MCD to determine if the breeding pair attempted to re-nest in the same territory. The time period for analysis was set as 30 days prior- and 30 days post-treatment for treated ravens. For untreated ravens, the time period was set as 30 days prior to and post June 15th, which was the center date for treatment of the three treated nests. We analyzed whether the distance a raven was from the nest depended on treatment status. GPS locations were not recorded when the raven was stationary, therefore this analysis reflects distance from the nest when off of the nest. Statistical analysis was a linear regression on log-transformed distance-to-nest for each breeding raven GPS location, with a single predictor variable reflecting whether a breeding raven was untreated, prior to treatment, or after treatment.

We found that the average distance from the nest for untreated breeding ravens was 368.5 m (95% CI 354.0 – 383.7 m), for pre-treatment ravens was 231.7 m (95% CI 91.7 – 585.7 m), and for post-treatment ravens was 833.3 m (95% CI 635.7 – 1092.3 m). Distance from nest was not significantly different for untreated and pre-treatment ravens ($p = 0.327$), but the distance from nest for post-treatment ravens was 3.6 times higher than the distances of the same ravens pre-treatment, which was statistically significantly farther from the nest than pre-treatment ($p = 0.009$) or untreated ravens ($p < 0.001$; Figure 3). This finding indicated that nest treatment was effective at inducing a significant difference in space use of breeding ravens, causing them to range widely and no longer be tied to the nest location.

Figure 3. Distance from nest for GPS-tagged breeding ravens as a function of days before and after raven nest treatment in northwest WY, USA, 2016-2017. Untreated ravens showed constant distances from the nest until ~17 days after June 15th, likely reflecting fully fledged and mobile young. Treated ravens showed low motility prior to treatment, then dramatic and sustained variable movements away from the nest beginning on the day of treatment.

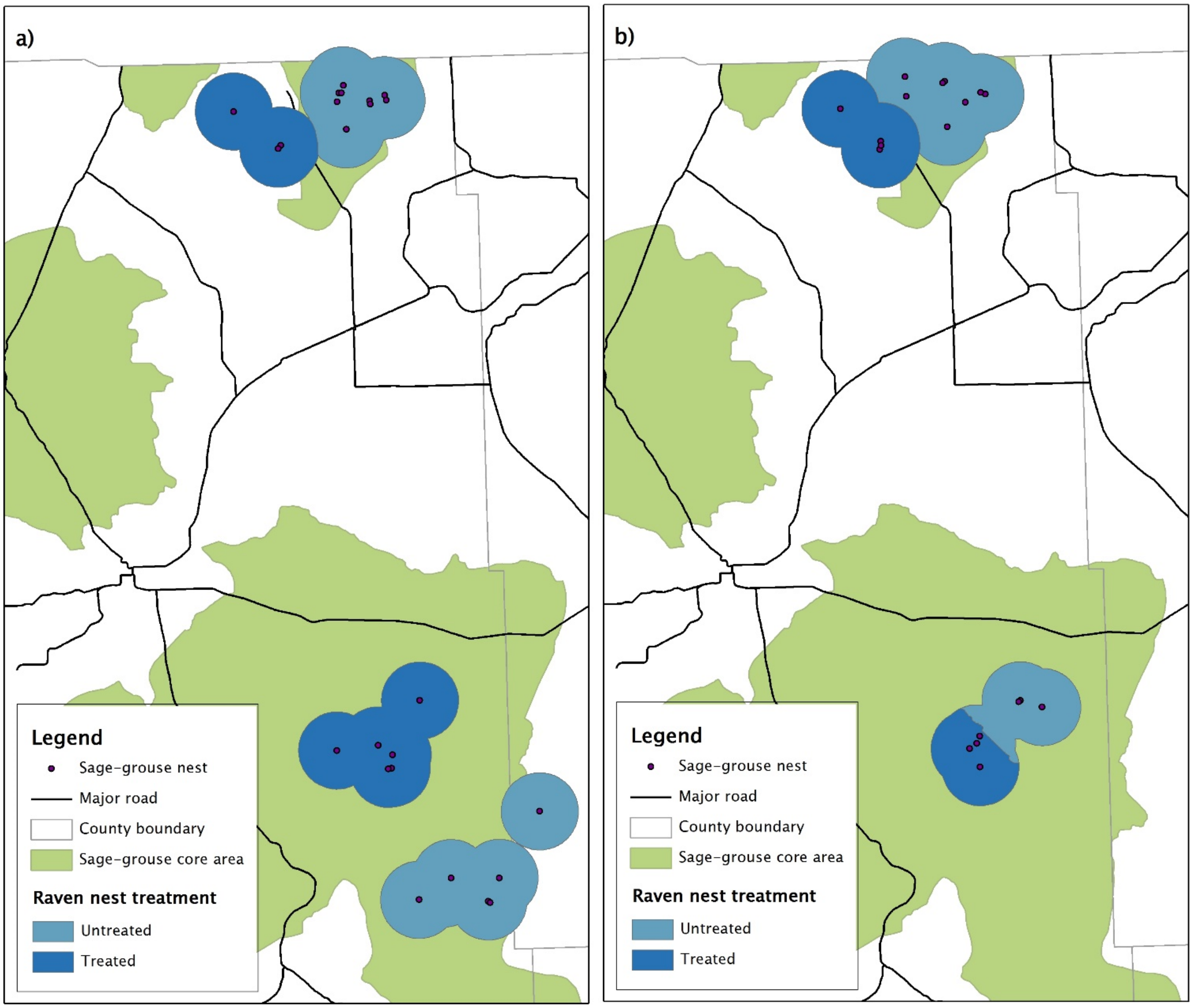


<u>Sage-grouse nest success in response to raven nest treatment</u>
Sage-grouse nesting success is one of the primary drivers of sage-grouse population dynamics (Taylor et al. 2012). Because raven predation can be a major component of sage-grouse nest failure, and because breeding ravens appear to be the raven population component that most frequently encounters sage-grouse nests, a key goal of this project was to determine whether destroying raven nests improved nesting success of sage-grouse (Coates 2007, Bui et al. 2010, Dinkins 2013).

We designed the study to try and test the raven nest hypothesis in spite of the spatiotemporal variability in other factors that influence sage-grouse nest success, such as weather, other predators, hen nutrition, etc. This included maximizing sample size of GPS-tagged sage-grouse, creating two separate landscape-level study areas, and conducting the experiment over two years. We then carried out the raven nest treatment portion of the study as thoroughly as possible (i.e., we conducted comprehensive raven nest searches in treatment areas; Figures 4a and 4b). We used logistic regression, with sage-grouse nest fate classified as a '1' if successfully hatching ≥1 chick and as a '0' if a nest failed, to determine whether sage-grouse in landscapes subject to raven nest control had higher success than sage-grouse nesting in natural untreated landscapes. We discuss the results in light of small sample sizes and without using a rigid definition of a specific p-value determining that a result was "significant".

Sample sizes were limited. In PB, there were 7 and 16 sage-grouse nests in treated and untreated areas, respectively, pooling both years. In YU Bench there were 10 and 9 sage-grouse nests in treated and untreated areas, respectively, pooling both years.

Figure 4. Treated and untreated areas for raven nest removal experiment in 2016 (a) and 2017 (b). Boundaries were set as a 4 km radius around nests of GPS-tagged sage-grouse. Boundaries shifted between years because they were defined by movement of free-ranging GPS-tagged sage-grouse. The southern portion of the southern study area (YU Bench) was dropped after 2016 due to logistical access issues.



Sage-grouse nest success was not statistically different in treated versus untreated areas when study areas were pooled together (p = 0.484; Figure 5). However, when differentiating between sage-grouse nest success in the PB study area versus YU Bench, in both years sage-grouse nesting in the treated portion of PB had considerably higher success than nests located in the untreated portion of PB (p = 0.0785, Figure 6a). Nest success was ~5x higher in 2016 and ~2x higher in 2017. The same pattern did not hold for YU Bench, where in 2016 sage-grouse nest success was equivalent in treated and untreated areas and in 2017 showed the opposite relationship to what we expected, where nest success was lower in treated areas (Figure 6b).

Figure 5. Sage-grouse nest success in landscapes with and without lethal treatment of raven nests in northwest Wyoming, USA, 2016-2017. PB and YU Bench study areas were combined in this graph.

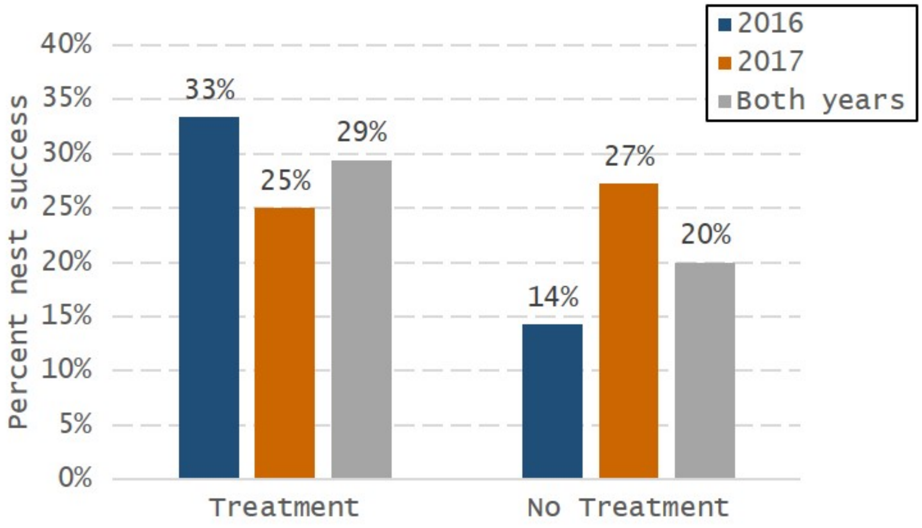
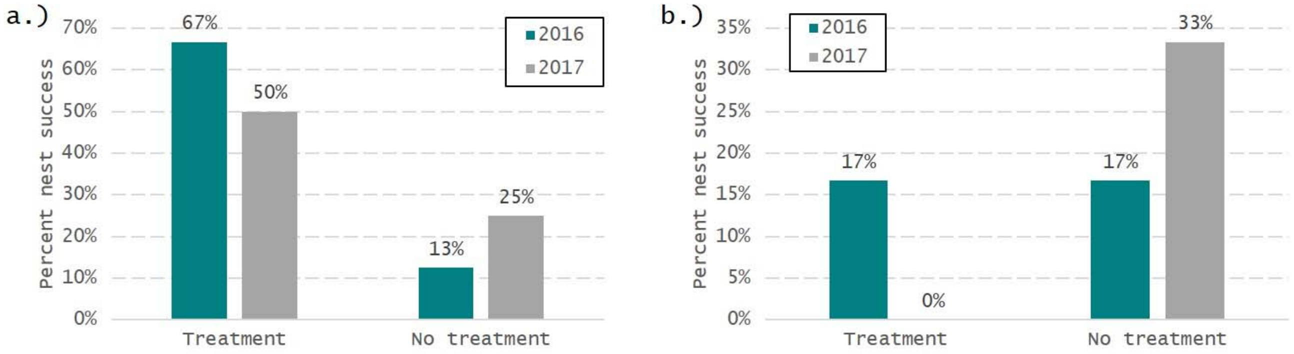


Figure 6. Sage-grouse nest success in response to raven nest lethal treatments at PB study area (a) and YU Bench study area (b) in northwest Wyoming, USA, 2016-2017. Sage-grouse nest success was notably higher in treated areas within PB in both years, but not in YU Bench.



Ultimately, sample size was limited by the number of GPS units available to be deployed on sage-grouse hens. This resulted in single-digit samples once split into treated and untreated portions in both study areas in both years. Nonetheless, the results are informative. First, raven nest treatment was associated with higher nest success in the PB study area. Earlier components of this study (2011 – 2015) found the highest rate of sage-grouse nest depredation was in the PB area and that ravens depredated nearly as many nests as coyotes (Taylor 2015). In contrast, Taylor (2015) found that the more southern study areas in the vicinity of our YU Bench study area had sage-grouse nest depredation driven primarily by coyotes. This could explain why the raven nest treatment was not effective at increasing sage-grouse nesting success in YU Bench, because coyotes were the main nest predators. Combining the results from this study and the recent predator research in these study areas supports the conclusion that raven nest control may be effective at raising sage-grouse nest success, but only in areas where ravens are a primary component of nest depredation.

Conclusion

This study tested three sequential hypotheses: 1) whether breeding ravens use space differently from nonbreeding ravens, 2) whether treating raven nests changes breeding raven space use to resemble nonbreeding raven space use, and 3) whether the change in breeding raven space use following nest treatment results in changes in sage-grouse nest success. The results from this project suggest that the answer to all three questions is 'yes'. The first section showed that breeding ravens use the landscape fundamentally differently than nonbreeding ravens, with respect to time and movement. Nonbreeding ravens showed minimum diurnal variation in movement rates, and in general moved at comparatively slow speeds. In contrast, breeding ravens and sage-grouse showed clear crepuscular increases in movement rate, with peaks for both groups occurring in late afternoon/evening. So, yes, breeding ravens had different spatiotemporal space use patterns than nonbreeding ravens.

The second section found that, after a raven nest was destroyed, the attending adults immediately shifted into a wide-ranging, erratic movement pattern and started using locations that were on average 3.6 times further away from the nest than prior to nest treatment. Untreated breeding ravens showed no such change in pattern during the same window, until a clear dispersal event likely coinciding with full fledging and dispersal of the young. So, yes, treating raven nests changed the way that breeding ravens used the landscape.

The third section found that raven nest treatment was strongly associated with improved sage-grouse nest success, but only in the PB study area. This may be explained by earlier research in these same areas that found a high level of raven predation in PB but low level of raven predation in YU Bench. The fact that the raven nest treatment didn't uniformly improve sage-grouse nest success, combined with independent knowledge of the suite of local predators, provides more evidence that the treatment may be successful in landscapes with large raven depredation issues.

In spite of a probable answer of 'yes' to the three research questions, caution is warranted due to the small sample size. Due to funding constraints we had a limited number of GPS units that could be deployed on both ravens and sage-grouse. In addition, ravens are notoriously difficult to capture, and in particular breeding ravens were very wary of humans in the capture phases of this study (C. Olson, pers. comm.). Add in field site access issues, and dealing with free-ranging animals that might die during the study or disperse out of the study area, and it becomes difficult to conclusively assess the effectiveness of any landscape-level field experiment. Nonetheless, all study results are consistent with hypotheses that breeding ravens use the landscape different than nonbreeding ravens, that destroying raven nests immediately changes how formerly breeding ravens use the landscape, and, in one of our study areas with a known high level of raven predation, that raven nest treatments were associated with marked improvements in sage-grouse nest success. Thus, while preliminary, these findings are promising.

Future research is crucial to determine if these findings hold up over time. Pertinent research questions are: Is raven nest treatment effective for long-term sage-grouse population uplift? Or does compensatory nest predation from coyotes and badgers ultimately negate any effectiveness of raven predation? Is raven nest treatment a useful short-term tool, but only applicable to areas with relative high raven and low coyote abundance? Or would it function in the long-term to ameliorate other human subsidies to raven populations that artificially increase raven impacts on sage-grouse populations? The answers to these questions, perhaps obtained through further experimental management, could lead to another useful tool in the toolbox of sage-grouse and land managers.

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MEETEETSE
CONSERVATION DISTRICT
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July 29, 2016

Kent Drake
Wyoming Animal Damage Management Board
2219 Carey Avenue
Cheyenne, WY 82002

Dear Kent,

Please find below the FY '16 final grant report and FY '16 financial reporting documents from the Meeteetse Conservation District (MCD) for the ADMB grant-funded project "Assessing and Reducing Common Raven Impacts on Greater Sage-grouse Nesting Ecology". This project began in 2011 and is ongoing as described in the presentations previously made to the ADMB.

ADMB Grant funds of $45,000 were awarded to MCD with an effective date of December 18, 2015 and required a total match of $120,500 as outlined in the revised project budget submitted on October 30, 2015. Please be aware that due to circumstances out of our control, the financial report will indicate that we were not able to meet the match requirement as conveyed to you during a phone conversation earlier this spring.

First, our proposed budget anticipated project expenses beginning December 1, 2015 but the contract was not executed until December 18, 2015. During that time, MCD paid project expenses totaling $8,440.

Second, as you might recall, expected revenues for the project that had been committed before the execution of the contract were later withdrawn due to the downturn in oil prices (and thus production) and associated revenues by the donor. We received $15,000 of the committed $60,000 leaving a $45,000 budget deficit. As a result, we were forced to cut project costs by shifting field duties originally to be performed by the project consultant and billed at $80/hr over to MCD staff at an average rate of $18.50/hr as in-kind contribution. This reduction in project revenues was in turn offset by a reduction in project expenses and resulted in our inability to meet the original match amount of $120,500. We did not feel as though a budget amendment was necessary though when we initially were made aware of the deficit because we still expected to meet or exceed the match amount but in hindsight, a budget amendment should have been initiated by MCD. It should be noted however that had the budget been amended to reflect the real project revenues and expenses, the (projected) amended match amount would've been met.

In summary, the supporting match fell short of the required $120,500 by $13,062.28.

Meeteetse Conservation District In-Kind	$94,077.53
Wildlife Services Personnel and Supplies, In-Kind (Park County PMD & Wyoming WS)	$9,861.50
Meeteetse Youth Work Program In-Kind	$998.69
Wyoming Woolgrowers Camp Trailer for seasonal staff	$2,500.00
WY Game & Fish-provided utilities and space for Camp Trailer for 1 month	
Total Supporting Funds	**$107,437.72**

Detailed records supporting the expenditure of the $45,000 grant funds, showing the match contributions, and other project expenditures can be found following the final grant report. Transactions met the contractual timing requirements.

Respectfully Submitted,

Steffen C. Cornell

Steffen Cornell
District Manager
Meeteetse Conservation District

Assessing and Reducing Common Raven Impacts on Greater Sage-grouse Nesting Ecology

Preliminary Report – July 29, 2016

In 2015, with funding support for a fifth consecutive year from ADMB, the Meeteetse Conservation District (MCD) entered into an agreement with Laramie based Hayden-Wing Associates (HWA) in an effort to build off of the first five years of data collection and analysis that had been previously conducted in partnership with researchers from National Wildlife Research Center in Logan, UT and Corvallis, OR. Beginning in the 2016 field season, the ongoing study shifted from an *evaluation of causes of mortality and predation rates of Sage-grouse in the Big Horn* to *assessing impacts of Common Ravens on Sage-grouse nesting success.* The following is meant to serve as a preliminary update on the status of the project to date, as data collection and other field activities are still currently underway and a final detailed analysis has not yet been prepared but will be distributed as soon as it is completed.

Brief Description of Project:

This project is a Control-Impact field experiment to 1) evaluate a targeted method for reducing raven impacts on sage-grouse nesting ecology, 2) quantify spatio-temporal interactions between raven and mammalian predators and sage-grouse hens, and 3) monitor sage-grouse hen movement, spatial ecology, and nesting ecology in the Bighorn Basin. We are conducting a combination non-lethal (raven nest removal) and lethal (raven egg removal) treatment method for two reasons. First, broad-brush lethal control of juvenile and adult ravens largely impacts transient individuals with minimal impact on nesting pairs that appear to have the largest impact on sage-grouse nest success (Bui et al. 2010, Dinkins 2013). Second, targeted lethal control of nesting pairs involves permit complications, locating and killing two mobile birds (rather than destroying the stationary nest), and results in an open nesting territory that subsequently will be occupied by another pair of breeding ravens. A targeted non-lethal/lethal option has the potential to effectively improve sage-grouse nest success while also being feasible to apply over large landscapes.

The other two aspects of this study (spatiotemporal interactions and sage-grouse hen ecology) will hopefully establish the link between the raven treatment and the sage-grouse response and will provide additional deliverables for use in population and land management for sage-grouse populations (e.g., demographic data, identifying critical seasonal habitats, etc.). Part of these two components is measuring the relative mammalian predation pressure across the study areas to differentiate the contribution of raven and mammalian predation in limiting sage-grouse nest success and brood survival. Specific deliverables will be the results of analyses including written reports, annual presentations, and peer-reviewed publications.

Field Activities and Preliminary Summary to Date:

We reduced the number of study sites from five (Fig. 1) across the Big Horn Basin to two study sites in eastern Park County. From previous field studies with the Big Horn Basin Sage-grouse Predation Project, we know that Polecat Bench (north of Powell) has higher raven depredation than the Sheets Flat project area (northeast of Meeteetse, the combination of previous study sites Oregon Basin and Fifteenmile) which are the field sites used in the experimental treatment component of the study. The downsizing of field sites to two locations allowed us to increase sample size in these areas and improve our analysis capabilities and replication.

Figure 1. 2011-2015 Study Areas

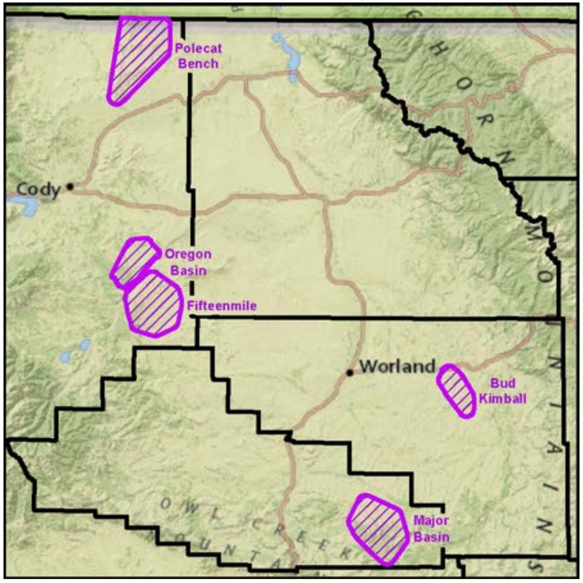
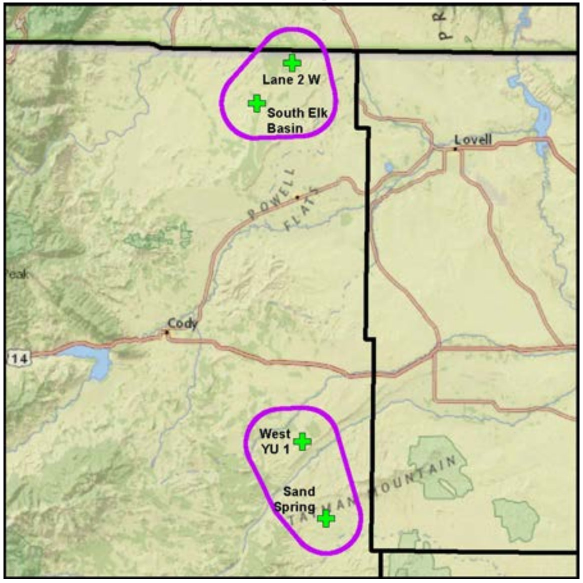


Figure 2. 2016 Capture Leks

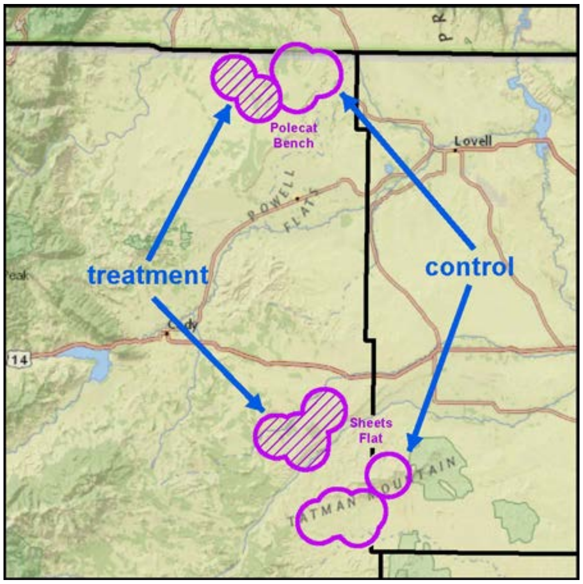


The 2016 field season began with Sage-grouse lek surveys in late February, early March. When target capture leks (Fig. 2) showed sufficient hen activity, captures were conducted in order to outfit hens with 30 gram solar-powered GPS/ARGOS PTT transmitters (Microwave Telemetry, Inc.). The goal was to have 10 sage-grouse tagged at each study area for a total of 20. Because there were still 3 tagged sage-grouse alive in the study areas from previous years, 17 sage-grouse hens were successfully captured in late March with the assistance of Wyoming Wildlife Services (WS), Park County Predator Management Board and other volunteers. 16 hens were caught using rocket nets and the other was a previously captured VHF bird (PB115) which was caught by spotlighting with hoop nets and an ATV.

Polecat Bench						Sheets Flat					
Hen ID	**Lek**	**Capt. Year**	**Hen ID**	**Lek**	**Capt. Year**	**Hen ID**	**Lek**	**Capt. Year**	**Hen ID**	**Lek**	**Capt. Year**
PB115	South Elk Basin	2015	PB028	Polecat Burn	2013	OB027	Fork in Road	2013	SFS61	Sand Spring	2016
PBW60	South Elk Basin	2016	PBE61	Lane 2 W	2016	OB047	Fork in Road	2014	SFS63	Sand Spring	2016
PBW62	South Elk Basin	2016	PBE63	Lane 2 W	2016	SFN60	West YU 1	2016	SFS65	Sand Spring	2016
PBW64	South Elk Basin	2016	PBE65	Lane 2 W	2016	SFN62	West YU 1	2016	SFS67	Sand Spring	2016
PBW66	South Elk Basin	2016	PBE67	Lane 2 W	2016	SFN64	West YU 1	2016	SFS69	Sand Spring	2016

Project personnel from HWA and MCD trapped a total of 12 ravens across both study areas. The goal was to capture 3 breeding ravens in each treatment or control half of each study area (Fig. 3) in order to evaluate the effect of nest treatments on sage-grouse nesting. We employed various methods of trapping ravens which included baiting with dead rabbits into remote-detonated net launchers or padded leg hold traps and surprise ambushes at nest sites by sneaking into the site after dark with hoop nets. The first two ravens were captured with hoop nets but this method was inefficient and dangerous in cliff habitat. Due to the wary nature of ravens they avoided the net launchers but at least 9 out of the 12 ravens were captured using padded leg hold trap sets at perch sites where ravens had been previously observed. It was discovered that 3 non-breeding ravens were inadvertently trapped on Polecat Bench after reviewing initial data downloads and mapping movement patterns.

Figure 3. 2016 Study Areas



6 male and 6 female ravens were outfitted with 30 gram solar powered CTT-1000-BT3 Series GPS-GSM transmitters (Cellular Tracking Technologies). These transmitters allow for much faster sampling intervals and have allowed us to measure raven movement patterns more accurately during the grouse nesting season. Raven transmitters were set to record positions at 3-5 minute intervals during the grouse nesting season. GPS locations from CTT transmitters are collected via cellular technology and have been regularly monitored. To date, we are still collecting data from 8 ravens and know that at least 1 other female raven is still alive and can see the transmitter on her even though the unit is not transmitting data which could be due to poor cellular strength or it has not recharged since spending the majority of her time in a cliff nest, out of direct sunlight.

Based on previous field studies by HWA in Wamsutter, WY, we note that ravens forage within 2 miles of their nests, most heavily within 1.5 miles of their nests (HWA, manuscript in prep). The majority of sage-grouse tend to nest within 3 miles of known leks (Holloran and Anderson 2005; HWA, unpublished data). Following this knowledge, the main focus for raven nest removal (treatment) for this project was within 4 miles of 2016 sage-grouse nests within the treatment side of each field site (Fig. 3). For the treatment side of each field site, MCD employees performed treatment actions throughout the raven nesting season, which included searching for and destroying or removing raven nests, chicks or eggs. 3 eggs and 4 chicks from 2 nests were removed from the PB treatment area and 17 chicks from 5 nests were removed from the SF treatment area. On the control sides of the field site, we did not remove raven nests to allow for comparison of treatment to control. Removal of active raven nests, chicks and eggs was approved by Wyoming Game and Fish (permit ID: 1056) and the U.S. Fish and Wildlife Service (permit # MB85114B-0).

Sage-grouse transmitters were programed to record 5-15 GPS-quality (±18 meters) locations per day for each hen, depending on the time of year, and the location data is received via the ARGOS satellite system (CLS America, Inc.) every three days (two days during nesting). Locations were downloaded regularly in order to locate nests, conduct brood counts and investigate causes of mortality. One hen slipped her transmitter (PBW60) and four hens have died. The table below illustrates total number of data points collected for each hen since April 1, 2016 as well as vital status.

Polecat Bench

Hen ID	Data Points	Status	Hen ID	Data Points	Status
PB115	1,165	Alive	PB028	1,385	Alive
PBW60	78	Slipped	PBE61	1316	Alive
PBW62	1,334	Alive	PBE63	1,234	Alive
PBW64	1,430	Alive	PBE65	1,206	Alive
PBW66	1,238	Alive	PBE67	132	Dead

Sheets Flat

Hen ID	Data Points	Status	Hen ID	Data Points	Status
OB027	1,352	Alive	SFS61	1,352	Alive
OB047	642	Dead	SFS63	1222	Alive
SFN60	1,395	Alive	SFS65	1,219	Alive
SFN62	545	Dead	SFS67	797	Dead
SFN64	1,329	Alive	SFS69	1,167	Alive

25 nests were initiated by 18 tagged sage-grouse with 5 being successful (≥ 1 egg hatching), 2 nests on the treatment side and 1 on the control side of Polecat Bench and 1 nest on both the treatment and control sides of Sheets Flat. 1 nest (PBW64) was inconclusive of nest fate and 19 nests failed, resulting in a 20% success rate which is lower than in years past for these areas. 3 broods were field verified at 35 days or after, 2 broods of 3 and 1 brood of 2. One bird that hatched successfully (SFS67) was found sick with no brood. The final was never field verified.

Figure 4. Polecat Bench Brood Movements

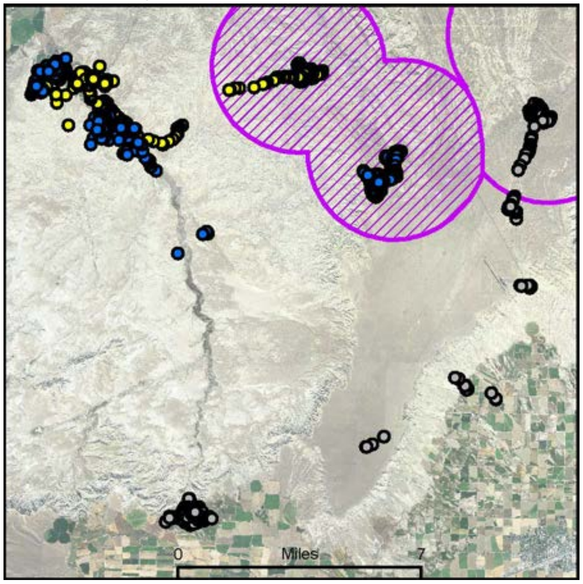
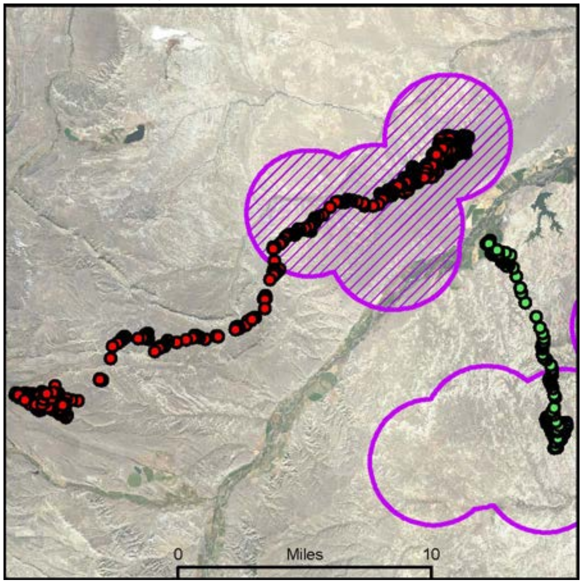


Figure 5. Sheets Flat Brood Movements



A camera grid was established in 2016 to quantify density of mammalian predators. The location of the camera grid survey was established within a 4km buffer around our 2016 SG nests for both the PB and SF study areas. Cameras were deployed systematically across the area in a series of 4 rounds (see Fig. 6 below for example). Cameras were placed in a northerly facing direction and skunk scent was applied as an attractant ~3-5m from the camera. Each camera location was recorded via GPS; therefore the detections of mammalian predators can be spatially represented. 3 of 4 rounds of surveys have already been conducted. In the 3 rounds, 259 cameras were placed for a total of 4,238 camera trap days. There were a total of 144 detections of mammalian predators, consisting mostly of coyotes, though badgers, fox, skunks, bobcats, and 1 weasel were also present. Polecat Bench accounted for 50 detections, while Sheets Flat had 94.

Site and Round	Cameras	Days Deployed	Detections	Camera Days
Polecat Bench 1	35	12	7	420
Polecat Bench 2	33	15	18	495
Polecat Bench 3	34	19	25	646
Sheets Flat North 1	25	15	9	375
Sheets Flat North 2	24	20	23	480
Sheets Flat North 3	28	16	12	448
Sheets Flat South 1	22	15	10	330
Sheets Flat South 2	29	20	16	580
Sheets Flat South 3	29	16	24	464
Total	259	148	144	4238

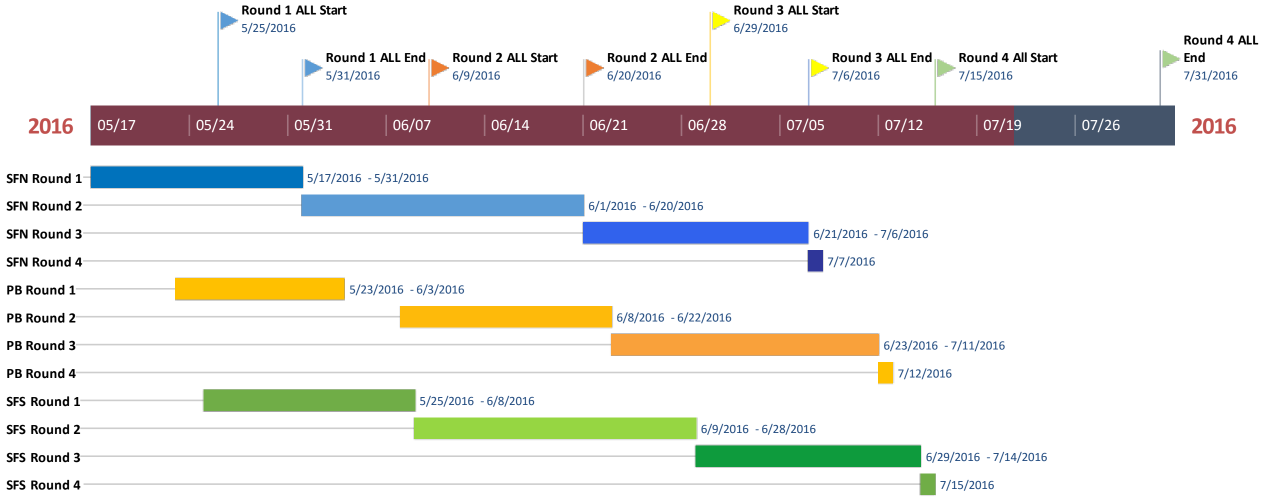
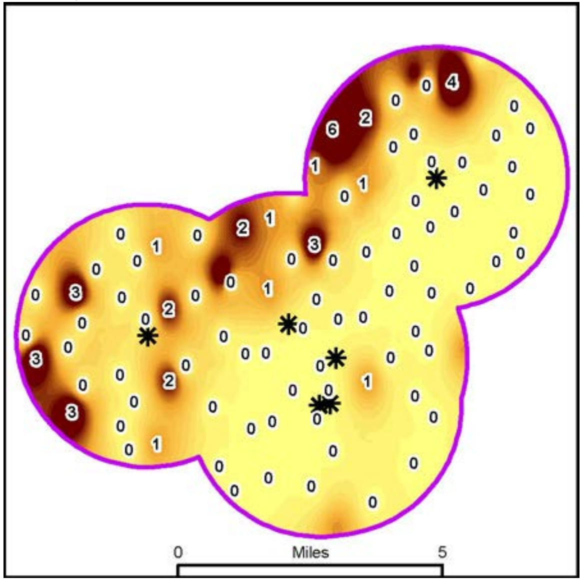


Figure 6. Sheets Flat North Predator Detections and SG nests



Detailed Financial Report from 12/1/15 to 7/11/16 .

		Type	Date	Num	Name	Memo	Paid Amount
	Sage G. Pred Proj						
	Contributions - Other						
		Deposit	12/28/2015		Wyo-Ben, Inc.	Wyo-Ben 015 Donation in support of SGPP	15,000.00
		Deposit	12/09/2015		Shoshone CD	Donation in support of SGPP	3,000.00
		Deposit	03/08/2016		Park Cnty Farm Bureau	2016 Donation in Support of SGPP	1,000.00
		Deposit	03/25/2016		Washakie Cnty CD	Donation in support of SGPP	2,000.00
	Total Contributions - Other						21,000.00
	ADMB Grant 2015-2016						
		Check	01/11/2016	3190	Nolan Hicks	Travel to/from Cody for PMD meeting for SGPP 60 miles #11-9719 (MCD reimbursed 02/17/16)	-33.60
		Check	01/11/2016	3190	Nolan Hicks	Field tested raven tracker units in 15 mile study area 58 miles #11-9719 (MCD reimburse...	-32.48
		Deposit	01/12/2016		State of WY - ADMB	ADMB 2015-2016 Grant Deposit	45,000.00
		Check	02/08/2016	3198	HWA, LLC	HWA - Admin/Project Mgr Wages - 14 hrs @ $85/hr (MCD reimbursed 02/17/16)	-1,190.00
		Check	02/08/2016	3198	HWA, LLC	HWA - Wildlife Biologist-I/GIS Specialist - 1.0 hr @ $80/hr (MCD reimbursed 02/17/16)	-80.00
		Check	02/08/2016	3198	HWA, LLC	HWA - Senior Tech/Office Mgmt - 5.5 hrs @ $65/hr (MCD reimbursed 02/17/16)	-357.50
		Check	02/08/2016	3198	HWA, LLC	HWA - WP/Ofc Assistant - 3.0 hrs @ $60/hr (MCD reimbursed 02/17/16)	-180.00
		Check	02/08/2016	3201	CLS America	CLS Telnet (2 @ $0.30 ea) (MCD reimbursed 02/17/16)	-0.60
		Check	02/08/2016	3201	CLS America	CLS ARGOS Location & Collection (74.25 @ $6.95/ea) (MCD reimbursed 02/17/16)	-516.04
		Check	02/08/2016	3201	CLS America	CLS Monthly Active Platform Fee for January (22.00 @ $13.90/ea) (MCD reimbursed 02/17/16)	-305.80
		Check	04/11/2016	3213	HWA, LLC	HWA - Administration/.Project Mgr Fees (32.0 hrs @ $85/hr) (MCD reimbursed out of WGIF-SGPP acc...	-2,720.00
		Check	04/11/2016	3213	HWA, LLC	HWA - Wildlife Biologist/I/GIS Specialist Fees (6.5 hrs @ $80/hr) (MCD reimbursed out of WGIF-...	-520.00
		Check	04/11/2016	3213	HWA, LLC	HWA - Senior Tech/Ofc Mgmt Fees (2.5 hrs @ $65/hr) (MCD reimbursed out of WGIF-SGPP account on...	-162.50
		Check	04/11/2016	3213	HWA, LLC	HWA - WP/Ofc Asst Fees (2.5 hrs @ $60/hr) (MCD reimbursed out of WGIF-SGPP account on 04-11-2016)	-150.00
		Check	04/11/2016	3213	HWA, LLC	HWA - Cellular Tracking Tech - 12 GPS-GSM solar-powered Telemetry Units/data service (MCD reimb...	-37,900.00
		Check	05/09/2016	3219	HWA, LLC	Wildlands Photography & Bio-Consulting (raven trapper) (MCD reimbursed 05/05/2016)	-851.48
	Total ADMB Grant 2015-2016						0.00
	MCD In Kind						
		Check	12/14/2015	3186	Pinnacle Bank - VISA	In Kind - Exxonmobile - Thermopolis - Travel to ADMB meeting coffees	-2.40
		Check	12/14/2015	3186	Pinnacle Bank - VISA	In Kind - Wonder Bar - Casper - Lunch during ADMB meeting	-50.78
		Check	12/14/2015	3187	Pinnacle Bank - VISA	In Kind - WEA Market - fuel for Ford Escape	-32.23
		Check	12/14/2015	3187	Pinnacle Bank - VISA	In Kind - USPS - mail documents to JT	-4.73
		Check	12/14/2015	3187	Pinnacle Bank - VISA	In Kind - USPS - mail documents to JT	-2.74
		Check	12/14/2015	3187	Pinnacle Bank - VISA	In Kind - mail GPS back to vender	-13.10
		Check	12/31/2015	3188	Nolan K Hicks	In Kind - developed contact sheet for landowners, researched explosive storage, studied maps, et...	-432.00

		Type	Date	Num	Name	Memo	Paid Amount
		Check	12/31/2015	3188	Nolan K Hicks	In Kind - attend Park cnty PMB meeting in Cody, field-tested tracking devices for HWA & sent dat...	-296.00
		Check	12/31/2015	3110	Steffen C. Cornell	In Kind - FWS permits, APHIS/NWRC amendments, mapping & field testing of GSM radios, ordered 4 A...	-1,922.40
		Check	01/11/2016	3120	Pinnacle Bank - VISA	In Kind - WEA Market - fuel for Escape	-14.00
		Check	01/11/2016	3120	Pinnacle Bank - VISA	In Kind - USPS - Meeteetse - mailed GPS back to HWA & mailed capture permit to F&G	-7.17
		Check	01/31/2016	3123	Virginia L. Davis	In Kind - telephone conference regarding APHIS/WS/NWRC agreement (3.0 hrs)	-42.00
		Check	01/31/2016	3197	Nolan K Hicks	In Kind - RS Wages - review HWA/MCD agreement, labelled & organized SG nest cameras, reviewed le...	-96.00
		Check	01/31/2016	3122	Steffen C. Cornell	In Kind - RS Wages - phone conferrences w/Mark Tobin/JT, talked to Jeremiah Rieman on FNRPA fund...	-1,800.00
		Check	02/08/2016	3130	Pinnacle Bank - VISA	In Kind - USPS - mailed out WS permit application & CD to Jimmy Taylor	-2.62
		Check	02/08/2016	3130	Pinnacle Bank - VISA	In Kind - Elkhorn Bar & Grill - Lunch for Special Board Meeting regarding APHIS/WS/NWRC agreement	-77.60
		Check	02/29/2016	3202	Nolan K Hicks	In Kind - labeled game cams (4.0 hrs)	-64.00
		Check	02/29/2016	3131	Steffen C. Cornell	In Kind - RS Wages - edits to landowner consent forms, met w/landowners for signatures, SGPP map...	-2,642.40
		Check	03/14/2016	3204	Microwave Telemetry, Inc	In Kind - MTI - 2 x 30g GPS PTT-100 Satellite Transmitters @ $3,950 each	-7,900.00
		Check	03/14/2016	3204	Microwave Telemetry, Inc	In Kind - MTI - 6 x GPS PTT-100 Satellite Transmitters (Refurbished) @ $200.00 each	-1,200.00
		Check	03/14/2016	3204	Microwave Telemetry, Inc	In Kind - MTI - 15 x Reporgramming @ $50.00 each	-750.00
		Check	03/14/2016	3136	Pinnacle Bank - VISA	In Kind - USPS - mailed plane antennas back for refund	-43.50
		Check	03/14/2016	3208	CLS America	In Kind - CLS America - ARGOS Location & Collection - Feb 2016 (33.75 @ $6.95 ea)	-234.56
		Check	03/14/2016	3208	CLS America	In Kind - CLS America - Monthly Active Platform Fee - Feb 2016 (10 @ $13.90 ea)	-80.02
		Check	03/14/2016	3203	Nolan Hicks	In Kind - Blackstone Gulch Lek for lek monitoring 28 miles #11-9719	-15.12
		Check	03/14/2016	3203	Nolan Hicks	In Kind - Blackstone Gulch Lek for lek monitoring 28 miles #11-9719	-15.12
		Check	03/14/2016	3203	Nolan Hicks	In Kind - Rimrock Basin Lek for lek monitoring 39 miles #11-9719	-21.06
		Check	03/14/2016	3203	Nolan Hicks	In Kind - Sand Spring Lek for lek monitoring 42 miles #11-9719	-22.68
		Check	03/14/2016	3208	CLS America	In Kind - CLS America - TELNET - Feb 2016 2016 (1 @ $.30 ea)	-0.30
		Check	03/28/2016	3210	Nolan Hicks	In Kind - Monitoring Blackstone Gulch & Rimrock Basin Leks 62 miles #11-9719	-33.48
		Check	03/28/2016	3210	Nolan Hicks	In Kind - Monitoring Oregon Basin & Fork in Road Leks 32 miles #11-9719	-17.28
		Check	03/28/2016	3210	Nolan Hicks	In Kind - Monitoring Blackstone Gulch & Rimrock Basin Leks 42 miles #11-9719	-22.68
		Check	03/28/2016	3210	Nolan Hicks	In Kind - To/From Cody to prep camper for SGPP summer techs 60 miles #11-9719	-32.40
		Check	03/28/2016	3210	Nolan Hicks	In Kind - Monitoring Blackstone Gulch & Rimrock Basin Leks 42 miles #11-9719	-22.68
		Check	03/31/2016	3142	Steffen C. Cornell	In Kind - RS Wages - edits to Roundup article, contacting landowners for access, permit inquiry ...	-2,503.20
		Check	03/31/2016	3142	Steffen C. Cornell	In Kind - RS Wages - ARGOS checks (9.5 hrs)	-228.00
		Check	04/11/2016	3212	Town of Meeteetse	In Kind - Registration for 2016 MYWP (Wilson Renner)	-275.00
		Check	04/11/2016	3215	CLS America	In Kind - ARGOS location & collection for animals contract #4374 Prog: 5894 56.7...	-394.41
		Check	04/11/2016	3215	CLS America	In Kind - Monthly active platform fee for March 2016 26.00 @ $13.90	-361.40
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Amazon.com - Contact cement for SGPP harnesses (SC)	-4.47

		Type	Date	Num	Name	Memo	Paid Amount
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Ace Hardware/Cody - misc supplies to repair camper for raven trappers (SC)	-19.74
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind- Ace Hardware/Cody - misc supplies to repair camper for reaven trappers (SC)	-5.48
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Amazon.com - 4 pkgs of 48 AA batteries for SGPP cameras 4 @ $12.09 (SC)	-48.36
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Cabela's - GARMIN RINO 650 (SC)	-389.99
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Amazon.com - QuickTite Super Glue Gel for SGPP harnesses (GD)	-6.14
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Amazon.com - QuickTite Super Glue Gel for SGPP harnesses (GD)	-5.15
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Ace Hardware/Cody - misc supplies needed to repair camper for raven trappers (GD)	-93.25
		Check	04/11/2016	3153	Pinnacle Bank - VISA	In Kind - Ron's ExxonMobile/Cody - propane for camper (GD)	-49.86
		Check	04/30/2016	3156	Steffen C. Cornell	In Kind - RS Wages - participated in raven captures, lek monitoring, raven locating (83.0 hrs)	-1,992.00
		Check	04/30/2016	3156	Steffen C. Cornell	In Kind - RS Wages - ARGOS checks (4.0 hrs)	-96.00
		Check	05/09/2016	3218	Steffen Cornell	In Kind - Lek monitoring, raven trapping, locating deceased grouse, etc. 864 miles 11-21291	-466.56
		Check	05/09/2016	3219	HWA, LLC	In Kind - Admin/Project Manager (32.5 hrs @ $85)	-2,762.50
		Check	05/09/2016	3219	HWA, LLC	In Kind - Wildlife Biologist - I/GIS Specialist (10.0 hrs @ $80)	-800.00
		Check	05/09/2016	3219	HWA, LLC	In Kind - Travel & Per Diem (3 days @ $250/day)	-450.00
		Check	05/09/2016	3219	HWA, LLC	In Kind - Travel & Per Diem (678 3/4 miles)	-678.75
		Check	05/09/2016	3219	HWA, LLC	In Kind - Wildlands Photography & Bio-Consulting (raven trapper)	-3,555.68
		Check	05/09/2016	3164	Pinnacle Bank - VISA	In Kind - Ace Hardware - Cody - supplies & materials for prepping camper for summer field help &...	-100.93
		Check	05/09/2016	3164	Pinnacle Bank - VISA	In Kind - Ace Hardware - Cody - tie wire for rebar - raven captures	-8.31
		Check	05/09/2016	3164	Pinnacle Bank - VISA	In Kind - Domino's Pizza - Cody - meal for SC & raven trappers while looking at maps, etc. (no ...	-28.07
		Check	05/09/2016	3164	Pinnacle Bank - VISA	In Kind - McCue Automotive - Cody - batteries for the camper	-265.00
		Check	05/09/2016	On-line	Pinnacle Bank - VISA	In Kind - WEA Market - fuel for Escape	-11.50
		Check	05/31/2016	3223	Karen R Fenton	In Kind - Monitor Blue Bank Lek & BK117's C&B nest sites (5.5 hrs)	-82.50
		Check	05/31/2016	3224	Wilson Renner	In Kind - raven captures on PB & FM, placed cameras in Powell at Polecat Bench & 15 Mile, raven ...	-606.25
		Check	05/31/2016	3225	Gary L Mizer	In Kind - assembled camera mounts, installed cameras, nest check across upper basiin area (115 ...	-2,070.00
		Check	05/31/2016	3224	Wilson Renner	In Kind - put batteries & sG cards in cameras, cut metal & assembled camera stands, placed camer...	-162.50
		Check	05/31/2016	3168	Steffen C. Cornell	In Kind - DM Wages - raven captures, Vanguard operating, raven nest removeals, worked with Seth ...	-2,855.00
		Check	05/31/2016	3168	Steffen C. Cornell	In Kind - DM Wages - ARGOS checks (1.0 hrs)	-25.00
		Check	06/13/2016	3226	Karen Fenton	In Kind - Mileage for monitoring Blue Bank Lek & BK117 B&C nesting sites 44 miles 11-1234	-23.54
		Check	06/13/2016	3228	HWA, LLC	In Kind - Wages - Administration/Project Manager (35.5 hrs @ $85/hr)	-3,017.50
		Check	06/13/2016	3228	HWA, LLC	In Kind - Wages - Wildlife Biologist-I/GIS Specialist (13.0 hrs @ $80/hr)	-1,040.00
		Check	06/13/2016	3228	HWA, LLC	In Kind - Wages - Senior Technician/Ofc Mgmt (1.5 hrs @ $65/hr)	-97.50
		Check	06/13/2016	3228	HWA, LLC	In Kind - Wages - Word Processing/Ofc Asst (2.5 hrs @ $60/hr)	-150.00
		Check	06/13/2016	3228	HWA, LLC	In Kind - Per Diem 2 days @ $150/day	-300.00

		Type	Date	Num	Name	Memo	Paid Amount
		Check	06/13/2016	3228	HWA, LLC	In Kind - Mileage 411 miles @ $1.00/mile	-411.00
		Check	06/13/2016	3228	HWA, LLC	In Kind - 5 hours ArcGIS @ $30/hr	-150.00
		Check	06/13/2016	3228	HWA, LLC	In Kind - Wildlands Photography & Bio-Consulting (raven trapper)	-4,055.58
		Check	06/13/2016	3230	Wea Market	In Kind - Receipt #2063 `Fuel for Can AM SGPP	-13.44
		Check	06/13/2016	3230	Wea Market	In Kind - Receiept #4255 Fuel for Can AM SGPP	-15.39
		Check	06/13/2016	3231	Gary Mizer	In Kind - Mileage for SGPP 994 miles AP9 9226	-536.76
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Albertson's - corn oil for raven eggs	-4.49
		Check	06/13/2016	3178	Pinnacle Bank - VISA	In Kind - WEA Market - fuel for Escape for use on SGPP	-10.68
		Check	06/13/2016	3235	CLS America	In Kind - ARGOS location & Collection 118.00 @ $6.95	-820.10
		Check	06/13/2016	3235	CLS America	In Kind - Monthly Active Platform Fee 23.00 @ $13.90	-319.70
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Amazon.com - 100 count ACDelco AA batteries 16 @ $22.99/bx	-367.84
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Roger's Sport Center - Wyoming Off Road Vehicle User Fee - CanAm	-15.00
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Ace Hardware - nuts and bolts for camera stands	-18.48
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Pro-Build - rebar and flat bar for camera stands	-80.91
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Ace Hardware - Cody - saw blade, clamps, pvc pipe for making scent traps	-21.54
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Amazon.com - silicone mold for making scent traps	-26.68
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Amazon.com - Odorless insect repellent, (14.99) SlimMate plastic storage clipboard (7.97)	-22.96
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Ace Hardware - Cody - plaster of paris for making scent traps	-1.24
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Amazon.com - Pete Rickard's fish oil 2 @ $5.20 ea	-10.99
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Pro-Build - rebar for camera stands	-13.48
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Rocky Mountain Discount Sports - Coyote Juice	-10.99
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - The UPS Store - mailed ADMB Grant proposal	-2.89
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Pizza Hut - Cody - meal for SC/GM/WR during late work session	-16.63
		Check	06/13/2016	3233	Pinnacle Bank - VISA	TBR - Exxonmobil (Good 2 Go) Ralston WY - Fuel for Escape during SGPP use	-17.23
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Pro-Build - rebar for camera stands	-13.48
		Check	06/13/2016	3233	Pinnacle Bank - VISA	In Kind - Amazon.com - Odorless Insect repellent spray	-14.99
		Check	06/30/2016	3236	Karen R Fenton	In Kind - RT & Other Wages - retrieved camera at Red Reflett Airport (2.5 hrs @ $15.00/hr)	-37.50
		Check	06/30/2016	3237	Joshua D Kipley	In Kind - RT & Other Wages - placed cameras in Sheep Flats, OB & PB, picked up & replaced camera...	-555.60
		Check	06/30/2016	3238	Gary L Mizer	In Kind - RS Wages - placed cameras, picked up cameras, prepped cameras, processed SD camera dow...	-3,171.60
		Check	06/30/2016	3239	Wilson Renner	In Kind - RT & Other Wages - Camera Grid Survey in OB, 15 Mile, PB, PTT Search in Thermopolis (...	-756.25
		Check	06/30/2016	3240	Karen Fenton	In Kind - To/from Red Reflett Airport 36 miles	-19.44
		Check	06/30/2016	3241	Gary Mizer	In Kind - Travel to/from various locations for raven nests, brook counts, posting & pickup of SG...	-695.52
		Check	06/30/2016	3242	Wilson Renner	In Kind - place cameras, pick up cameras, grid surveys, etc. SGPP 11-19870 378 miles	-204.12

		Type	Date	Num	Name	Memo	Paid Amount
		Check	06/30/2016	3242	Wilson Renner	In Kind - 4-wheeler miles in 15 Mile for camera grid survey 127 miles	-64.67
		Check	06/30/2016	3179	Steffen C. Cornell	In Kind - DM Wages - worked w/RS & RT personnel in field w/cameras, etc. (116.7 hrs)	-2,917.50
		Check	07/11/2016	3246	Steffen Cornell	In-Kind - mileage reimbursement for raven captures, nest removals, trail cam placements in OB, P...	-342.36
		Check	07/11/2016	3246	Steffen Cornell	In-Kind - Park County Library - copies for SGPP	-1.50
		Check	07/11/2016	3246	Steffen Cornell	In Kind - Maverick (Powell) - fuel for CanAm	-10.00
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - Ghostown - Casper - fuel for Escape during ADMB meeting in Casper	-30.21
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - Maverik - Thermopolis - fuel for Escape during travels to ADMB meeting in Casper	-15.23
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - KFC - Casper - lunch during ADMB meeting in Casper	-12.47
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - Outlaw Cafe - Pizza for staff working through dinner on SGPP	-18.71
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - Walmart - Cody - swivels & "bolo mechete???)	-38.89
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - Walmart - Cody - 500 ct swabs for SGPP	-21.80
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - Ace Hardware - Cody - rental deposit & use fee for metal detector ($20 deposit was ref...	-31.00
		Check	07/11/2016	3249	Pinnacle Bank - VISA	In Kind - Walmart - misc for SGPP (no receipt)	-12.82
	Total MCD In Kind						-59,892.25
	MCD TBR						
		Check	07/11/2016	3244	Joshua Kipley	TBR - Mileage reimbursement for locating hens, placing & picking up cameras in OB & SF 11-27...	-124.74
		Check	07/11/2016	3245	Wilson Renner	TBR - mileage reimbursement for placing cameras in 15 Mile, camera grid survey & placing camers ...	0.00
		Check	07/11/2016	3245	Wilson Renner	TBR - 4-wheeler mileage reimbursement for camera grid surveys in 15 mile 127 miles @ $.51	0.00
		Check	07/11/2016	3247	Wea Market	TBR - Wea Market - fuel for Escape and CanAm	-125.81
		Check	07/11/2016	3251	HWA, LLC	TBR - Labor - Administration/Project Manager 12.0 hrs @ $85/hr	-1,020.00
		Check	07/11/2016	3252	CLS America	TBR - ARGOS Location & Collection 111.50 @ $6.95/ea	-774.93
		Check	07/11/2016	3252	CLS America	TBR - Monthly Active Platform Form 22 @ $13.90/ea	-305.80
		Check	07/11/2016	3249	Pinnacle Bank - VISA	TBR - Amazon.com - Transcend 32 GB Flash Memory Cards 10 @ $11.99 ea	-119.90
		Check	07/11/2016	3249	Pinnacle Bank - VISA	TBR - Amazon.com - Transcend 32 GB Flash Memory Cards 10 @ $11.99 ea	-119.90
		Check	07/11/2016	3251	HWA, LLC	TBR - Labor - Wildlife Bioilogist-I/GIS Specialist 11.0 hrs @ $80/hr	-880.00
		Check	07/11/2016	3251	HWA, LLC	TBR - Labor - Senior Tech/Ofc Mgmt 1.0 hr @ $65/hr	-65.00
		Check	07/11/2016	3251	HWA, LLC	TBR - Labor - Word Processing/Ofc Asst 2.0 hrs @ $60/hr	-120.00
		Check	07/11/2016	3251	HWA, LLC	TBR - Per Diem - 1/2 Day @ $150/day	-75.00
		Check	07/11/2016	3251	HWA, LLC	TBR - Travel Expenses (Mileage) - 151 miles @ $1/mile	-151.00
		Check	07/11/2016	3251	HWA, LLC	TBR - Misc - ArcGIS - 2 hrs @ $30/hr	-60.00
	Total MCD TBR						-3,942.08
	Wyo-Ben Funds						
		Check	12/14/2015	3184	HWA, LLC	Pre-contract work - Admin/Project Manager (Chad) 20.0 hrs @$85.00/hr (MCD reimbursed 02/17/16)	-1,700.00

		Type	Date	Num	Name	Memo	Paid Amount
		Check	12/14/2015	3184	HWA, LLC	Pre-contract work - Wildlife Biologist - I/GIS Specialist (Seth & Jen) 61.5 hrs @ $80.00/hr (M...	-4,920.00
		Check	01/11/2016	3189	CLS America	CLS America - ARGOS location & collection for December 2015 (29.75 @ $6.95) (MCD reimbursed 02...	-206.76
		Check	01/11/2016	3189	CLS America	CLS America - Monthly active platform fee for December 2015 (7.00 @ $13.90) (MCD reimbursed 02...	-97.30
		Check	03/14/2016	3204	Microwave Telemetry, Inc	MTI - 2 x 30g GPS PTT-100 Satellite Transmitters @ $3,950 each (MCD reimbursed 05/05/2016)	-7,900.00
		Check	03/28/2016	3210	Nolan Hicks	BK116 AGROS Retrieval 186 miles #11-9719 (MCD reimbursed 05/05/2016)	-100.44
		Check	04/30/2016	3216	Karen R Fenton	RT & Other Wages - lek monitoring BK area (6.5 hrs) (MCD reimbursed 05/05/2016)	-98.21
		Check	05/09/2016	3217	Karen Fenton	Mileage - Lek monitoring in BK area 50 miles #20-6843 (MCD reimbursed 05/05/2016)	-52.38
		Check	05/09/2016	3220	CLS America	ARGOS Location & Collection for April, 2016 (117.75 @ $6.95 ea) (MCD reimbursed 05/05/2015)	-818.36
		Check	05/09/2016	3220	CLS America	Monthly active platform fee (24.00 @ $13.90 ea) (MCD reimbursed 05/05/2016)	-333.60
	Total Wyo-Ben Funds						-16,227.05
	Sage G. Pred Proj - Other						
		Check	12/14/2015	3184	HWA, LLC	Pre-contract work - Senior Technician/Office Mgmt (Linda) 5.5 hrs @ $65.00/hr (MCD reimbursed ...	-357.50
		Check	12/14/2015	3184	HWA, LLC	Pre-contract work - Word Processing/Offc Asst (Connie) 2.0 hrs @ $60.00/hr (MCD reimbursed 02/...	-120.00
		Check	12/14/2015	3184	HWA, LLC	Travel & Per Diem - 1 Day @ $150.00/day (MCD reimbursed 02/17/16)	-150.00
		Check	12/14/2015	3184	HWA, LLC	Travel (flight & parking) (MCD reimbursed 02/17/16)	-877.70
		Check	12/14/2015	3185	CLS America	CLS America - ARGOS location & Collection for Nov 2015 (29.25 @ $6.95 ea) (MCD reimbursed 02/1...	-203.29
		Check	12/14/2015	3185	CLS America	CLS America - Monthly active platform fee for Nov 2015 (8.00 @ $13.90 ea) (MCD reimbursed 02/1...	-111.20
		Check	01/31/2016	3122	Steffen C. Cornell	RS Wages - ARGOS checks (5.0 hrs) (MCD reimbursed 02/17/16)	-120.00
		Check	03/14/2016	3205	HWA, LLC	HWA - Administration/Project Manager Wages 7.5 hrs @ $85/hr (MCD reimbursed 05/05/2016)	-637.50
		Check	03/14/2016	3205	HWA, LLC	HWA - Senior Technician/Office Mgmt Wages 1.0 hr @ $65/hr (MCD reimbursed 05/05/2016)	-65.00
		Check	03/14/2016	3205	HWA, LLC	HWA - Word Processing/Office Asst Wages 1.5 hrs @ $60/hr (MCD reimbursed 05/05/2016)	-90.00
		Check	03/14/2016	3136	Pinnacle Bank - VISA	Various vendors for capture items	-156.41
		Check	03/14/2016	3208	CLS America	CLS America - Monthly Active Platform Fee - Feb 2016 (10 @ $13.90 ea) (MCD reimbursed 05/05/2016)	-58.98
		Check	04/30/2016	3216	Karen R Fenton	RT & Other Wages - lek monitoring BK area (3.5 hrs) (MCD reimbursed 05/05/2016)	-51.79
		Check	05/09/2016	3219	HWA, LLC	Senior Tech/Ofc Mgmt (1.0 hr @ $65/hr) (MCD reimbursed 05/05/2016)	-65.00
		Check	05/09/2016	3219	HWA, LLC	Word Processing/Office Assistant (1.0 hr @ $60) (MCD reimbursed 05/05/2016)	-60.00
		Check	05/09/2016	3219	HWA, LLC	3 Hours ArcGIS @ $30/hr (MCD reimbursed 05/05/2016)	-90.00
		Check	05/09/2016	3219	HWA, LLC	Step Wilson (raven trapper) (MCD reimbursed 05/05/2016)	-10,695.00
		Check	05/09/2016	3164	Pinnacle Bank - VISA	Taco Johns - Powell - meal while capturing ravens	-8.53
		Check	05/09/2016	3164	Pinnacle Bank - VISA	WEA Market - fuel for Escape - raven captures	-18.00
		Check	05/09/2016	3219	HWA, LLC	Travel & Per Diem (80 1/4 miles) (MCD reimbursed 05/05/2016)	-80.25
	Total Sage G. Pred Proj - Other						-14,016.15
Total Sage G. Pred Proj							**-94,077.53**

Steffen Cornell

From: Burrell, Michael B - APHIS <Michael.B.Burrell@aphis.usda.gov>
Sent: Thursday, July 07, 2016 10:07 AM
To: 'Steffen Cornell'
Subject: RE: time spent on SG captures

Hi Steffen,

Here are some totals:

244.5 total hours spent on sage grouse project.

180.5 were from field employees while 54 hours were from field and management time by district supervisor. Another 10 hours was spent by administration in State Office.

Total amount: 180.5 x 35$= $6,317.50, 64 x 50.5= $3,232.00 = $9549.50

Thanks.

Michael Burrell
District Supervisor, USDA APHIS Wildlife Services
3520 Cottonwood Ave.
Cody, Wyoming 82414
Office: 307-527-1115
Cell: 307-250-9409

From: Steffen Cornell [mailto:mcdrs@tctwest.net]
Sent: Wednesday, July 06, 2016 8:42 AM
To: Burrell, Michael B - APHIS <Michael.B.Burrell@aphis.usda.gov>
Subject: time spent on SG captures

Hey Mike,

I'm needing to turn in a year-end report very soon and could use that information on the cumulative time spent by yourself and your guys on the project. Thanks

Steffen Cornell
District Manager
Meeteetse Conservation District
307-868-2484

Wildlife Society Bulletin 40(2):281–287; 2016; DOI: 10.1002/wsb.661

Original Article

Effectiveness of the Toxicant DRC-1339 in Reducing Populations of Common Ravens in Wyoming

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MICHAEL R. CONOVER,[1] *Department of Wildland Resources, Utah State University, 5230 Old Main Hill, Logan, UT 84322, USA*

ABSTRACT Common raven (*Corvus corax*) populations have increased several-fold in the western United States during the past century; these birds cause problems when they kill new-borne lambs and calves and depredate nests of greater sage-grouse (*Centrocercus urophasianus*). The toxicant DRC-1339 is used by U.S. Department of Agriculture/Animal and Plant Health Inspection Service Wildlife Services to manage common raven populations and reduce the severity of these problems, but it is difficult to determine how many ravens are killed by an application because carcasses are rarely found. We examined the effectiveness of DRC-1339 applications for preventative control of ravens at 3 landfills and 5 nearby roosts in Wyoming, USA, from 2013 through 2015. Wildlife Services removed 23%, 34%, and 7% of the radiomarked sample of ravens in southwestern Wyoming during 2013, 2014, and 2015, respectively, according to Kaplan–Meier survival estimates. During the 3 winters, 235 of 240 raven carcasses that we collected died from DRC-1339 poisoning. The following year, raven fecundity and immigration had offset most, but not all, of the mortality produced by the DRC-1339 program. Raven population estimates declined 9% from the 2013 winter to the 2014 winter and 12% from the 2014 winter to the 2015 winter, based on telemetry data and roost counts. Ravens did not avoid landfills after they were treated with DRC-1339 probably because few ravens died there. Estimated mortality rates from DRC-1339 applications based on carcass counts underestimated the actual rates by 79% and landfill counts of ravens underestimated it by 49%. Roost count estimates of mortality were within 15% of the actual mortality rate. © 2016 The Wildlife Society.

KEY WORDS *Centrocercus urophasianus*, common ravens, DRC-1339, population reduction, predator management, wildlife damage management.

Common raven (*Corvus corax*; hereafter, ravens) populations have increased several-fold in the western United States during the past several decades (Boarman 1993, Boarman and Berry 1995, Sauer et al. 2008). These burgeoning populations are managed using toxicants for the protection of human health, livestock, and species of conservation concern, including desert tortoise (*Gopherus agassizii*) and greater sage-grouse (*Centrocercus urophasianus*). Often the toxicant of choice is 3-chloro-p-toluidine hydrochloride (DRC-1339) because ravens are more susceptible to it than many other avian species or mammals (Decino et al. 1966, Eismann et al. 2003). This toxin is often injected into chicken eggs or sprayed on dog food. These treated baits are then distributed where they will be consumed by ravens that are causing problems, often after a prebaiting program so that the local ravens acclimate to the bait. DRC-1339 is slow-acting, causing death 1–3 days after ingestion (Larsen and Dietrich 1970).

Removal efforts using DRC-1339 have varied in long-term effectiveness. In Oregon, Larsen and Dietrich (1970) found only 10 ravens (5% of the original population of 200 ravens) at the treatment site during the year following application. In contrast, raven numbers returned to pretreatment levels in Nevada 1 year after treatment, indicating that the raven population at large was not affected by the raven take during the previous year (Coates et al. 2007). An intensive removal program in Iceland removed an average of 4,116 common ravens annually from 1981 to 1985, yet the number of breeding pairs did not fluctuate significantly during this time period; however, a decline in the nonbreeding population was observed (Skarphédinsson et al. 1990). Ravens die 1–3 days after they ingest DRC-1339 (Larsen and Dietrich 1970); this long period before death, when combined with the mobility of ravens, makes it difficult to determine how many ravens are killed during an application of the toxicant. Techniques used to monitor raven mortality after an application of DRC-1339 vary considerably and include

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estimating mortality from bait consumption, carcass searches, and raven counts before and after a DRC-1339 application. Coates et al. (2007) estimated his take of ravens by assuming that 1 raven died for every 11 poisoned eggs that disappeared or were eaten. Butchko (1990) conducted extensive searches in the landfill where eggs treated with DRC-1339 were distributed and retrieved 78 raven carcasses; he used this number, combined with the number of shot ravens, to calculate the mortality rate. Larsen and Dietrich (1970) never reported finding any raven carcasses after using DCR-1339, only that ravens were absent at the lambing grounds. However, the presence of dead or dying ravens after a DRC-1339 application may deter ravens from returning to baited areas, so counting ravens at baiting sites may overestimate the number of ravens killed (Merrell 2012, Peterson and Colwell 2014). The actual effects of DRC-1339 applications must be estimated with consistency and precision before we can manage its use responsibly.

In southwestern Wyoming, large-scale raven management by U.S. Department of Agriculture/Animal and Plant Health Inspection Service Wildlife Services was employed in winter to protect nesting sage-grouse, livestock, and human health from ravens. Raven feces create a sanitary problem when ravens roost in buildings or above sites used by humans (Merrell 2012); ravens also serve as a reservoir for zoonotic diseases (Conover and Vail 2015). We monitored the effectiveness of a Wildlife Services program using DRC-1339 to reduce raven numbers. To achieve this, we had to determine which method provided the best estimates of raven mortality: carcass counts, landfill–foraging area counts, or roost counts. Another objective was to determine whether ravens learned to avoid areas where DRC-1339 was applied or local roosts.

STUDY AREA

Our study area included 3 counties in southwestern Wyoming: Uinta, Lincoln, and Sweetwater (Fig. 1). Within these counties, we monitored raven activity at 3 landfills and 5 large communal roosts from 2013 through 2015. The Kemmerer Landfill was monitored all 3 years and it was where we captured most ravens for radiomarking. Garbage at this landfill was packaged into large bales, stacked in an open pit, and covered with dirt multiple times per week. We trapped ravens at the Green River and Rock Springs landfills and monitored them for raven activity during 2015 after the discovery of radiomarked ravens in these locations in November 2014. Both of these landfills used a "loose-fill" approach: garbage was dumped into an open pit, crushed with a compactor, and covered with dirt.

We examined numerous bridges and chemical plants with radiotelemetry, questioned plant personnel and local residents, used night-surveys (visual and audio), and surveyed for whitewash (areas of large amounts of raven fecal matter) to locate 5 raven roosts from 2012 to 2015. We considered roosts as being "local" to landfills if radiomarked birds from these roosts regularly attended the local landfill and observed constantly commuting from a roost to a landfill. Ravens using the Viaduct, Shute Creek, Port of Entry, and the Encana roosts used the Kemmerer Landfill for feeding, whereas ravens roosting at Solvay Chemicals Roost foraged at the Green River and Rock Springs landfills (Fig. 1).

METHODS

All applications of DCR-1339 were conducted by Wildlife Services from January to the end of March (2014 and 2015) or April (2013). We received verbal intent of removing ravens at landfills and roosts at the beginning of every year from Wildlife

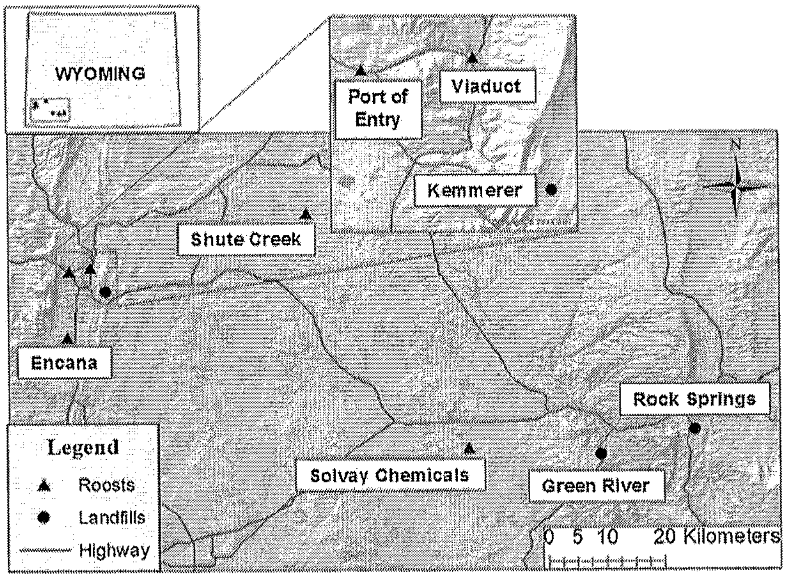

Figure 1. Map of the study area showing the locations of 5 roosts and 3 landfills used by radiomarked ravens, southwestern Wyoming, USA, 2012–2015. The Kemmerer area is enlarged to show detail.

Services; we were updated as to the timing of a DCR-1339 application. Wildlife Services personnel used dried dog food (Hi-Standard® 26/18 Soy Free Premium Performance Dog Food; Hi-Standard Dog Food, Pinckneyville, IL, USA) as the primary bait for their applications. This dog food was treated with DRC-1339 by spreading the dog food onto a flat surface and using a spray bottle of diluted DRC-1339 to obtain the desired application rate specified by the U.S. Environmental Protection Agency label. The lethal dose of DRC-1339 to kill 50% of the ravens (LD_{50}) is 13 mg/kg of body mass (Larsen and Dietrich 1970, Eismann et al. 2003). Once bait was treated, it was distributed either alone or mixed with untreated dog food at landfills, next to roosts, on flight paths <2 km from roosts, or in areas experiencing raven problems (e.g., lambing grounds or natural-gas sequestration tanks). The amount of bait placed out during a removal event was dictated by the number of ravens visiting the treatment area prior to baiting; bait was increased when more ravens were observed. Bait was placed mainly on the ground; however, feeding troughs were sometimes attached to perching locations (i.e., snow fences) to distribute bait. We monitored Wildlife Services employee effort (i.e., man-hours) as a reflection of how much a site was prebaited.

We used treatment and posttreatment counts of ravens at landfills and other foraging sites to estimate the number of ravens killed by DRC-1339. Treatments refer to particular days when DRC-1339 was applied at a site (landfill or roost) for the purpose of raven removal. Posttreatment data were based on the 3-day time period for ravens to succumb to DRC-1339 (Decino et al. 1966). We compared landfill counts on the date of application with landfill counts on the third day after DRC-1339 was distributed. We monitored ravens during the winter removal periods at the landfills targeted by Wildlife Services multiple times per week to assess changes in raven numbers within each removal year and among removal years. Point counts were conducted every 15 min; most surveys lasted from dawn until a few hours before dark. Treatment–posttreatment counts were conducted using daily maximum counts.

We conducted evening roost counts 1–2 times/week by counting individual ravens as they entered the roost or associated staging areas. Counts began 1–2 hr before dusk, before most ravens arrived, and continued until the loss of visibility prevented further counting. These roost counts were used to estimate the number of ravens killed by an application of DCR-1339 by comparing the number of ravens immediately prior to an application to the number of ravens 3 days after an application.

We searched for raven carcasses once per week at landfills, roosts, and treatment sites but our search effort increased to every 1–2 days following a DRC-1339 application. Carcass searches were conducted within the landfill boundaries and on the perimeter fences, at the staging areas of roosts, within the roosts themselves, and at treatment sites outside of landfills and roosts. Raven carcasses were also recovered outside of treatment areas with the aid of reports from the public, carcass checks on highways for road-killed ravens, or radiotelemetry. Intensive carcass retrieval did not occur in the winter of 2013. We assumed that a raven died of DRC-1339 if we found the carcass within a week following an application of DRC-1339 and the carcass was in good body condition with no obvious wounds.

We captured ravens using number 3 leg-hold traps (Oneida Victor® Soft Catch® Coil, Euclid, OH, USA) placed within landfills and near road-kills or carcasses. Ravens were equipped with either a 19- or 24-g Very High Frequency (VHF) backpack transmitter (Model A1135/A1140; Advanced Telemetry Systems, Isanti, MN, USA) or 30-g solar-powered Global Positioning System (GPS) Platform Transmitter Terminal transmitter (North Star Science and Technology, King George, VA, USA) that weighed <3% of their body weight. All ravens were released at their capture site as soon as transmitters were attached. This research was approved by the Institutional Animal Care and Use Committee of Utah State University (protocol 2031).

We monitored ravens carrying VHF transmitters at roosts and landfills with stationary data-loggers (Model 4500S; Advanced Telemetry Systems) equipped with 3-element Yagi antennas (Communications Specialists, Orange, CA, USA). We programmed the data-loggers to continually detect transmitter frequencies. When data-loggers were not in use, we stationed someone continuously during daylight hours at landfills to monitor ravens using a Communications Specialists (R-1000) receiver and 3-element Yagi antenna (Communications Specialists) at landfills. We also monitored ravens at roosts once at night where data-loggers were not stationed. Ravens equipped with GPS transmitters were monitored on a daily basis using data collected from Argos satellites. Six points per raven per day were collected at 0000 hours, 0700 hours, 1000 hours, 1300 hours, 1600 hours, and 1900 hours (Mountain Standard Time). Most (98%) of the days contained GPS fixes; solar-charging issues (e.g., feathers covering the solar cell) and raven behavior, especially roosting behavior, contributed to most of the lost fixes (2%).

Radiomarked ravens were monitored at roosts and landfills during the DRC-1339 application period and during the months before and after application at roost and landfill locations. We used mortality of the radiomarked ravens as an accurate estimate of survival for the raven population at large. We then compared the estimated mortality rate with rates determined using carcass, landfill, and roost counts to determine which counts most closely represented the actual mortality rate. Each winter, survival of radiomarked birds was recorded weekly starting when the first ravens were captured and ending in April or May when we conducted aerial flights to locate all radiomarked ravens. Ravens that survived this period were considered to have survived the winter. We defined a removal period as the period of time from the first DRC-1339 application to 1 week after the last DRC-1339 application. In 2013, the removal period went from 27 February to 11 April. However, data-logger data were only available after 7 March. In 2014, the removal period went from 17 January to 12 March; data-loggers were available throughout the entire period. In 2015, the removal period went from January 21 through 10 February. Roost attendance and landfill attendance were monitored constantly throughout the removal periods from 2013 to 2015.

From 2013 to 2015, we periodically censused the raven population in our study area by counting ravens in all known roosts during 3 consecutive nights (hereafter, total raven count). Simultaneously, we checked the same roosts for the presence of radiomarked ravens. We defined raven detectability as the number of radiomarked ravens we located in roosts divided by the total number of radiomarked ravens known to be alive. We determined the maximum population estimate by correcting the total raven count for raven detectability. This was achieved by dividing the total raven count by raven detectability.

We used a Kaplan–Meier estimator (Kaplan and Meier 1958) to estimate weekly survival of radiomarked ravens from the time of first capture to the telemetry flight during spring (Pollock et al. 1989). The Kaplan–Meier estimator is the nonparametric maximum-likelihood estimation of survival, $S(t)$, where the maximum survival is calculated over the set of all piecewise survival curves with breakpoints at the event times t_i (in this case, weeks). It is expressed as

$$S(t) = \prod\nolimits_{t_i<t}(1 - d_i/r_i)$$

In this equation, r_i is the number of ravens at risk just prior to time t_i. The number at risk fluctuates with regard to death; if a raven dies during 1 week, it cannot be at risk in subsequent weeks. Right-censoring, where ravens were not located weeks before survival monitoring ended, also is accounted for in the Kaplan–Meier estimator; the number at risk drops after an individual raven disappears from the study. Thus, r_i is the number of survivors minus the number of losses, either due to death or disappearance. The number at risk also fluctuates with staggered entrance; in our study, ravens entered the study area at different time periods. The parameter d_i represents the number of deaths at time t_i. We also determined apparent survival, which we defined as the proportion of radiomarked birds known to be alive at the start of winter that were also known to be alive at its end.

We monitored how often radiomarked ravens switched from one roost to another during the removal period to determine whether ravens responded to DRC-1339 applications by switching roosts. Roost-switching occurred when a raven moved from one roost to another on consecutive nights. We did not consider ravens moving between the Port of Entry Roost and the Encana Roost as switching roosts because movement of birds between these 2 roosts occurred frequently. These 2 roosts were close together (12 km), whereas the other roosts were separated by 40–80 km. In this analysis, each individual raven was the sampling unit, and a single raven may have been alive during several applications of DCR-1339. To avoid pseudo-replication, we calculated the proportion of times each raven switched roost during the 1-week preapplication period to the proportion during the 1-week postapplication period and used these proportions in our statistical tests.

We searched for dead ravens during each roost count; sometimes after a DRC-1339 application, we found dead ravens on the ground below a roost. To determine the effect of dead ravens on roost-switching, we compared the proportion of times a raven switched roosts when there was a dead raven at a roost to when there were no dead ravens. We used the Wilcoxon's signed-rank test to test whether a DRC-1339 application or the presence of a raven carcass affected how frequently ravens switch roosts. We compared the number of radiomarked ravens that abandoned landfills between 1 week prior to, and 1 week after, a DRC-1339 application.

If landfills showed increases in raven numbers from treatment to posttreatment counts, we recorded no mortality estimates for that particular DRC-1339 application. We estimated the number of individual ravens using a landfill on a day as the maximum count of ravens for that particular day. We adjusted for individuals that were not present at the time of the maximum count by noting how many of the radiomarked ravens were present at the time of the maximum raven count and how many had visited the landfill that day, regardless of when they were there. We then divided the maximum raven count by the proportion of radiomarked ravens at the landfill during the maximum count by the total number of radiomarked ravens at the landfill that day. To determine how many ravens were killed by an application of DRC-1339 based on landfill counts, we subtracted the daily number of ravens using the landfill 3 days after an application to the number of ravens prior to the application. During 2013, Wildlife Services occasionally applied small amounts of DRC-1339 outside of landfills in response to a complaint, such as ravens killing a lamb. These applications were conducted on short notice, and we were unable to count ravens before application. Wildlife Services conducts their own raven counts before and after applying DRC-13339, and we used their counts when unable to conduct our own.

RESULTS

The estimated population size for the entire study area peaked at 2,363, 2,146, and 1,886 ravens during 2013, 2014, and 2015, respectively (Fig. 2) based on counts of all roosts and correcting this value for raven detectability. We collected

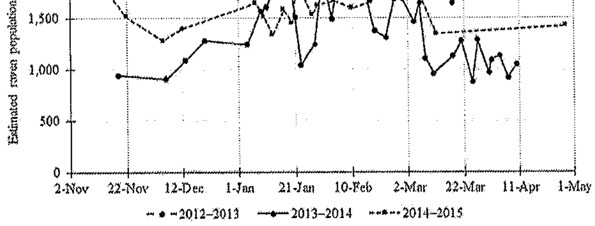

Figure 2. Estimated winter raven population sizes based on combined winter–spring roost count data and telemetry data, southwestern Wyoming, USA, 2012–2015. The raven population size at each combined roost count was calculated by dividing the total number of ravens roosting at all active roosts in the study area by the proportion of radiomarked ravens at all roosts.

240 raven carcasses during our study; only 5 died from causes other than poisoning (3 were electrocuted on power poles and 2 died from vehicle collisions). Most raven carcasses (91%) were retrieved at roosts; <1% of carcasses were recovered at landfills or other sites where DCR-1339 was distributed.

We captured and radiomarked 73 ravens during this study (23, 25, and 25 during the winter of 2013, 2014, and 2015, respectively). The number of ravens known to be alive was 23 during the winter of 2013, 32 during 2014, and 34 during 2015; these include surviving ravens marked in prior years. Wildlife Services personnel applied 34, 43, and 30 g of DRC-1339 in treated dog food at our study sites and spent 14 hr, 68 hr, and 32 hr of labor during the 2013, 2014, and 2015 removal periods, respectively. Fifteen radiomarked ravens died during our study; 11 of them were recovered at roosts in the days immediately following applications of DRC-1339, and 3 died immediately after an application of DRC-1339 but died away from the roost. During all 3 years of monitoring, only one radiomarked raven was killed by something other than DRC-1339; the exception was killed by a mammalian predator. Apparent survival rates of radiomarked ravens were 78%, 70%, and 94% in 2013, 2014, and 2015, respectively.

Estimated raven survival based on the Kaplan–Meier estimator was 77% (95% CI = 63–97%) during the winter 2013. All of the observed mortality occurred during a 3-week period (weeks 10–12; 14 Mar–3 Apr) during and immediately following DRC-1339 applications (Fig. 3). The survival rate during the winter 2014 was 66% (95% CI = 50–88%). Mortality of radiomarked ravens was observed first on week 10 (17–23 Jan); the survival curve gradually declined throughout the rest of the study (Fig. 3). The third year of study (winter 2015) had a survival rate of 93% (95% CI = 84–100%). Mortalities occurred from 1 February to 7 February, which was during and immediately after DRC-1339 applications (Fig. 3). Based on our survival estimates, the number of ravens killed from DRC-1339 applications during 2013, 2014, and 2015 was 543, 730, and 132 ravens, respectively.

The daily percentages of radiomarked birds foraging at landfills, out of the entire sample size of radiomarked birds, declined, increased, and remained stable following DRC-1339 applications. Over all 3 years, 9% (95% CI = −23% to 41%) of the radiomarked ravens present at the onset of DRC-1339 applications abandoned landfills during the week following a DRC-1339 application. Fifty-one ravens were alive and in the area during an application of DRC-1339; 7 of them switched roosts the week prior to the application and 14 switched roosts in the week immediately following each application. This difference was significant ($W = 4.0$, $P = 0.02$). The presence or absence of dead ravens on the ground below a roost did not influence the number of ravens that switched roosts ($W = 10.5$, $P = 0.32$).

Based on maximum raven counts at landfills and other foraging areas, an estimated 240, 288, and 93 ravens were killed by DRC-1339 during 2013, 2014, and 2015, respectively. When these values were adjusted for the

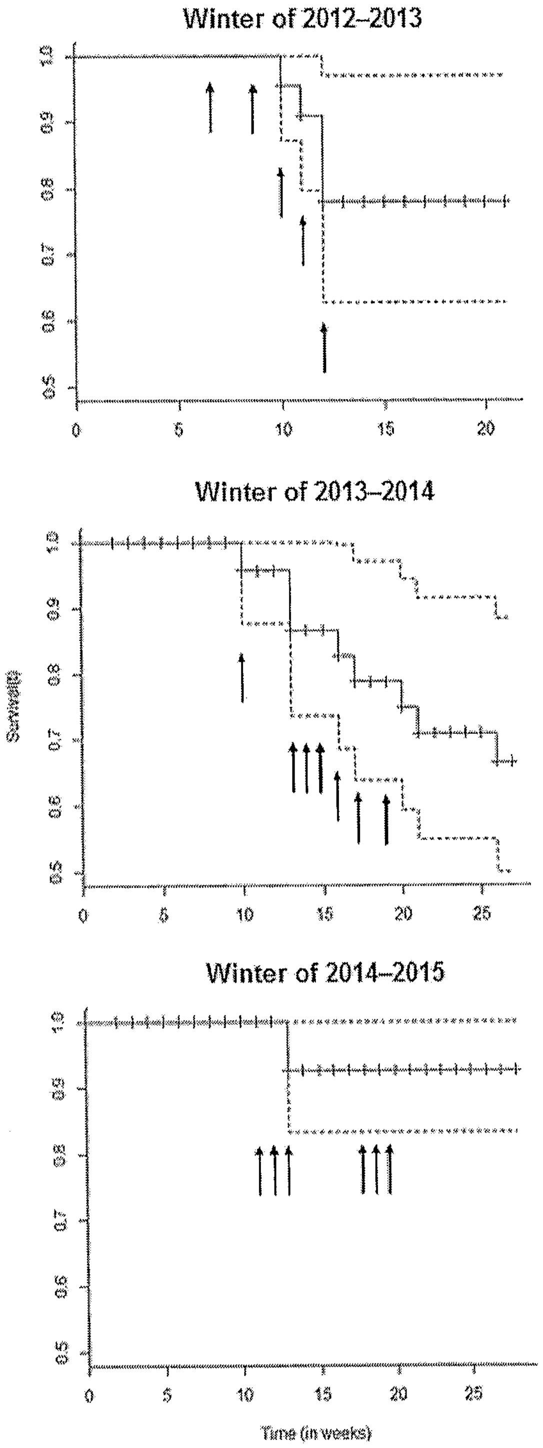

Figure 3. Kaplan–Meier survival curve (black line), with 95% confidence intervals (dashed lines) depicting weekly survival of radiomarked ravens, southwestern Wyoming, USA. Arrows indicate weeks when U.S. Department of Agriculture/Animal and Plant Health Inspection Service Wildlife Services applied DRC-1339 to remove ravens. During the winter of 2012–2013, the survival time started from the first week of raven capture (3–7 Jan) and ended the last week when spring-dispersal telemetry flights were conducted (22–28 May). During 2013–2014, survival time started from the first week of raven capture (15–22 Nov) and ended the last week when spring-dispersal telemetry flights were conducted (16–22 May). During 2014–2015, survival time started from the first week of raven capture (9–15 Nov) and ended the last week when spring-dispersal telemetry flights were conducted (24–30 May).

proportion of radiomarked ravens present at the time of maximum count at landfills, an estimated 338, 559, and 160 ravens were killed by DRC-1339 during the winter of 2013, 2014, and 2015, respectively. Based on roost counts, an estimated 462, 619, and 153 ravens were killed by DRC-1339 during 2013, 2014, and 2015, respectively.

DISCUSSION

Our results indicate that Wildlife Services annually removed 7–34% of a raven population of approximately 2,000 ravens with DRC-1339 by killing an average of 468 ravens annually in Sweetwater, Lincoln, and Uinta counties of Wyoming. This average winter kill by DRC-1339 was greater than the 190 ravens removed by Larsen and Dietrich (1970) at lambing grounds, 115 ravens removed in Butchko's (1990) study at a single landfill, and 69–157 ravens Coates et al. (2007) estimated to have been killed at sage-grouse leks. The only study in the United States that removed more ravens than this study was reported in a raven removal project covering 7 counties in Nevada; Bradley et al. (2013) reported a raven take of 2,000 ravens annually during the last 2 years of his study.

During our study, most mortalities (93%) of our radiomarked ravens were due to the ingestion of DRC-1339. Likewise, 98% of the dead ravens that we found had died during the week following a DRC-1339 application. Few ravens died from other known causes; these included electrocution caused by powerlines, vehicle collisions, and depredation.

Raven populations can be hard to depress. In Iceland, an annual take exceeding 4,000 ravens did not decrease the raven population 1 year later (Skarphédinsson et al. 1990). Greater than 10,560 chicken eggs (2,640/yr) treated with DRC-1339 were distributed near sage-grouse leks in Nevada from 2002 to 2005; even with this massive removal effort, raven indices at these leks rebounded back to the same levels or increased the following year (Coates et al. 2007). During our study, the raven population in southwestern Wyoming dropped by 9% from the 2013 winter to the 2014 winter, and the raven population dropped 12% from the 2014 winter to the 2015 winter. This suggests that the local raven population was suppressed for ≥ 1 year by the applications of DRC-1339 that we monitored.

We hypothesized that ravens would learn to avoid landfills and roosts after an applicant of DRC-1339 because ravens often avoid areas where they observe dead ravens (Merrell 2012). Instead, we found that radiomarked ravens did not stop foraging at treated landfills following the application of DRC-1339. Apparently the surviving ravens did not associate the increase in mortality rates with foraging at landfills. This may have resulted because ravens die 1–3 days after they ingest DRC-1339 (Larsen and Dietrich 1970), which gives ravens ample time to travel from where they ingested bait. In fact, we only found 2 of 238 raven carcasses at landfills. Instead, most carcasses were retrieved under roosts and in the sagebrush >2 km away from landfills. Thus, ravens may not perceive danger at landfills. In support of this hypothesis, Coates et al. (2007) did not find video evidence of avoidance behavior by ravens of eggs treated with DRC-1339. However, ravens switched roosts more often after a DRC-1339 application; we witnessed some ravens struggling to fly and some dying on the ground below the roost. Such scenes may startle healthy ravens and encourage them to move to another roost. American crows (*Corvus brachyrhynchos*), a similar corvid species, relocated to a new roost after DRC-1339 was distributed at the staging area of the former roost (Boyd and Hall 1987).

Estimates of raven mortality based on carcass counts were 79% lower, on average, than our mortality estimates calculated from the radiomarked ravens. Most of these ravens died away from roads and in remote terrain. Carcass retrieval outside of treatment areas would be time-consuming and costly, because the search area exponentially increases as the search radius from the treatment areas increases. Outside of radiotelemetry, carcass retrieval in southwestern Wyoming is an inefficient method for assessing raven take.

Raven mortality estimates based on raw landfill and foraging area counts were 49% lower than estimates obtained from raven survival data in all 3 years of the study. In our study, radiomarked ravens attended landfills at different times of the day, suggesting that a maximum count of ravens at one point in time does not truly estimate the total numbers of ravens utilizing the landfill on a daily basis. Ravens also are inconsistent in the time of day they forage at lambing grounds, agricultural areas, and other areas where ravens regularly visit (Larsen and Dietrich 1970, Engel and Young 1992). We conclude that use of raw counts of ravens at landfills and other treatment sites is an inefficient method for assessing raven mortality in southwestern Wyoming. Raven mortality estimates based on counts in local roosts differed by an average of 15% from estimates provided by the Kaplan–Meier estimator. Hence, we conclude that raven counts at roosts provided a better estimate of population changes caused by poisoning than landfill–treatment area counts or carcass counts.

MANAGEMENT IMPLICATIONS

Raven management with DRC-1339, when used in a preventative manner before problems arise, can be used to depress raven populations; however, it is a short-term solution that must be conducted annually. Reducing sources of anthropogenic sources of raven food will likely improve removal efforts by increasing raven attendance at treatment sites; regularly picking up road-kill and limiting access to landfills are just a few methods that should be explored.

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RESEARCH ARTICLE

Microhabitat Conditions in Wyoming's Sage-Grouse Core Areas: Effects on Nest Site Selection and Success

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Abstract

The purpose of our study was to identify microhabitat characteristics of greater sage-grouse (*Centrocercus urophasianus*) nest site selection and survival to determine the quality of sage-grouse habitat in 5 regions of central and southwest Wyoming associated with Wyoming's Core Area Policy. Wyoming's Core Area Policy was enacted in 2008 to reduce human disturbance near the greatest densities of sage-grouse. Our analyses aimed to assess sage-grouse nest selection and success at multiple micro-spatial scales. We obtained microhabitat data from 928 sage-grouse nest locations and 819 random microhabitat locations from 2008–2014. Nest success was estimated from 924 nests with survival data. Sage-grouse selected nests with greater sagebrush cover and height, visual obstruction, and number of small gaps between shrubs (gap size $\geq$0.5 m and <1.0 m), while selecting for less bare ground and rock. With the exception of more small gaps between shrubs, we did not find any differences in availability of these microhabitat characteristics between locations within and outside of Core Areas. In addition, we found little supporting evidence that sage-grouse were selecting different nest sites in Core Areas relative to areas outside of Core. The Kaplan-Meier nest success estimate for a 27-day incubation period was 42.0% (95% CI: 38.4–45.9%). Risk of nest failure was negatively associated with greater rock and more medium-sized gaps between shrubs (gap size $\geq$2.0 m and <3.0 m). Within our study areas, Wyoming's Core Areas did not have differing microhabitat quality compared to outside of Core Areas. The close proximity of our locations within and outside of Core Areas likely explained our lack of finding differences in microhabitat quality among locations within these landscapes. However, the Core Area Policy is most likely to conserve high quality habitat at larger spatial scales, which over decades may have cascading effects on microhabitat quality available between areas within and outside of Core Areas.

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Introduction

Quantity and quality of breeding habitat have been suggested as the most important factors dictating the productivity of greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) populations [1,2,3]. Studies have reported that sage-grouse select nest sites based on a preference for different microhabitat characteristics, such as sagebrush density [4,5], sagebrush cover [6,7], shrub height [8], grass height [7,8,9], and grass cover [7,10]. These studies all indicated that sage-grouse choose nest locations in habitats with greater concealment cover. However, there are differences in the quality of local microhabitat available as nesting habitat for female sage-grouse across Wyoming.

While sage-grouse select for microhabitat characteristics that provide greater concealment cover from predators and protection from weather, selection of habitat is limited to the range of microhabitat conditions that are available. Microhabitat characteristics around a nest, such as sagebrush cover and grass height, can facilitate or impede a predator from depredating a nest [11,12], and this varies among different types of nest predators [11,13]. Sage-grouse consistently select for greater sagebrush cover [7,9,14,15,16]; however, the connection between sagebrush cover and nest success has been more variable with many studies failing to find a relationship between nest success and sagebrush cover with some exceptions [8,17,18]. The current knowledge of sage-grouse nesting ecology indicates that sagebrush (or shrub) cover is important, but the effect of sagebrush cover on nest success among local areas is variable. Holloran et al. [9] suggested that within patch scales, sagebrush metrics remain relatively constant throughout and among breeding seasons, whereas, grass cover and height were more variable and dependent on weather conditions. A study in southeast Montana and northeast Wyoming found that grass height variability influenced by spring precipitation was highly predictive of nest success in sage-grouse [19]. Habitat quality is highly variable and depends on multiple environmental and anthropogenic factors. Variability in the condition of available microhabitat throughout sage-grouse range may significantly influence specific life-history stages and associated vital rates (e.g., nest success). Therefore, studies across broader ranges and more diverse microhabitat have the greatest potential to identify microhabitat variables that influence nest selection and success of sage-grouse at regional scales.

As a result of the 2008 Wyoming Governor's Sage-grouse Executive Order, the State of Wyoming implemented the Core Area Policy to conserve sage-grouse populations in Wyoming [20]. This policy focuses on minimizing impacts to the highest quality sage-grouse habitats [21,22]. We have compiled an expansive dataset designed to evaluate sage-grouse nest site selection and nest success, where data were collected from multiple regions throughout Wyoming starting in the initial year of the Core Area Policy. The purpose of our study was to use microhabitat data collected over a broad range of sagebrush habitats in Wyoming to 1) identify microhabitat characteristics that influence sage-grouse selection of nest sites, 2) compare available microhabitat within and outside of Core Areas, 3) compare microhabitat used by sage-grouse for nesting between areas protected and not protected under the Core Area Policy, and 4) evaluate the influence of microhabitat on nest success and compare nest success within and outside of Core Areas. Our analysis contains an evaluation of several Core and non-Core Areas and distinct sage-grouse populations within Wyoming.

Study Areas

Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) at lower elevations and mountain big sagebrush (*A. t. vaseyana*) at higher elevations dominated our study areas [23]. Black sagebrush (*A. nova*) and/or low sagebrush (*A. arbuscula*) were found on exposed ridges. Other shrub species common to various study areas included alderleaf mountain mahogany

(*Cercocarpus montanus*), antelope bitterbrush (*Purshia tridentata*), chokecherry (*Prunus virginiana.*), common snowberry (*Symphoricarpos albus*), greasewood (*Sarcobatus vermiculatus*), and rabbitbrush (*Chrysothamnus* and *Ericameria* spp.). Isolated stands of juniper (*Juniperus* spp.) and quaking aspen (*Populus tremuloides*) were found at higher elevations. Data within our study areas were collected 2008–2014, but active data collection differed for some of the study areas (Table 1). Annual precipitation within study areas ranged from approximately 22.3 cm to 49.3 cm (mean = 32.5 cm [2.7 SE]). All study areas had some anthropogenic features. In the less disturbed study areas this mainly consisted of unimproved 4-wheel drive roads. Oil and gas extraction activities occurred in each of the study areas (range 0.004–0.236 wells per km^2) and consisted of conventional natural gas, coalbed methane natural gas, and/or conventional oil with an average of 0.18 per km^2 outside Core Areas and 0.01per km^2 within Core Areas. Livestock grazing by domestic sheep and cattle was a primary land use in all of the study areas.

Atlantic Rim

The Atlantic Rim study area was located in southern Carbon County, Wyoming, extending approximately 77 km north and south between Rawlins and Baggs (Fig 1). This study area was located within and adjacent to the South Rawlins and Greater South Pass Core Areas. The area included approximately 64% federal, 5% state, and 31% private lands. The Atlantic Rim is within the semi-desert grass-shrub zone and is characterized by sagebrush steppe with low average annual precipitation. Elevation within the study area ranged from 1,982 to 2,529 m. Major land uses included oil and gas extraction.

Bighorn Basin

The Bighorn Basin study area was located in Big Horn and Washakie counties, Wyoming (Fig 1). This study area was located within and adjacent to the Hyattville, Shell, and Washakie Core Areas. The area extends northeast of Greybull, Wyoming and south to near Ten Sleep, Wyoming in the eastern Bighorn Basin on the west slope of the Bighorn Mountains. The area included approximately 74% federal, 7% state, and 19% private lands. Elevation within the study area ranged from 1,300 to 2,850 m. Major land uses in this area included bentonite mining.

Jeffrey City

The Jeffrey City study area was in portions of Fremont and Natrona counties, Wyoming (Fig 1). This study area was located within and adjacent to the Greater South Pass Core Area. The area included approximately 81% Federal, 7% State, and 12% privately administered lands. Elevation ranged from 1,642 to 2,499 m. There is interest to resume uranium mining, which historically was once a major land use in the area.

Table 1. Summary of nest and random location sample sizes used for occurrence, availability (random-random), and nest success analyses, in central and southwestern Wyoming, USA, 2008–2014.

Sage-grouse study area	Years	Nests	Random
Atlantic Rim	2008–2011	123	122
Bighorn Basin	2011–2014	291	290
Jeffrey City	2011–2014	270	166
Southwest Wyoming	2008–2011	193	190
Stewart Creek	2008–2011	51	51
Total of all studies	2008–2014	928	819

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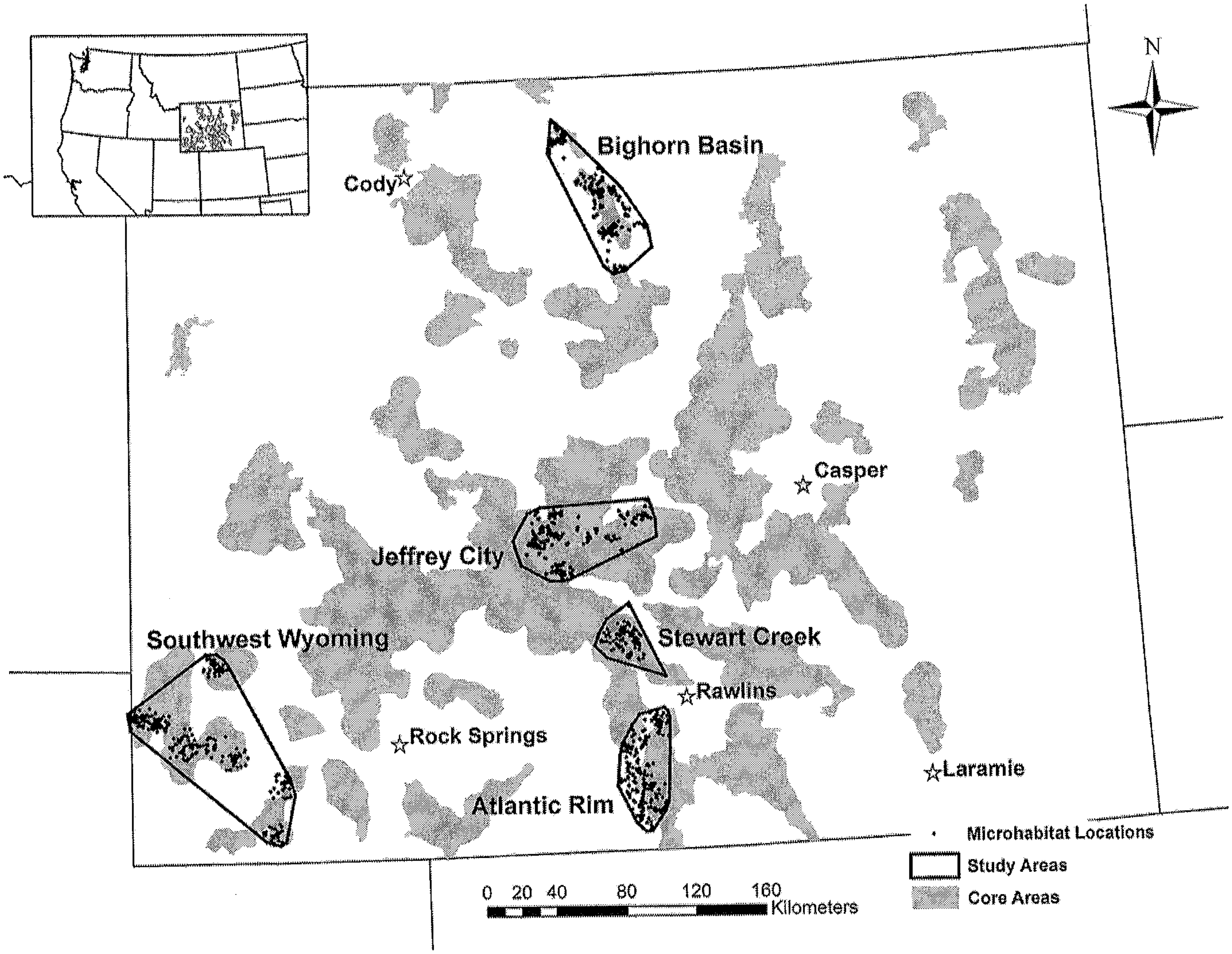

Fig 1. Map of study areas and microhabitat sampling points across five regions in central and southwestern Wyoming, USA, 2008–2014. Boundaries for each study area were demarcated by a 100% minimum convex polygon encompassing 928 sage-grouse nests and 819 random locations. However, the southwest Wyoming minimum convex polygon was an aggregation of 8 separate 8-km areas around sage-grouse leks. Locations of 31 sage-grouse Core Areas are also illustrated in gray.

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Southwest Wyoming

The Southwest Wyoming study area consisted of eight distinct study sites that were approximately 16 km in diameter centered on leks; this distance was based on results found by Holloran and Anderson [24] that indicated 93% of 415 nests were within 8.5 km from leks in central and southwestern Wyoming (Fig 1). The Southwestern Wyoming study area was located within and adjacent to the Fontenelle, Sage, and Uinta Core Areas. Five study sites were located in Lincoln, one in Sweetwater, and two in Uinta counties, Wyoming. Study sites were chosen to provide a representation of overall sage-grouse nesting habitat in southwestern Wyoming. Elevation ranged from 1,925 to 2,550 m. The area included approximately 65% Federal, 4% State, and 31% privately administered lands. Oil and gas development was present in 37.5% of the study area.

Stewart Creek

The Stewart Creek study area was located in northern Carbon County, approximately 32.2 to 64.4 km north and west of Rawlins, Wyoming (Fig 1). This study area was located within and adjacent to the Greater South Pass Core Area. The area includes approximately 70% federal, 5% state, and 25% privately administered lands. The Stewart Creek area is within the semi-desert grass-shrub zone, characterized by sagebrush steppe with low annual precipitation. Elevation ranged from 1,982 to 2,529 m.

Methods

Capture and monitoring

We captured and radio-marked female sage-grouse from leks in spring by spot-light and hoop-net methods [25,26] from 2008–2014. We also used roosting locations of radio-marked adult females captured in spring to capture and radio-mark additional females in late summer each year. We aged females as juveniles or adults based on the shape and condition of the outermost wing primaries, the outline of the primary tail feathers, and coloration of undertail coverts [27,28]. We attached radio transmitters (22 g, Model A4060; Advanced Telemetry Systems Incorporated, Isanti, MN, USA) to females with a PVC-covered wire necklace. In the Bighorn Basin and Jeffrey City study areas, we attached GPS transmitters (22-g Solar Argos/GPS PTT-100, Microwave Telemetry, Columbia, MD, USA or Model 22 GPS PTT, North Star Science and Technology, King George, VA, USA) via rump mounts instead of necklace radio collars to a small portion of captured females. These GPS transmitters were programmed to acquire 4 locations per day via satellite (Argos, www.argos-system.org) from 15 March to 30 April, and 5 locations per day from 1 May to 24 August. We located VHF-collared females weekly beginning mid-to-late April each year with R-1000 hand-held receivers and 3-element Yagi antennas (Communication Specialists, Orange, CA, USA). All sage-grouse were captured, marked, processed, and monitored in adherence with approved protocols (Atlantic Rim and Stewart Creek studies [Wyoming Game and Fish Department {WGFD} Chapter 33 permits 572 and 699 and University of Wyoming Institutional Animal Care and Use Committee {UW IACUC} protocol 03032009]; Bighorn Basin study [WGFD Chapter 33–800 permit and UW IACUC protocols 03142011 and 20140228JB00065]; Jeffrey City study [WGFD Chapter 33–801 permit and UW IACUC protocols 03132011 and 20140128JB0059]; Southwest Wyoming study [WGFD Chapter 33 permit 657 and Utah State University IACUC protocol 1357]).

We located nests by circling a radio-marked (necklace collars) female until the surveyor visually located the female under a shrub or isolated the hen's location. To minimize human-induced nest depredation or nest abandonment, we subsequently monitored nests of radio-marked females with triangulation from a distance of at least 30 m. For GPS-equipped females, we visually inspected potential nests after the female left a location of clustered GPS points. Nest success (i.e., nests with at least 1 hatched egg) was determined by examining egg shells after the female was no longer located at the nest site.

Microhabitat sampling

We sampled microhabitat at nest and random locations for all study areas in all years with the exception that no random sampling was conducted in Jeffrey City during 2014. In the Atlantic Rim, Southwest, and Stewart Creek study areas, random locations for comparison to nest locations were established throughout the study area within 8 km of all leks where sage-grouse capture was conducted with ArcMap. We used Northwest GAP land-cover data [29] to constrain random locations to sagebrush habitats while excluding areas of inappropriate habitat such as exposed rock, open water, and conifer stands. In the Bighorn Basin and Jeffrey City study areas, we constrained random sampling at a random distance and direction 0.1–0.5 km from each paired nest location [30]. We chose a simulated nest site at random locations by selecting the closest shrub taller than or equal to 30 cm [9,31].

We used established protocols to measure the vegetation characteristics of microhabitat surrounding nests and random locations [5]. We began sampling nest microhabitat plots after the first successful hatch and attempted to sample nest and random locations concurrently within 2 weeks of known nest fate. We measured microhabitat characteristics along two perpendicular 10-m transect lines centered on each nest or random location extending in each cardinal direction (Table 2). We recorded shrub canopy cover with the line intercept method [32,33]. We

Table 2. Descriptions of microhabitat variables used to evaluate selection, availability (random-random), and nest success of sage-grouse. Data were collected at 928 sage-grouse nests and 819 random locations in in 5 study areas in Wyoming, USA, 2008–2014.

Variable Name	Description
Categorical Variables	
Nest Shrub Spp.	Shrub species at nest or center of random plots. Classified as sagebrush or non-sagebrush
Shrub Characteristics	
Shrub[1,2]	Mean total shrub cover (%)
Artr[1,2]	Mean big sagebrush cover (%)
Shrub_H	Mean shrub height (cm)
Artr_H	Mean big sagebrush height (cm)
Gap[3]	Count of spaces between shrubs
VO	Mean visual obstruction (horizontal; cm) 5 m from plot location
Grass Height	
PerGrass_H	Mean maximum perennial droop height (cm)
ResGrass_H	Mean maximum residual droop height (cm)
Herbaceous Canopy Cover (%)[4]	
AnGrass[4,5]	Mean annual grass cover
PerGrass[4,5]	Mean perennial grass cover
ResGrass[4,5]	Mean residual grass cover
FoodF[4,6]	Mean food forb cover
NFoodF[4,6]	Mean non-food forb cover
Ground Cover (%)[4]	
BGround[4,7]	Mean bare cover
Cactus[4]	Mean cactus cover
BioCrust[4]	Mean biological soil crust cover
Rock[4,7]	Mean gravel and rock cover
Litter[4]	Mean litter cover

[1] Cover assessed at 1, 2.5, and 5 m away from transect center

[2] Proportion of Artr to Shrub assessed at 1, 2.5, and 5 m away from transect center [3] Gap spacing was categorized as ≥0.5 m and <1.0 m ($Gap_{0.5m}$), ≥1 m and < 2.0 m (Gap_{1m}), ≥2.0 m and <3.0 m (Gap_{2m}), and ≥3.0 m and <4.0 m (Gap_{3m}) counted along transect lines

[4] Cover assessed at 1.5 and 3.5 m away from transect center and between 2.5–3.5 m away from transect center

[5] Variables combined to assess total grass cover (Grass)

[6] Variables combined to assess total forb cover (Forb)

[7] Variables combined to assess total bare, gravel and rock ground cover (BareRock)

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measured height (cm) at each shrub that intercepted the line. Average canopy cover and height were quantified as total shrub and big sagebrush species. Sagebrush cover and height calculations excluded mat-forming sub-shrub species (e.g., prairie sagewort [*A. frigida*]) that could not be considered concealment cover for nests. Average sagebrush and shrub cover were calculated at three microhabitat spatial scales by averaging values from the two perpendicular lines from the nest or random location to 1, 2.5, or 5 m away from the nest or random location. We estimated visual obstruction to the nearest 5 cm by visually estimating the closest point to the ground visible on a modified Robel pole from 5 m away from nest and random locations and 1-m above the ground [34,35]. We estimated cover of annual grasses, perennial grasses, residual perennial grasses, food forb cover (for list, *see* [7]), non-food forb cover, gravel and rock, bare soil, biological soil crust, and litter by recording cover in 6 cover classes within 20 x 50 cm quadrats (0.1 m^2; [36]). Quadrats were placed along each transect line at the center of each transect (nest bowl or center of random location) and centered at 1 and 3 m from the transect intersection in each cardinal direction for a total of $n = 9$ quadrats at each microhabitat plot. Cover classes were demarcated as 1 = 0.1–1%, 2 = 1.1–5%, 3 = 5.1–25%, 4 = 25.1–50%, 5 = 50.1–75%, and 6 = 75.1–100%. Average cover for quadrat variables were calculated at three microhabitat spatial scales by averaging values from the inner 5 quadrats (transect center and quadrats place 1 m from the transect center; 1 m spatial scale), the outermost 4 quadrats (values describing average values 2.5 to 3.5 m [width of the quadrat frame] away from the nest or random location), and all 9 quadrats (3.5 m spatial scale). We measured the height of perennial and residual perennial grasses (cm) as the tallest portion of the plant (droop height) within 1 m of each quadrat.

Descriptions of shrub characteristics (sagebrush and total shrub cover, sagebrush and total shrub height, gaps in shrub cover, and visual obstruction), grass height (perennial and residual grass height), herbaceous canopy cover (annual, perennial, residual grass, and forb cover), and ground cover (bare ground, biological soil crust, rock, and litter cover) variables calculated from transect lines, Robel poles, and quadrats are provided in Table 2. In addition to measured shrub characteristics, we calculated the proportion of sagebrush to total shrub cover (ARTRpShr) at all microhabitat spatial scales, and we generated number of shrub cover gaps in four categories. Shrub cover gaps were classified as $Gap_{0.5m}$ ($\geq$0.5 m and <1.0 m), Gap_{1m} ($\geq$1 m and < 2.0 m), Gap_{2m} ($\geq$2.0 m and <3.0 m), or Gap_{3m} ($\geq$3.0 m and <4.0 m), then the number of each gap classification was summed along transect lines. The proportion of sagebrush to total shrub within plots was intended to assess differences in shrub composition relative to sagebrush as a measure of shrub diversity between sage-grouse nests and random locations, within and outside of Core Areas for random and nest locations, and nest success. We also recorded the dominant shrub species at the center of nest and random locations, which was used as a categorical variable classifying the shrub directly above a nest or center of a random location as sagebrush or non-sagebrush.

Data analysis

For all analysis types, we used an information theoretic approach for modeling [37]. All statistical analyses were conducted in R [38]. We compared models with Akaike's information criterion corrected for small sample sizes (AIC_c) and Akaike weights w_i; [39] with function 'model.sel' in package MuMIn version 1.13.4 in R. We screened each variable to identify potentially informative variables, which were defined as variables with regression coefficient values with 85% confidence intervals (CIs) that did not overlap zero [40]. For variable screening, variables with 85% CIs that overlapped zero were eliminated from all further AIC_c modeling. We based our inference on regression models within 4 AIC_c of the top selected model [39]. For variables measured at multiple microhabitat spatial scales, we compared single variable models and only used the microhabitat spatial scales that were not correlated or the variable with the lowest AIC_c in additive models. Our modeling approach allowed us to use variables with the most predictive potential to make inferences about selection and nest success [41] at different microhabitat scales. Model averaging of coefficients and standard errors was employed when there was model uncertainty, which was defined as multiple competing models within 4 ΔAIC_c of the top model. For all competitive final models, we report 95% CI for parameter estimates and odds ratios, because we considered predictor variables with 95% CI not overlapping zero to be precise and predictor variables that had 95% CI that overlapped zero to be marginal. Thus, we focused our interpretations on the precise predictor variables.

All models included year (2008–2014) and the 30-year normal of annual precipitation as random effects to account for seasonal weather and overall habitat differences among nest and/or random locations across years and study areas. The 30-year normal of annual precipitation consistently accounted for more variation among sampling locations than study area; thus, we used the 30-year normal of precipitation as a random factor rather than study area. The 30-year normal of annual precipitation was extracted at a 1-km spatial resolution from PRISM [42]. Differences in sampling design for random locations were also accounted for with these random effects. To prevent multicollinearity, we did not include any two co-varying variables ($|r \geq 0.65|$) in any model as determined by a Pearson's correlation matrix. When variables were correlated, we included the variable with the lowest AIC_c in that model.

Selection and availability models. We used binomial generalized mixed models (GLMMs) to evaluate 1) nest selection of sage-grouse, 2) availability of microhabitat within and outside of Core Areas, and 3) to compare nest selection by sage-grouse within and outside of Core Areas. For ease of interpretability, we referred to these analysis types as 1) nest-random, 2) random-random, and 3) nest-nest. The nest-random analysis employed a use-availability design to evaluate sage-grouse nest site selection with binary logistic regression [43], whereas, the random-random and nest-nest analyses were intended to classify differences in microhabitat between locations (random or nest) within and outside of Core Areas.

We fitted GLMMs with year and 30-year normal of precipitation as random effects with function 'lmer' in package lme4 version 1.1–7 in R. Random locations were coded as the reference category for our nest-random analysis, random locations outside of Core Areas were coded as the reference category for our random-random analysis, and nest locations outside of Core Areas were coded as the reference category for our nest-nest analysis. Microhabitat variables considered as predictors included shrub characteristics, grass height, herbaceous canopy cover, and ground cover variables (Table 2). We compared all possible combinations of informative variables as additive models for each analysis type with AIC_c and w_i. The interpretations of change in odds ratios (selection probabilities) per unit change in variables were calculated as the median change in odds bound by the range of variable values for that variable with the other variables in the model held at their mean value. We report means and SE for nest-random microhabitat data in S1 Table.

Nest success models. Nest success was evaluated with a mixed effects version of the Cox proportional hazard (Cox PH) model using function 'coxme' in package coxme version 2.2–4 in R. We used Cox PH to identify relationships between microhabitat predictor variables and nest success. Analysis of nest success was based on time-to-event data, and Cox PH models are commonly used to analyze time-to-event survival data [44]. The risk of failure (hazard ratio) is a function of the non-parametric baseline hazard, and the parametric predictor variables affecting failure [45]. Thus, beta estimates were presented as the risk of a nest failing with positive beta values indicating a variable was positively related to a greater risk of nest failure. In Cox PH models, the baseline hazard is assumed to have a proportional hazard of failure over time (proportional hazard assumption) for all predictor variables [45]. Thus, we tested the proportional hazard assumption for each predictor variable with the function 'cox.ph' in the coxme package in R [46]. As in our GLMMs, we fit Cox PH models with year and 30-year normal of precipitation as random effects.

We assessed the effect of microhabitat including shrub characteristics, grass height, herbaceous canopy cover, and ground cover variables on nest success (Table 2). In addition to the microhabitat variables, we compared nest success within and outside of Core Areas with a categorical variable (Cor_NonCore). All possible combinations of informative variables were included as additive models and compared with AIC_c and w_i. Nest success estimates were calculated with the Kaplan-Meier product-limit estimator [47].

Results

We obtained microhabitat samples at 928 nests and 819 random locations across study areas from 2008 to 2014 (Table 1). All nests and random locations (n = 1,747) were used in the nest-random analysis, 819 random locations were used in the random-random analysis, and 928 nests were used in the nest-nest analysis. We recorded information on nest success at 924 nests, which were used in nest success analysis. Microhabitat sampling locations were predominantly in Core Areas where 82% of nests and 73% of random locations occurred.

Nest-Random

Competitive models that best explained sage-grouse microhabitat nest selection included 12 predictor variables that described shrub characteristics, grass height, herbaceous canopy cover, and ground cover microhabitat characteristics (Table 3). In the nest-random modeling set, 73 models were competitive with the top model (ΔAIC_c = 0.25–3.96). The global model (K = 15, ΔAIC_c = 10.25) was not in the competitive model set. Model averaging indicated that the 95% confidence interval for the odds ratio estimate of Gap_{3m}, PerGrass_H, $Grass_{5m}$, $Forb_{1m}$, $BioCrust_{5m}$, and $Litter_{5m}$ overlapped 1 (Table 4); therefore, we considered those to be marginal predictor variables and limited our interpretations to primarily focus on the $Shrub_{1m}$, $Artr_{2.5m}$, Artr_H, $Gap_{0.5m}$, V0, and $BareRock_{5m}$ variables. Supported microhabitat variables encompassed all three microhabitat scales (1-m, 2.5-m, and 5-m). For every 10% increase in shrub cover at the 1-m scale ($Shrub_{1m}$), the relative probability of nest selection increased by approximately 48%. A 10% increase in big sagebrush cover within 2.5 m ($Artr_{2.5m}$) resulted in an increase in relative probability of nest selection by approximately 23%. For every 1 unit increase in the number of spaces between shrubs at the plot scale ($\geq$0.5 m and <1.0 m; $Gap_{0.5m}$) relative probability of nest selection increased by approximately 8%. Increased visual obstruction (VO) by 10 cm increased the relatively probability of nest selection by 28%.

Random-Random

Models that best explained microhabitat availability between Core and Non-Core Areas included 5 predictor variables (Table 3). The candidate model set consisted of 7 models (ΔAIC_c = 0.35–3.48). Model averaging indicated that the 95% confidence intervals for odds ratio estimates of the 5 predictor variables did not overlap 1 (Table 4). Therefore, our top model explaining microhabitat availability included the variables $Gap_{0.5m}$, $ResGrass_{1m}$, $Cactus_{1m}$, $BioCrust_{2.5-3.5m}$, and $Litter_{5m}$ at all 3 microhabitat scales. The number of shrub gap spaces ($\geq$0.5 m and <1.0 m; $Gap_{0.5m}$) and biological soil crust between 2.5 and 3.5 m away from the center of the transect ($BioCrust_{2.5-3.5m}$) were strong positive predictors of microhabitat availability in Core Areas. Residual grass cover within 1 m ($ResGrass_{1m}$) of center of random locations, cactus cover between 2.5 and 3.5 m away from the center of the transect, and

Table 3. Model comparisons of binomial generalized linear mixed models evaluating nest-site selection of sage-grouse (nest-random), availability of microhabitat within and outside of Core Areas (random-random), and sage-grouse use of microhabitat within and outside of Core Areas (nest-nest). Cox proportional hazard models were used to evaluate nest success of sage-grouse within and outside of Core Areas. Top five models for each analysis type were compared with Akaike's information criterion (adjusted for small sample sizes; AIC$_c$) and Akaike weights (w_i). Nests and random locations were located in five distinct study areas (n = 928 nests, n = 819 random locations, and n = 924 nests with survival data) throughout central and southwestern Wyoming, USA, 2008–2014.

	Model fit statistics			
Model[1]	K	ΔAIC	w_i	Deviance
Nest-random				
Shrub$_{1m}$ + Artr$_{2.5m}$ + Artr_H + Gap$_{0.5m}$ + VO + BareRock$_{5m}$	9	0.00	0.03	1965.12
Shrub$_{1m}$ + Artr$_{2.5m}$ + Artr_H + Gap$_{0.5m}$ + VO	8	0.25	0.03	1967.39
Shrub$_{1m}$ + Artr$_{2.5m}$ + Gap$_{0.5m}$ + VO + BareRock$_{5m}$	8	0.56	0.03	1967.70
Shrub$_{1m}$ + Artr$_{2.5m}$ + Gap$_{0.5m}$ + VO	7	1.07	0.02	1970.23
Shrub$_{1m}$ + Artr$_{2.5m}$ + Artr_H + Gap$_{0.5m}$ + Gap$_{3m}$ + VO + BareRock$_{5m}$	10	1.25	0.02	1964.34
Null AIC$_c$ = 400.13				
Random-random				
Gap$_{0.5m}$ + ResGrass$_{1m}$ + Cactus$_{1m}$ + BioCrust$_{2.5–3.5m}$ + Litter$_{5m}$	8	0.00	0.22	428.30
Gap$_{0.5m}$ + ResGrass$_{1m}$ + Cactus$_{1m}$	6	0.35	0.19	432.72
Gap$_{0.5m}$ + ResGrass$_{1m}$ + Cactus$_{1m}$ + BioCrust$_{2.5–3.5m}$	7	0.72	0.15	431.06
Gap$_{0.5m}$ + ResGrass$_{1m}$ + Cactus$_{1m}$ + Litter$_{5m}$	7	1.28	0.12	431.62
Gap$_{0.5m}$ + ResGrass$_{1m}$ + BioCrust$_{2.5–3.5m}$ + Litter$_{5m}$	7	1.82	0.09	432.16
Null AIC$_c$ = 14.12				
Nest-nest				
Artr_H + Gap$_{0.5m}$ + Bare$_{5m}$	6	0.00	0.06	373.98
Artr_H + Gap$_{0.5m}$	5	0.01	0.06	376.02
Artr_H + Gap$_{0.5m}$ + Bare$_{5m}$ + Rock$_{5m}$	7	0.07	0.06	372.02
Artr_H + Bare$_{5m}$ + Rock$_{5m}$	6	0.57	0.05	374.54
Artr_H + Gap$_{0.5m}$ + Rock$_{5m}$	6	0.62	0.05	374.60
Null AIC$_c$ = 3.30				
Nest success				
ARTRpShr$_{2.5m}$ + Gap$_{2m}$ + Rock$_{2.5–3.5m}$	5	0.00	0.54	6056.86
ARTRpShr$_{2.5m}$ + Gap$_{2m}$	4	2.40	0.16	6063.43
Gap$_{2m}$ + Rock$_{2.5–3.5m}$	4	3.11	0.11	6057.00
ARTRpShr$_{2.5m}$ + Gap$_{2m}$	4	3.55	0.09	6054.18
Gap$_{2m}$	3	4.60	0.05	6054.12
Null AIC$_c$ = 9.74				

[1] Only the top five models and the null model are reported for each analysis type.

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litter within 5 m away from the transect center (Litter$_{5m}$) were all negative predictors of microhabitat availability in Core Areas. We report means and SE for microhabitat data at random locations within and outside of Core Areas nest-nest in S2 Table.

Nest-Nest

The models that explained nest site selection between Core and Non-Core Areas included 5 predictor variables across 31 models, including the null model (ΔAIC$_c$ = 0.01–3.30). The null model was competitive with our top model—within 4 ΔAIC$_c$, which indicated that the top model was not much better at explaining differences between Core and Non-Core Area nests than the null model. The global model (K = 8, ΔAIC$_c$ = 16.00) was not in the competitive

Table 4. Model-averaged parameter estimates and odds ratios with 95% confidence intervals (CI). Data were collected from five distinct study areas (*n* = 928 nests and *n* = 819 random locations) in central and southwestern Wyoming, USA, 2008–2014.

			95% CI			95% CI	
Parameter	**Estimate**	**SE**	**Lower**	**Upper**	**Odds ratio**	**Lower**	**Upper**
Nest-random							
Intercept	3.92						
$\text{Shrub}_{1\text{m}}$	0.04	0.01	0.03	0.05*	1.04	1.03	1.05*
$\text{Artr}_{2.5\text{m}}$	0.02	0.01	0.01	0.03*	1.02	1.01	1.03*
Artr_H	0.01	0.01	0.00	0.02*	1.01	1.00	1.02*
$\text{Gap}_{0.5\text{m}}$	0.08	0.01	0.05	0.11*	1.08	1.05	1.12*
$\text{Gap}_{3\text{m}}$	-0.08	0.08	-0.26	0.10	0.92	0.77	1.10
VO	0.02	0.01	0.01	0.03*	1.02	1.01	1.03*
PerGrass_H	0.01	0.01	-0.01	0.02	1.01	0.99	1.02
$\text{Grass}_{5\text{m}}$	-0.00	0.01	-0.02	0.02	1.00	0.98	1.02
$\text{Forb}_{1\text{m}}$	-0.00	0.01	-0.02	0.02	1.00	0.98	1.02
$\text{BareRock}_{5\text{m}}$	-0.01	0.01	-0.02	0.00*	0.99	0.98	1.00*
$\text{BioCrust}_{5\text{m}}$	0.01	0.02	-0.03	0.05	1.01	0.98	1.05
$\text{Litter}_{5\text{m}}$	0.00	0.01	-0.01	0.01	1.00	0.99	1.01
Random-random							
Intercept	10.57						
$\text{Gap}_{0.5\text{m}}$	0.38	0.10	0.19	0.56*	1.46	1.22	1.76*
$\text{ResGrass}_{1\text{m}}$	-0.16	0.04	-0.24	-0.07*	0.86	0.79	0.93*
$\text{Cactus}_{1\text{m}}$	-0.69	0.31	-1.30	-0.08*	0.50	0.27	0.92*
$\text{BioCrust}_{2.5\text{–}3.5\text{m}}$	0.17	0.08	0.01	0.34*	1.19	1.01	1.40*
$\text{Litter}_{5\text{m}}$	-0.03	0.02	-0.07	0.00*	0.97	0.94	1.00*
Nest-nest							
Intercept	10.29						
Artr_H	-0.03	0.02	-0.06	0.00*	0.97	0.94	1.00*
$\text{Gap}_{0.5\text{m}}$	0.16	0.10	-0.03	0.35	1.17	0.97	1.42
AnGrass	-0.08	0.06	-0.19	0.04	0.93	0.83	1.04
$\text{Bare}_{5\text{m}}$	0.06	0.04	-0.02	0.13	1.06	0.98	1.14
$\text{Rock}_{5\text{m}}$	-0.04	0.03	-0.10	0.02	0.96	0.90	1.02
Nest Success							
$\text{Gap}_{2\text{m}}$	-0.06	0.04	-013	0.01	0.95	0.87	1.01
$\text{ARTRpShr}_{2.5\text{m}}$	0.30	0.19	-0.07	0.67	1.35	0.93	1.96
$\text{Rock}_{2.5\text{–}3.5\text{m}}$	-0.01	0.01	-0.02	0.00*	0.99	0.98	1.00*

* Indicates 95% CI not overlapping 0 for beta estimates or 1 for odds ratios

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model set. Our top model comparing microhabitat differences between Core and Non-Core Areas included the variables Artr_H, $\text{Gap}_{0.5\text{m}}$, and $\text{Bare}_{5\text{m}}$. Model averaging indicated that the 95% confidence intervals for the odds ratio estimate of Artr_H did not overlap 1 (Table 4). Nests in Core Areas tended to have lower mean sagebrush height within 5 m of those nests compared to nests in Non-Core Areas. Model averaging indicated that the 95% confidence interval for the odds ratio estimates of $\text{Gap}_{0.5\text{m}}$, AnGrass, $\text{Bare}_{5\text{m}}$, and $\text{Rock}_{5\text{m}}$ overlapped 1 (Table 4); therefore, we considered those to be marginal predictor variables. We report means and SE for microhabitat data at nests within and outside of Core Areas nest-nest in S3 Table.

Nest Success

Average annual apparent nest success for all nests was 48.1% (444 hatched nests of 924), and the Kaplan-Meier nest success estimate for a 27-day incubation period was 42.0% (95% CI: 38.4–45.9%). No microhabitat variables in our final models violated the proportional hazards assumption of the Cox proportional hazards model. We did not find a difference in nest success between nests within and outside of Core Areas.

The top model describing nest success of sage-grouse included $\text{ARTRpShr}_{2.5\text{m}}$, $\text{Gap}_{2\text{m}}$, and $\text{Rock}_{2.5\text{–}3.5\text{m}}$. There were three other competitive models within $\Delta\text{AIC}_c = 2.40\text{–}3.55$ that included these variables (Table 3); thus, we model-averaged coefficient estimates. Model averaging indicated that $\text{Rock}_{2.5\text{–}3.5\text{m}}$ was the only variable to have model-averaged 95% CI of odds ratios that did not overlap 1 (Table 4). Although $\text{Gap}_{2\text{m}}$ and $\text{ARTRpShr}_{2.5\text{m}}$ were considered in additive modeling, those variables were marginal predictors with model-averaged 95% CI of odds ratios overlapping 1 (Table 4). Therefore, we limited our interpretations to primarily focus on the $\text{Rock}_{2.5\text{–}3.5\text{m}}$ variable (Table 4). The top model included all variables considered in additive modeling, but was not the global model (i.e., model including all hypothesized variables). The null model was not competitive ($\Delta\text{AIC}_c = 9.74$) with models used in model averaging (Table 3). Rock cover between 2.5 and 3.5 m away from a nest ($\text{Rock}_{2.5\text{–}3.5\text{m}}$) was negatively associated with failure; thus, greater rock ground cover was associated with higher nest success (Table 4). We report means and SE for microhabitat data at successful and unsuccessful nests in S4 Table.

Discussion

Similar to other studies, we found that sage-grouse selected nesting habitat with greater concealment cover including sagebrush cover and height, and visual obstruction [7,9,14,15]. We found a positive association between nest selection and perennial grass height; however, this relationship had marginal support. Microhabitat characteristics associated with less bare ground and rock cover were not selected for compared to random locations. Females selected for more small gaps between shrubs (gap sizes ≥ 0.5 m and < 1.0 m; $\text{Gap}_{0.5\text{m}}$). Locations with more small gaps but few large gaps may indicate 1) areas with greater homogeneity in shrub cover with more sagebrush distributed across the plot (i.e., no large holes in cover) or 2) provide adequate concealment while simultaneously allowing the female to detect and escape from predators.

From our random-random analyses, the availability of small gaps between shrubs was the only shrub variable that differed within and outside of Core Areas, with Core Areas having greater availability of small gaps. Core Areas had lower availability of residual grass and litter cover. This may be related to greater livestock grazing in these areas [e.g., 48], but we do not have data to support this and Wyoming's Core Area Policy does not include any measures that alter livestock grazing in Core Areas. Randomly available locations in Core Areas had more biological soil crust indicating areas with better soil stability. However, biological soil crusts can be compromised by excessive livestock trampling, especially during the growing season when crusts are not frozen [49], suggesting that grazing may not be reducing residual grass and litter in Core Areas compared to nearby non-Core Areas.

Sage-grouse use of microhabitat within and outside of Core Areas (nest-nest analysis) indicated that nests within Core Areas had lower big sagebrush height. Sage-grouse nests within Core Areas had shorter sagebrush heights, which may be associated with differing composition of sagebrush species. For instance, sage-grouse nests in the Jeffrey City study area primarily occurred in Core Area in Wyoming big sagebrush communities, whereas nests in the Bighorn Basin study area often occurred outside of Core Areas in taller mountain big sagebrush communities. We found little support to suggest that annual grass, bare ground, and rock cover were predictive of nests within and outside Core Areas. Albeit, annual grasses are an important indicator of the resistance and resilience of sage-grouse habitats to respond to disturbance [50]. In addition, nest sites selected by sage-grouse in the Atlantic Rim and Stewart Creek of south-central Wyoming were negatively correlated with the presence of cheatgrass (*Bromus tectorum*), but positively correlated with greater perennial grass cover, litter, sagebrush cover, and visual obstruction [7].

Most of our microhabitat sampling locations were in Core Areas (82% of nests and 73% of random locations); however, we found little supporting evidence that Wyoming's Core Area Policy increased the availability of quality microhabitat for sage-grouse between 2008 and 2014. Because the Core Area Policy is relatively new and the primary focus of this policy is on landscape scale conservation—such as limits on oil and gas development—and not on anthropogenic activities more likely to affect microhabitat conditions such as grazing, it is not surprising that we only detected a slight difference. We found some differences in microhabitat characteristics within and outside Core Areas, but these differences were relatively minor relative to a landscape scale conservations policy. Also, our microhabitat sampling locations outside of Core Areas were adjacent to Core Areas (mean distance from Core Areas = 3.1 km [SD = 2.3] km with range of 0.04–12.0 km). Many of our locations outside of Core Areas had not been subject to greater surface disturbance than locations within Core Areas, and we did not continually monitor in landscapes being actively developed for more than 4 years. Thus, our sampling locations (nest and random locations) within and outside of Core Areas were generally in similar habitats.

The connection between specific microhabitat characteristics and nest success has not been consistently documented. Our nest success results need to be interpreted as effects of microhabitat characteristics within the range of what sage-grouse selected compared to what was available to them. Rock cover in our study areas was composed mainly of small diameter gravel <3 cm. It is possible nest placement within areas of greater rock ground cover may be a conferred adaptive advantage related to female concealment during incubation. Female sage-grouse have cryptic grayish-brown plumage [51] that may conform to nesting areas with a high percent of rock ground cover, which could lead to a lower probability of being discovered by visual predators. Nests with greater rock ground cover could also be correlated with areas closer to ridgelines that tend to be less traveled by olfactory predators, which tend to utilize drainage bottoms [52].

Although a marginal finding, we found that nests with greater heterogeneity in shrub species within 2.5 m of a nest were more successful, which could be related to areas with greater vegetative productivity. While most sage-grouse nests are found under sagebrush species [17], Musil [53] found that sage-grouse used shrub species other than big sagebrush more than expected in Idaho. Contrary to our expectations, sage-grouse had higher nest success at nests with more ≥ 2 m and <3.0 m (Gap_{2m}) gaps between shrubs within 5 m of the nest and more rock cover between 2.5 and 3.5 m away from a nest; however, this variable was a marginal finding with 95% CI of odds ratios overlapping 1. This finding is bounded by our results illustrating that sage-grouse selected areas with fewer large gaps. The olfactory ability of mammals is impeded by more updrafts and greater wind turbulence at the microhabitat-scale, and both of these climatic conditions are more likely to occur in areas with local heterogeneity in vegetation height [52]. Conover et al. [54] did not find any differences in updrafts or wind turbulence between nest and random or successful and unsuccessful sage-grouse nests. However, they only tested wind conditions directly above the nest or random location. There may be a nest success trade-off between areas with greater visual obstruction (where sage-grouse typically choose to place their nests) and areas with better olfactory obstruction near the nest (nests with more medium sized gaps within 5 m of the nest that create local updrafts and allow for higher wind velocities near the nest); however, this is an untested hypothesis. Alternatively, there may be a potential correlation of this size gap with a microhabitat characteristic that was not measured (e.g., micro-scale topography, etc.).

Although general trends did emerge, we found few differences between microhabitat selection by sage-grouse within and outside of Core Areas, and no difference in nest success. Sage-grouse selected nests with greater concealment cover, and we found little evidence to suggest that there were differences in concealment cover at available habitats or nest sites in and outside of the Core Areas that were assessed. In addition, we found no evidence that concealment cover was important for nest success in our study areas. The Core Area Policy was designed to reduce negative impacts to quality sage-grouse breeding habitat [21], but our results suggest that the policy may primarily operate at larger spatial scales. As resource selection is a function of available habitats [55], changes in habitat quality may be manifested through management practices resulting in vegetative changes through time. Sage-grouse are a landscape species, with studies demonstrating that both nest selection and success are influenced by habitat characteristics at multiple spatial scales [6,16,56,57]. It is possible that changes in habitat quality at larger spatial scales would eventually have cascading effects on microhabitat quality. Continued assessment of differences in available habitat and nest success will be important steps to assess the viability of Wyoming's Core Area Policy. We found strong evidence that conservation of sage-grouse needs to maintain the availability of concealment cover at the microhabitat spatial scale for nesting. The inclusion of microhabitat information in sage-grouse conservation strategies will help management agencies better understand the relationships between fine scale microhabitat attributes and how those attributes influence sage-grouse nest selection, nest success, and ultimately habitat quality.

Supporting Information

S1 Table. Nest-random microhabitat data. Mean habitat characteristics (± SE) sampled within 5 m of nest and random locations for nest-random comparison in 5 study areas in central and southwestern Wyoming, USA, 2008–2014.
(DOCX)

S2 Table. Nest-random microhabitat data. Mean habitat characteristics (± SE) sampled within 5 m of nest and random locations for nest-random comparisons in 5 study areas in central and southwestern Wyoming, USA, 2008–2014.
(DOCX)

S3 Table. Nest-random microhabitat data. Mean habitat characteristics (± SE) sampled within 5 m of nest locations within and outside of Core Areas for nest-nest comparisons in 5 study areas in central and southwestern Wyoming, USA, 2008–2014.
(DOCX)

S4 Table. Nest-random microhabitat data. Mean habitat characteristics (± SE) sampled within 5 m of successful and unsuccessful nest locations in 5 study areas in central and southwestern Wyoming, USA, 2008–2014.
(DOCX)

S5 Table. Nest and random location microhabitat data. Microhabitat data for random and nest locations. Nest data includes data on nest survival.
(CSV)

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Author Contributions

Conceived and designed the experiments: JBD KTS JLB MRC CPK ACP. Performed the experiments: JBD KTS CPK ACP. Analyzed the data: JBD KTS. Contributed reagents/materials/analysis tools: JLB MRC. Wrote the paper: JBD KTS CPK ACP JLB MRC.

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Microhabitat selection by greater sage-grouse hens during brood rearing

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Abstract: Greater sage-grouse (*Centrocercus urophasianus*) populations have declined throughout the western United States over the past century. Loss of large stands of sagebrush is a major factor leading to the decline of sage-grouse populations. We captured, marked, and tracked hen sage-grouse in Wyoming during the summer of 2012 to study where sage-grouse hens keep their chicks given the dual needs to provide them with food and to keep them safe from avian predators. Vegetation surveys and avian point counts were performed at early-season brood locations, late-season brood locations, and random locations. We conducted multinomial models to determine which habitat variables were most informative in predicting site selection by hen sage-grouse. Hens with and without broods selected sites that had more shrub cover during the early-brood season but not during the late-brood season. During the early-brood season, hens without broods avoided sites where there were American kestrels (*Falco sparverius*) and common ravens (*Corvus corax*), but brood hens did not avoid these sites. During late-brood season, brood hens chose sites with fewer small-avian predators (e.g., black-billed magpies [*Pica hudsonia*] and American kestrels), as well as medium-sized avian predators, such as common ravens, Buteo hawks (*Buteo* spp.), and northern harriers (*Circus cyaneus*). Our results suggest that habitat selection by sage-grouse hens is focused more on avoiding predators than on finding food.

Key words: brood site selection, *Centrocercus urophasianus*, habitat selection, microhabitat, predator avoidance, predator–prey interactions, sage-grouse

Over the past century, greater sage-grouse (*Centrocercus urophasianus*; Figure 1) populations have declined throughout the western United States (Patterson 1952, Connelly and Braun 1997, Connelly et al. 2004, Connelly et al. 2011). Greater sage-grouse (hereafter, referred to as sage-grouse, hens, broods, or chicks) use sagebrush (*Artemisia* spp.) throughout the year for food, shelter, and cover (Bent 1963, Connelly et al. 2011). Loss of sagebrush-dominated habitat has played a major role in the decline in sage-grouse populations throughout the West (Schroeder et al. 2004, Connelly et al. 2011, Kirol et al. 2012).

One way to stabilize sage-grouse populations is to increase the production of juvenile sage-grouse, but this requires suitable brood habitat (Crawford et al. 1992). Most chick mortality occurs when chicks are <3 weeks old (Patterson 1952). Sage-grouse hens keep their newly-hatched broods in sagebrush highlands for 2 to 3 weeks, until the chicks develop the ability to fly. The amount of time that hens keep their broods close to nesting habitat varies each year based on weather and food availability (Holloran and Anderson 2005). In Wyoming, most young broods were located within 3 km of their nest sites (Slater 2003, Holloran and Anderson 2005).

Forbs and insects are important foods for sage-grouse chicks. Therefore, it is not surprising that early-brood habitat is characterized by thick stands of sagebrush with a forb and grass understory containing an abundance of insects (Connelly et al. 2000, Aldridge and Brigham 2002, Kirol 2012). Late-brooding sites often are mesic sites that contain forbs and insects (Holloran 1999, Connelly et al. 2000, Holloran and Anderson 2005, Connelly 2011, Kirol 2012). Hens with late-broods also select for habitat with increased visual obstruction where chicks can hide from predators (Holloran and Anderson 2005).

Predators, including common ravens (*Corvus corax*) and hawks, are a common source of mortality of young sage-grouse (Girard 1937, Patterson 1952, Willis et al. 1993, Cote and Sutherland 1997, Guttery 2011). Survival of sage-grouse during the summer is lowest in: (1) risky habitat where there are perches that hawks can use for hunting; and (2) areas frequented by Buteo hawks (*Buteo* spp.),

Figure 1. Greater sage-grouse. (*Photo by D. Menke, courtesy U.S. Fish and Wildlife Service*)

northern harriers (*Circus cyaneus*) and golden eagles (*Aquila chrysaetos;* Schroeder et al. 1999, Dinkins et al. 2014*b*). Sage-grouse hens can protect their broods from predators by moving them to areas where there are fewer avian predators (Dinkins et al. 2012, 2014*a*, *b*).

The purpose of this study was to examine how habitat selection by sage-grouse hens with broods is impacted by the dual needs to provide food for their chicks and to keep them safe from avian predators. We examined if sage-grouse hens with and without broods differed in their habitat selection and predator avoidance during the early- and the late-brood seasons. We also compared sites occupied by sage-grouse hens to sites where sage-grouse were killed by predators to determine if some habitats were more risky than others.

Study area

Our study area included 11 circular sites in southwest and south-central Wyoming, each 16 or 24 km in diameter (7 study sites of 16-km diameter and 4 study sites of 24-km diameter). Five study sites were located in Lincoln County, two in Sweetwater County, two in Uinta County, and three in Carbon County. Each study site in southwest Wyoming was 16-km in diameter and centered on the specific lek where hens had been captured. Study sites in south-central Wyoming all were 24-km in diameter, because sage-grouse were captured at several adjacent leks. Study site diameters were based on Holloran and Anderson (2005); they found that 93% of observed nests were <8.5 km from leks where they bred. Study sites were chosen to provide a representation of overall sage-grouse brood-rearing habitat in southern Wyoming with a variety of land uses and topographic features (Holloran 2005, Dinkins et al. 2012, Kirol et al. 2012). Elevation ranged from 1,950 m to 2,530 m at all study sites. Land at most of our study sites was federally owned, and administered by the U.S. Bureau of Land Management; a small percentage of sites were on private land. Domestic sheep (*Ovis aries*) and cattle (*Bos taurus*) grazing were the dominant land uses. All study sites had anthropogenic development, which consisted mostly of unimproved 4-wheel drive roads. Conventional natural gas, conventional oil, and coal-bed methane natural gas extraction activities were present in 50% of our study sites. Removal of common ravens for the benefit of the local livestock producers was conducted by USDA Wildlife Services in 50% of the study sites. The vegetation at all study sites was dominated most commonly by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), mountain big sagebrush (*A. t. vaseyana*), black sagebrush (*A. nova*), or dwarf sagebrush (*A. arbuscula*). Other common shrub species in our study sites included antelope bitterbrush (*Purshia tridentata*), snowberry (*Symphoricarpos albus*), chokecherry (*Prunus virginiana*), alderleaf mountain mahogany (*Cercocarpus montanus*), rabbitbrush (*Chrysothamnus* spp.), greasewood (*Sarcobatus vermiculatus*), and spiny hopsage (*Grayia spinosa*). Isolated stands of juniper (*Juniperus* spp.) and quaking aspen (*Populus tremuloides*) were found at the higher elevations on north-facing slopes.

Methods

Sage-grouse capture and monitoring

Each April from 2008 to 2011, we captured sage-grouse hens at night using ATVs, spotlights, and hoop-nets (Giesen et al. 1982, Wakkinen et al. 1992). Hens were released at capture sites after we fitted them with 17.5-g or 22-g (<1.5% body mass) necklace radio collars made by Holohil Systems Ltd. (Carp, Ontario, Canada or Advanced Telemetry Systems Inc, Isanti, Minn.).

We monitored sage-grouse hens during nesting and brood rearing from late March

Table 1. Top avian and vegetation models from all possible combinations of informative variables for the early-brood season. Top models were used to compare locations of sage-grouse brood hens, nonbrood hens, and random points. (LARGE = golden eagle density; MED = common raven, Buteo hawk, and northern harrier density; BUTEO = Buteo hawk density; CORA = common raven density; AMKE = American kestrel density; SHRUB = percent shrub cover; BARE = percent bare ground, INGRASS = height of tallest grass in plot; OUTGRASS = height of tallest grass within 1 m outside plot; ROBEL = average Robel pole reading; RESGR = height of residual perennial grass).

Model	K	ΔAIC_c	w_i
Early-brood season — Avian predators			
LARGE + CORA + AMKE	8	0.00	0.20
MED + MAKE	6	0.35	0.17
CORA + MAKE	6	0.39	0.17
CORA + BUTEO + MAKE	8	0.58	0.15
LARGE + AMKE	6	3.05	0.04
LARGE + MED	6	3.26	0.04
LARGE + AMKE + BUTEO	8	3.30	0.04
LARGE + CORA	6	3.61	0.03
AMKE + BUTEO	6	3.79	0.03
MED	4	3.82	0.03
NULL (INTERCEPT ONLY)	2	8.32	0.00
Early-brood season—Vegetation			
SHRUB	6	0.00	0.27
SHRUB + BARE + INGRASS	8	2.12	0.09
SHRUB + BARE + ROBEL	8	2.23	0.09
SHRUB + ROBEL	6	2.65	0.07
SHRUB + BARE + OUTGRASS	8	3.40	0.05
SHRUB + BARE + INGRASS + RESGRASS	10	3.91	0.04
SHRUB + BARE + GRAVEL	8	4.18	0.03
SHRUB + RESGRASS	8	4.32	0.03
SHRUB + BARE + GRAVEL + INGRASS	10	4.73	0.03
SHRUB + INGRASS + RESGRASS	8	4.83	0.02
NULL (INTERCEPT ONLY)	2	25.0	0

through July 2012. We located radio-tagged hens weekly with Communications Specialists receivers and 3-element Yagi antennas (Communications Specialists, Orange, Calif.). Collared hens were identified with binoculars while we were approximately 25 m away by circling each hen until it was visually located. We monitored hens weekly for survival and brood presence throughout the brood-rearing season. Locations within 20 days after hatching were considered early-brood locations (Thompson et al. 2006). We identified hens unaccompanied by broods after we repeatedly failed to observe any brooding behavior by the hen or chicks. Hens without broods were located at the same time as hens with broods. We used the average of the hatching days of all successful nests as the starting point to label unaccompanied hens as early- or late-brood.

Vegetation surveys

We conducted vegetation surveys at sites where radio-collared hens were located during early- and late-brood seasons to determine micro-habitat characteristics. Surveys were also conducted at an equal number of randomly generated points within each study site. To restrict random locations to habitat considered available to sage-grouse for brood-rearing, we used ArcMap 10.1 (ESRI Inc., Redlands, Calif.) to generate random locations only in sagebrush-dominated habitat as classified by the Northwest ReGAP land cover data during 2008 (Lennartz 2007). Random locations were selected to be >1000 m apart from each other. We generated 12 random locations in each 16-km diameter study site and 20 random locations in each 24-km diameter study site.

Hereafter, hens with broods will be referred to as brood hens, and hens without broods will be referred to as nonbrood hens. Each early- and late-brood location was paired with a random-point location and surveyed for shrub height, shrub density, ground cover, and visual obscurity.

At each location, shrub height and density were determined along 20-m transects in the north-south and east-west directions centered on the location of observed hen or random point. Height, size and species of shrub (i.e. woody vegetation) were documented on the same transects using techniques previously reported by Gregg et al. (1994), Thompson et al. (2006), Connelly et al. (2011), and Kirol et al. (2012). We measured the highest point (cm) of all shrub species encountered on the transect and averaged their heights per location (hereafter, called shrub height). We calculated shrub density by counting the number of live shrubs within 1 m of each transect line. Visual obscurity was determined by using a 1-m Robel pole (Robel et al. 1970) placed at each hen's location and random point. Visual obscurity was measured at 5-m increments from each cardinal direction by looking back at the Robel pole at a height of 1-m. We recorded the lowest observable point on the Robel pole that was not obscured by vegetation from each distance. Canopy and ground cover were determined visually within 6 cover classes in 20 × 50-cm quadrants (Daubenmire 1959). Quadrants were placed along each transect along the north-south and east-west transects at distances of 0, 4, 6, 8, 10, 12, and 14 m radiating from the center point.

Canopy and ground cover were grouped into 6 categories based on the percent of ground covered by vegetation with: 1 = 0 to 1% coverage; 2 = 1.1 to 5% coverage; 3 = 5.1 to 25% coverage; 4 = 25.1 to 50% coverage; 5 = 50.1 to 75% coverage; and 6 = 75.1 to 100% coverage. Ground-cover categories were: annual grass, perennial grass, residual grass (i.e., dead sections of grass still standing from the previous year); food forb (forbs that are known to be eaten by sage-grouse (Mabray 2015); nonfood forb (species sage-grouse are not known to eat); gravel and rock (crushed stone of any size); bare soil (soil not covered by any other material); cryptobiotic crust (cyanobacteria, lichens, moss, green algae, microfungi and bacteria); cacti (*Opuntia* spp., *Pediocactus* spp.); and litter (dead vegetative matter, or scat). In addition, we measured the tallest portion of annual, perennial, and residual perennial grass (cm) blades within 1 m of the leading outer edge of each Daubenmire quadrant.

Avian-predator point counts

Avian predator point counts were performed at each sage-grouse location and weekly at an equal number of randomly generated locations (Dinkins et al. 2012, Dinkins et al. 2014*a*). Avian-predator point counts consisted of 10-minute observation periods during which we recorded all avian predators including, common raven, black-billed magpie (*Pica hudsonia*), golden eagle, Buteo hawks, northern harrier, and American kestrel (*Falco sparverius*). We determined a weighted average for avian-predator densities to eliminate differences in number of visits that each random point and sage-grouse location received over the summer.

Data analysis

We compared multinomial models using Akaike's information criterion corrected for small sample sizes (AIC_c) and Akaike weights (w_i; Burnham and Anderson 2002) with function aictab in package AICCMODAVG R. Multinomial models were used because of the multiple plot type variables (early-brood, early-hen, late-brood, late-hen, mortality, and random). The following multinomial equation was used:

$$(x_1 + x_2 + \cdots + x_k)^n = \sum_{n_1,n_2,\ldots,n_1 \geq 0} \frac{n!}{n_1!\,n_2!\ldots n_k!} x_1^{n_1} x_2^{n_2} \ldots x_k^{n_1}$$

AICc was used to determine the model that best described the variation in the data collected. Variables that we tested included all vegetation covariates, including shrub cover, ground cover, and visual-obscurity. The objective of our analysis was to determine the variables that hen sage-grouse selected during early- and late-brood rearing season regardless of their reproductive status. Therefore, we compared site selection by all hens compared to available habitat. All combinations of season and hens (early-season nonbrood hens, early-season brood hens, late-season nonbrood hens, and late-season brood hens) were compared to random-site locations. Bird locations were analyzed based on the temporal group (early-season or late-season) in which they were observed, regardless of reproductive status. This allowed us to determine what

Table 2. Top models for both early- and late-brood seasons based on their AICc scores. Top models compared locations of sage-grouse brood hens, nonbrood hens, and random points. (LARGE = golden eagle density, MED = common raven, buteo hawk, and northern harrier density, SMALL = black-billed magpie and American kestrel density, CORA = common raven density, AMKE = American kestrel density, SHRUB = percent shrub cover, BARE = percent bare ground, INGRASS = height of tallest grass in plot, OUTGRASS = height of tallest grass within 1 m outside plot, ROBEL = average robel pole reading, RESGRASS = height of residual perennial grass in plot, GRAVEL = percentage of gravel cover).

Model	K	ΔAIC_c	w_i
SHRUB + CORA + AMKE	8	0.00	0.20
SHRUB + BARE + ROBEL + CORA + AMKE	12	0.01	0.19
SHRUB + BARE + ROBEL + LARGE + CORA + AMKE	14	2.69	0.05
SHRUB + BARE + OUTGRASS + CORA + AMKE	12	2.75	0.05
SHRUB + BARE + INGRASS + CORA + AMKE	12	2.82	0.05
SHRUB + ROBEL + CORA + MAKE	10	3.05	0.04
SHRUB + LARGE + CORA + MAKE	10	3.07	0.04
SHRUB + CORA + BUTEO + AMKE	10	3.13	0.04
SHRUB + BARE + ROBEL + CORA + BUTEO + AMKE	14	3.35	0.04
SHRUB + MED + MAKE	8	3.94	0.03
NULL (intercept only)	2	28.65	0.00
SMALL + MED + SHRUB + BARE + GRAVEL + ROBEL	10	0.00	0.37
SMALL + MED + SHRUB	12	1.61	0.16
SMALL + MED + LARGE + SHRUB + BARE + GRAVEL + ROBEL	12	2.95	0.08
SMALL + MED + LARGE	8	3.21	0.07
SMALL + MED + LARGE + SHRUB + OUTGRASS + ROBEL	10	4.80	0.03
SMALL + MED + SHRUB + OUTGRASS + ROBEL	10	4.80	0.03
SMALL + MED + SHRUB + ROBEL	12	4.96	0.03
SMALL + MED + LARGE + SHRUB	14	5.26	0.03
SMALL + CORA + SHRUB	12	5.32	0.03
SMALL + MED + SHRUB + BARE + OUTGRASS	14	5.83	0.02
SMALL + MED + BARE + GRAVEL	12	5.84	0.02
NULL (intercept only)	2	18.64	0.00

environmental factors hen sage-grouse selected during early- and late-brooding seasons. We based inference on multinomial models within 4 AIC_c of the top-selected model and conducted model averaging of parameter estimates from models within 4 AIC_c of the top-selected model (Burnham and Anderson 2002). Variable importance was calculated for each parameter estimate that was model averaged by summing the w_i across all models with that variable (Arnold 2010).

Covariates

We grouped avian predators by body size (Dinkins et al. 2012, 2014*b*). Small predators (SMALL) included black-billed magpies (BBMA; mean mass = 178 g) and American kestrels (AMKE; mean mass = 117 g). Medium predators (MED) included: common ravens (CORA; mean mass = 1150 g); buteo hawks (BUTEO; mean mass = 1000 g); and northern harriers (NOHA; mean mass = 890 g). We considered golden eagles (GOEA; mean mass = 4500 g) to be the only large avian predator (LARGE) on the landscape. Average body mass

Table. 3. Parameter estimates for the early-brood season with 95% confidence intervals (CI) for top AICc selected multinomial regressions. The top model compared avian-predator densities (CORA = Common raven; AMKE = American kestrel) and vegetation data (Shrub cover = percent shrub cover) at locations of sage-grouse brood hens, nonbrood hens, and random points. Early-season locations included locations for 8 brood hens, 32 nonbrood hens, and 92 random locations.

Variable	Estimate	SE	95 % CI Lower	95 % CI Upper
Brood intercept	- 12.72	38.94	-89.05	63.61
Shrub cover	0.10	0.03	0.04	0.11*
CORA density	- 1.35	5.64	-12.40	9.69
AMKE Density	0.28	0.15	-0.02	0.58
Nonbrood intercept	-15.26	0.02	-15.03	-15.21*
Shrub cover	0.08	0.02	0.04	0.15*
CORA density	- 0.32	0.13	-0.57	-0.07*
AMKE Density	- 1.47	0.16	-1.77	-1.15*

* Denotes 95% CI that does not include zero.

was obtained from Sibley (2003).

We considered 3 main sub-groups of vegetation covariates: shrub cover, ground cover, and visual obscurity. Shrub cover included all data collected during transect surveys; these covariates include: live-shrub cover (LIVESHR); live-shrub height (LIVESHR_HT); dead-shrub cover (DEADSHR); dead-shrub height (DEADSHR_HT); live-sagebrush cover (LIVEART); live-sagebrush height (LIVEART_HT); dead-sagebrush cover (DEADART); dead-sagebrush height (DEADART_HT); total-sagebrush cover (TOTALART); and total-sagebrush height (TOTALART_HT). Ground cover covariates included: annual grass cover (AGRASS); annual grass height (AGRASS_HT), perennial grass cover (PGRASS); perennial grass height (PGRASS_HT); residual grass cover (RESGR); bare dirt cover (BARE); litter cover (LITTER); cryptobiotic crust cover (CRYPTO); and gravel cover (GRAVEL). Visual obscurity was composed of a single covariate per site, the average measurements from all Robel pole readings at all vegetation plot locations (ROBEL). All shrub cover data were converted to a single value per plot (SHRUB).

Model construction and selection

We ran multinomial models containing all variables independently to determine informative variables from the overall set of collected data for early- and late-brood seasons for sage-grouse hens with and without broods. All models with a ΔAICc below that of the null model (the null model functions as a statistical null hypothesis for detecting pattern) were removed from all further analysis (Gotelli 2006, Arnold 2010). We kept all variables that performed better than the null and had an 85% confidence intervals did not overlap zero. We ran them in all possible combinations to determine the most informative avian and vegetation models for both early- and late-brood seasons to be used in final analysis. All models that ranked within 4 AICc of the top model were kept for further analysis. An individual variable was considered statistically significant if the 95% confidence interval of its regression did not overlap zero.

Results

Vegetation sampling and avian-predator point counts were each performed at 173 sage-grouse and random-point locations. Samples included 40 early-season bird locations, 35 late-season locations, 92 random-points and 7 locations where we located a dead sage-grouse hen that had been depredated. The 40 early-season locations included locations for 8 brood hens and 32 nonbrood hens. Late-season locations contained 7 brood hens and 33 nonbrood hens.

Habitat used by hen sage-grouse during early-brood season differed from available sage-grouse habitat (i.e., random points) in having more shrub cover, more visual obscurity, and lower densities of common ravens and American kestrels (Tables 1 and 2). Two models

Table. 4. Top avian and vegetation models using all possible combinations of variables for the late-brood season. Top models were used to compare locations of sage-grouse brood hens, nonbrood hens, and random points. (LARGE = golden eagle density; MED = common raven, Buteo hawk, and northern harrier density; SMALL = black-billed magpie and American kestrel density; NOHA = northern harrier density; CORA = common raven density; AMKE = American kestrel density; SHRUB = percent shrub cover; BARE = percent bare ground; INGRASS = height of tallest grass in plot; OUTGRASS = height of tallest grass within 1 m outside plot; ROBEL = average Robel pole reading; RESGRASS = height of residual perennial grass in plot; GRAVEL = percentage of gravel cover).

Model	K	ΔAIC_c	w_i
Avian models			
SMALL + MED	6	0.00	0.42
SMALL + MED + LARGE	8	2.18	0.14
SMALL + CORA	6	3.38	0.08
MED + MAKE	6	4.49	0.04
SMALL	4	4.92	0.04
SMALL + CORA + NOHA	8	4.97	0.04
SMALL + LARGE + CORA	8	5.90	0.02
SMALL + CORA + BUTEO	8	6.08	0.02
MED	4	6.34	0.02
MED + LARGE + MAKE	8	6.55	0.02
NULL (intercept only)	3	215.63	0.00
Vegetation models			
SHRUB + ROBEL	6	0.00	0.17
BARE + GRAVEL	6	1.11	0.10
SHRUB + BARE + ROBEL	6	2.04	0.06
SHRUB	8	2.26	0.06
SHRUB + INGRASS + RESGRASS	8	2.39	0.05
BARE + GRAVEL + RESGRASS	8	2.67	0.05
SHRUB + BARE + OUTGRASS	8	2.86	0.04
SHRUB + GRAVEL + ROBEL	8	2.95	0.04
SHRUB + INGRASS + ROBEL	8	3.22	0.03
SHRUB + BARE + GRAVEL + ROBEL	10	3.93	0.02
NULL (intercept only)	3	214.91	0.00

scored within 2 AICc; they were (SHRUB) + (CORA + AMKE) (AICc = 176.69 with a log likelihood of -79.76) and (SHRUB + BARE + ROBEL) + (CORA + AMKE) (AICc=176.70 and a log likelihood of -75.03). During the early-brood season, hens with and without broods preferred areas with more shrubs (Table 3). Nonbrood hens avoided sites where there were common ravens or American kestrels, but nonbrood hens did not.

Our best-fit models for describing site selection by hen sage-grouse during late-brood season contained shrub cover and densities of small and medium-sized avian predators (Table 4). The top 2 models, within 2 AICc, were (SMALL+ MED) + (SHRUB + BARE + GRAVEL + ROBEL) (AIC = 163.06 and a log likelihood of -70.57), and (SMALL + MED) + SHRUB (AIC = 164.67 and a log likelihood of -68.96). During the late season, sage-grouse hens, both with and without broods, selected sites that had more shrub cover than random sites (Table 5). Hens with broods avoided sites with either small avian predators (black-billed magpies

Table. 5. Parameter estimates for the late-brood season with 95% confidence intervals (CI) for top AICc selected multinomial regressions. The top model compared avian-predator densities (Small = American kestrel and black-billed magpies, Medium = buteo hawks, common ravens and northern harriers) and vegetation data (Shrub cover = percent shrub cover) at locations of sage-grouse brood hens, nonbrood hens, and random points. Late-season locations included 7 brood hens, 33 nonbrood hens, and 92 random locations.

Variable	Estimate	SE	95 % CI	
			Lower	Upper
	Brood			
Intercept	- 1.17	1.80	-4.70	2.36
Small predators	- 18.89	4.67E -8	-18.90	- 18.90*
Medium predators	- 24.96	6.05E -5	-24.96	- 24.96*
Shrub cover	0.05	0.05	-0.03	0.14
Bare ground	- 0.07	0.05	-0.17	0.01
Gravel	- 0.11	0.11	-0.27	0.17
Robel pole	- 0.04	0.04	-0.12	0.03
	Nonbrood			
Intercept	- 1.17	0.88	-1.90	2.36
Small predators	- 2.24	6.37E -6	-25.42	-25.42*
Medium predators	- 0.29	2.31E -1	-0.07	0.83
Shrub cover	0.08	0.02	-0.01	0.07
Bare ground	0.01	0.02	-0.11	0.01
Gravel	0.03	0.02	-0.08	0.01
Robel pole	- 0.07	0.04	-0.07	0.01

* Denotes 95% CI that does not include zero.

and American kestrels) or medium-sized avian predators (common raven, Buteo hawk, and northern harrier).

Vegetation surveys and avian point counts were performed at sites where 5 hen sage-grouse had been killed by either avian or mammalian predators. When models were run comparing mortality sites to random sites, no variables were significant.

Discussion

We found that sites occupied by hen sage-grouse, regardless of whether they were accompanied by a brood, differed from random sites based on multiple variables. During the early-brood season, hens select sites that contained more shrub cover. Guttery (2011) found during early-brood season that hen sage-grouse select sites with high density of black sagebrush. Black sagebrush is shorter and denser than big sagebrush (Wyoming big sagebrush and mountain big sagebrush) and provides concealment for chicks without the brush obscuring the vision of hens.

We found that sage-grouse hens, both with and without broods, avoided sites where there were higher densities of small and medium-sized avian predators when compared to random locations although the results for brood hens were not statistically significant during the early season. Dinkins et al. (2012, 2014*a*) also reported that hens with broods select sites with lower densities of avian predators. Small and medium-sized avian predators kill sage-grouse chicks, and medium-sized predators, Buteo hawks in particular, can kill adult sage-grouse. Connelly et al. (2000) reported that predation is not a limiting factor on sage-grouse populations. However, sage-grouse will avoid the predators that pose a threat to their survival. Small predators, such as black-billed magpies and American kestrels, were avoided by all hen sage-grouse during both the early and late seasons, whereas medium-sized predators were avoided only by those hens that had an active brood during the late-season. Other than this one variable, habitat selection was similar between the early-brood season and late-brood season. Our results indicate that sage-grouse hens select sites based more on avoiding predators than on the sites vegetation.

Management implications

Anthropogenic development of sagebrush stands not only leads to the loss of suitable habitat for sage-grouse but also leads to an increase in predator densities (Dinkins et al. 2014*b*). Tall structures, including rural homes, communication towers, oil and gas structures, and power poles provide nesting and perching opportunities for raptor species. Increase in nesting and perching opportunities across the landscape has caused an increase in predator densities (Dinkins et al. 2014*b*).

Sage-grouse minimize the threat of predation by avoiding areas where they observe predators (Conover et al. 2010). The results of this study and Dinkins et al. (2014*a*) demonstated that sage-grouse also avoiding habitat that the birds perceive as riskier, such as areas near tall structures and other anthropogenic features. Avoidance of avian predators and anthropogenic features allows hen sage-grouse to lower their risk of predation, but also has the unfortunate effect of concentrating sage-grouse into smaller areas.

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FY2016 Annual Report

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Resource Denial as Means to Reduce Avian Predation of Greater Sage Grouse

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Common ravens (*Corvus corax*, hereafter ravens) are significant nest predators of greater sage-grouse (*Centrocercus urophasianus*), and their populations have increased dramatically across the western U.S. over the last century. Several authors have suggested that management of anthropogenic food subsidies may be a viable option to manage ravens in the western U.S., but this management strategy has not been tested. In the winter of 2015/2016, we denied ravens food resources in an effort to disrupt and disperse two large winter roosts near Kemmerer, Wyoming.

We to surveyed roost attendance at roosts located at the Solvay Soda Ash Mine (72 km from Kemmerer and our control), the Shute Creek Natural Gas Plant (38 km from Kemmerer), and the Encana Sulfur Loading Terminal/Kemmerer Port of Entry Railroad Bridge which function as 1 roost. Because ravens in southwest Wyoming form large winter roosts, we can census the population by monitoring roosts. Each roost was surveyed at least once per week.

To determine daily movements and roost locations of ravens in the area, we deployed 7 solar GPS telemetry backpacks. Ravens were captured in the Kemmerer landfill with padded #3 foothold traps which had their springs weakened. Ravens were then fitted with the GPS backpack, banded, and released. These backpack units were the same as the units deployed by Peebles in the winter of 2014/2015 and will augment those units that still survive. Of the 5 units Peebles deployed, 1 unit functioned throughout the winter of 2015/2016. One unit was recovered from a dead raven and will be refurbished and deployed again in the winter of 2016/2017 (Figure 1). Another unit, that was feared lost in the fall of 2015, came back on-line in the spring of 2016. We suspect that feathers covered the solar panel and prevented the unit from charging, and that when the raven molted in the spring, the solar panel was left unobstructed.

To deny ravens food resources in and around Kemmerer, we collected roadkills and harassed ravens in the Kemmerer landfill to prevent them from foraging at the landfill. We removed all roadkill, on and within the road right-of-way (approximately 100 m wide) within 32km of Kemmerer on the roads US 30 and WY 189. We patrolled each section of road at least every other day at a random time. When adverse weather prevented patrolling for roadkills, we patrolled all roads the next day that weather conditions allowed. We disposed of all roadkill collected in the Kemmerer landfill per WGFD Chapter 33 Permit #657. Between January and April, 2016, we collected >2000 kg of roadkill.

The monthly average number of ravens roosting at the Encana/Port of Entry roost decreased by 35% from February to March (Figure 2). Similarly, the monthly average number of ravens roosting at the Shute Creek roost decreased by 38% from February to March (Figure 3). In contrast, the roost at the Solvay Soda Ash Mine, our control, saw an increase in the monthly average of ravens roosting of 13% between February and March (Figure 4). More data and further analysis of these data are required to draw conclusions regarding the efficacy of this technique, but our first-year results are encouraging.

To determine how ravens respond to the removal of roadkill, we established 8 observation points, at least 16 km apart, along the roadkill removal route. From these points, we counted all ravens observed, at any distance, within a 15-minute period. For each raven observed, we assessed its behavior, flock size, and visually estimated its distance perpendicular to the road. We will use this data to evaluate changes in behavior and proximity to the road by binning distances into 0-100 m, 100-500 m and >500 m for each behavior. We chose these bins to capture the raven use of roadways. We assume that if the raven is within 100 m of a road, it can visually observe roadkill. If it is 100-500 m from the road, the raven may be periodically checking the road for roadkill. If the raven is >500 m from the road, it is not utilizing the road for foraging. We will also overlay all daylight GPS telemetry points on a road map and determine perpendicular distance to the nearest road, bin the distances, and analyze the same way as the observation data.

Between January and April, 2016, we observed 217 ravens during 69 observation periods (41% of all observation periods). To increase the number of raven observation during the 2016/2017 winter, we will double the number of point counts along the roadkill removal route. In February, the average distance ravens were observed from the road was 191 m. In March, the average distance ravens were observed from the road was 85 m. However, we observed 37% fewer ravens in March than in February (Table 1).

Another goal of this project is to characterize raven nest site selection in southwest Wyoming. To locate raven nests, we examined roost location data from our sample of GPS backpacked ravens. When a raven roosted in approximately the same location for greater than 28 days, we noted the location and investigated on foot. In 2016, only 1 GPS marked raven was determined to be nesting. We accessed the area and were able to determine that the raven did have a nest, as evidenced by its aggressive behavior, but were unable to visualize the nest due to the dense canopy of sub-alpine fir (*Abies lasiocarpa*).

In addition to our surveys of ravens during the winter to determine responses to resource denial, we will leverage the wealth of spatial data that we have collected, and will continue to collect. Our GPS telemetry backpacks are programmed to record location every 4 hours during the day, and at midnight, to allow us to determine where the bird roosted. Data with this temporal and spatial resolution has not been previously collected for ravens. We will use these data to create resource selection functions before, during, and after resource denial. These resource selection functions will incorporate natural layers such as land cover, elevation, and water sources, as well as anthropogenic layers such as landfills, roads, transmission lines, railroad tracks, and oil/gas wells. These models will give us a better insight into how ravens utilize resources on the landscape in the winter. We will also develop resource selection functions for both mated and un-mated ravens during greater sage-grouse nesting season. We will incorporate the same layers as the winter models, but will also incorporate greater sage-grouse leks with >10 males in attendance. These models will give us insight into how ravens utilize resources on the landscape during the period in which they are in conflict with greater sage-grouse, and may open the door for new management strategies.

Our Publications in Peer-reviewed Journals in FY2016

Dinkins, J. B., K. T. Smith, J. L. Beck, C. P. Kirol, A. C. Pratt, and M. R. Conover. 2016. Microhabitat conditions in Wyoming's sage-grouse core areas: effects on nest site selection and success. PloS one 11: e0150798.

Mabray, S. T., and M. R. Conover. 2015. Microhabitat selection by greater sage-grouse hens during brood rearing. Human-Wildlife Interactions 9:219–228.

Peebles, L., and M. R. Conover. 2016. Effectiveness of the toxicant DRC-1339 in reducing populations of common ravens in Wyoming. Wildlife Society Bulletin 40:281–287.

Figure 1: A Solar GPS satellite telemetry backpack which was recovered from a dead raven. The raven caused significant damage to the antenna attachment point.

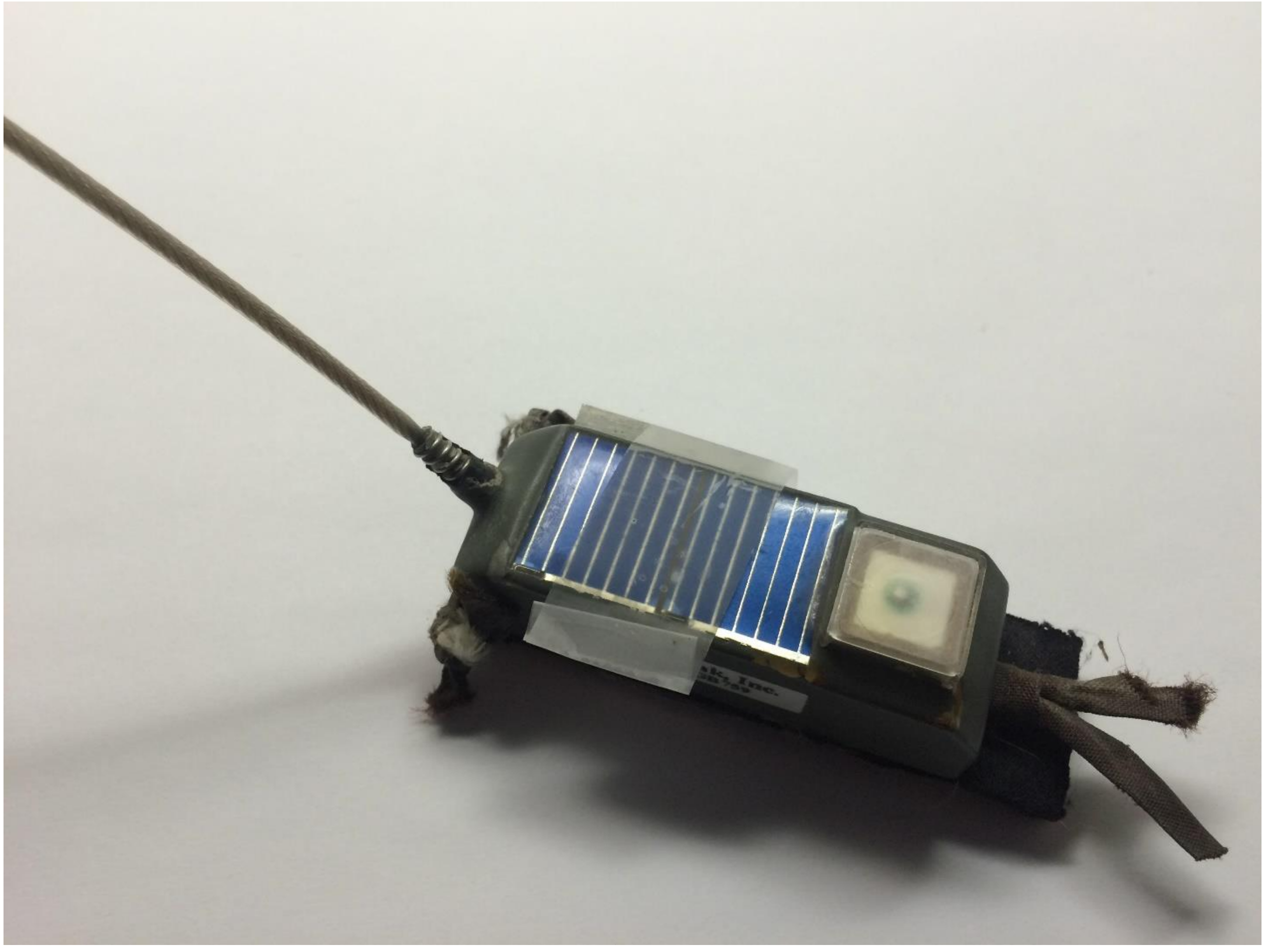

Figure 2: Combined raven attendance at the Encana and Port of Entry roosts near Kemmerer, WY where we denied ravens food resources during the winter of 2015/2016. These roosts function as 1.

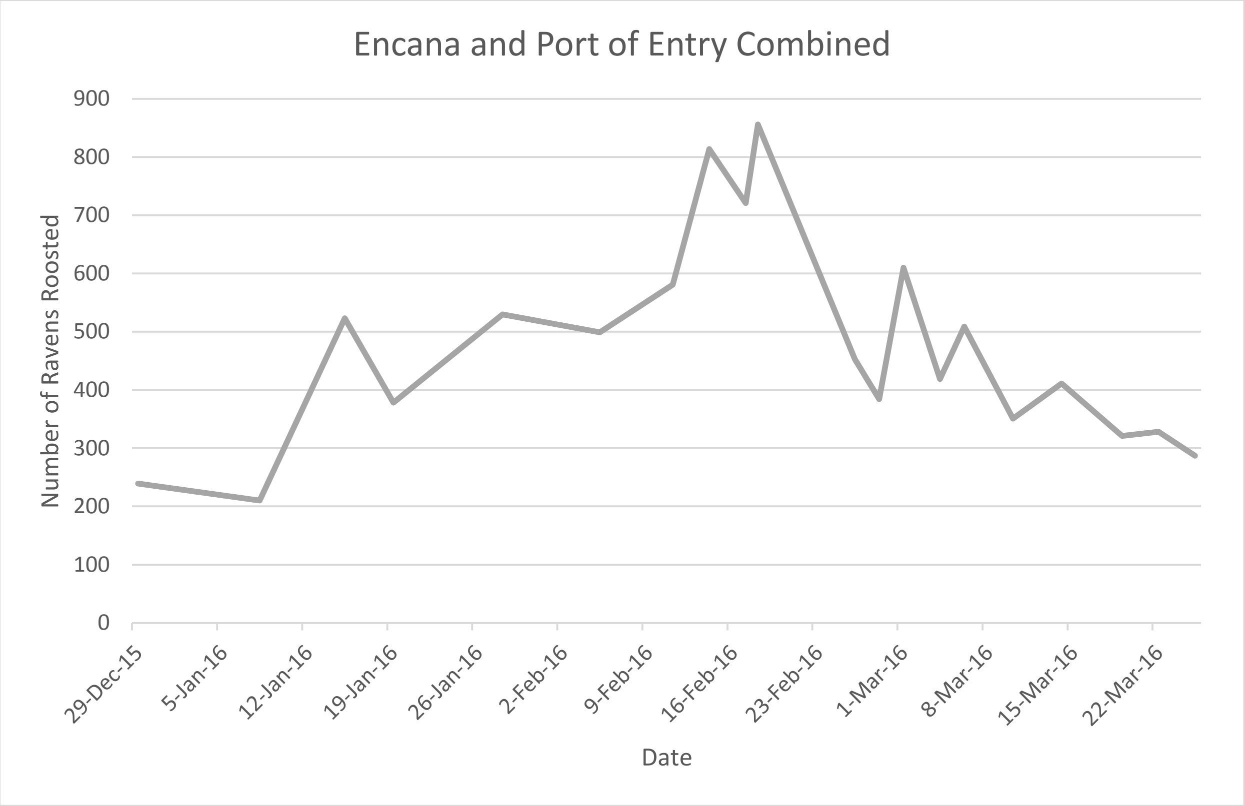

Figure 3: Raven attendance at the Shute Creek roost, 38 km northeast of Kemmerer, WY where we denied ravens food resources during the winter of 2015/2016.

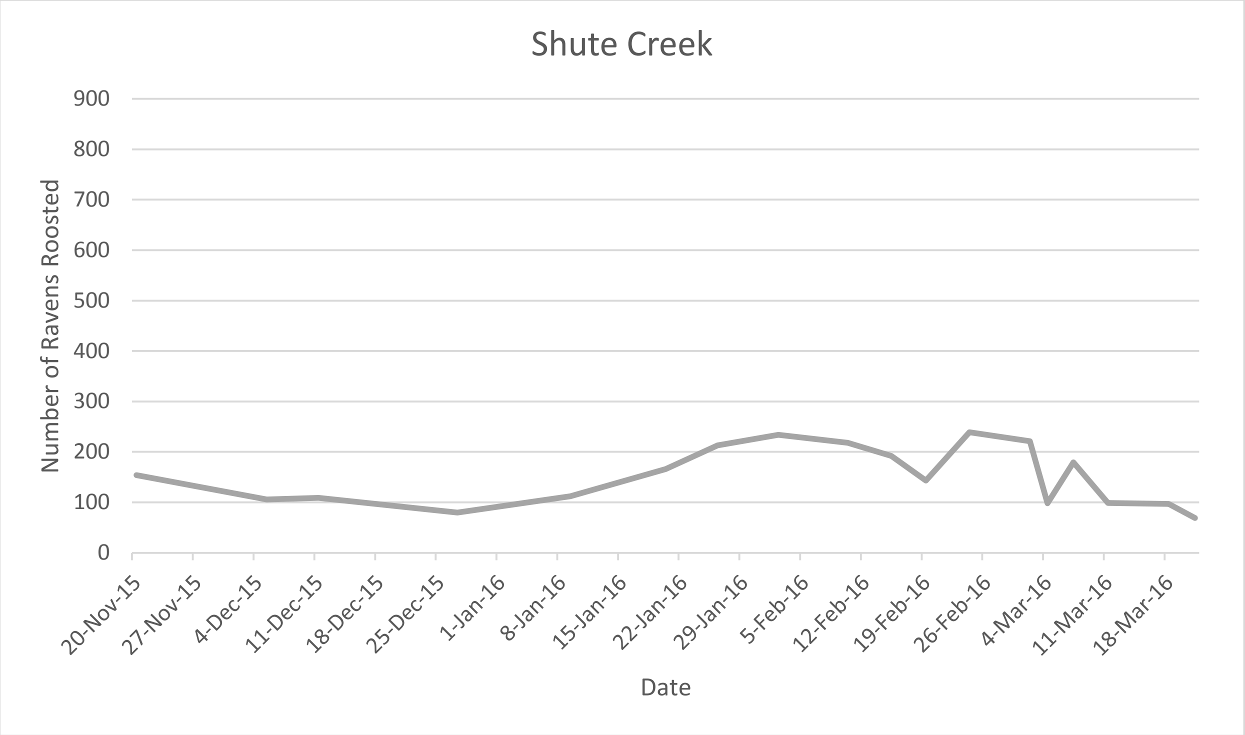

Figure 4: Raven attendance at the Solvay Soda Ash Mine roost 72 km east of Kemmerer, WY during the winter of 2015/2016. This roost served as a control (we did not remove food resources).

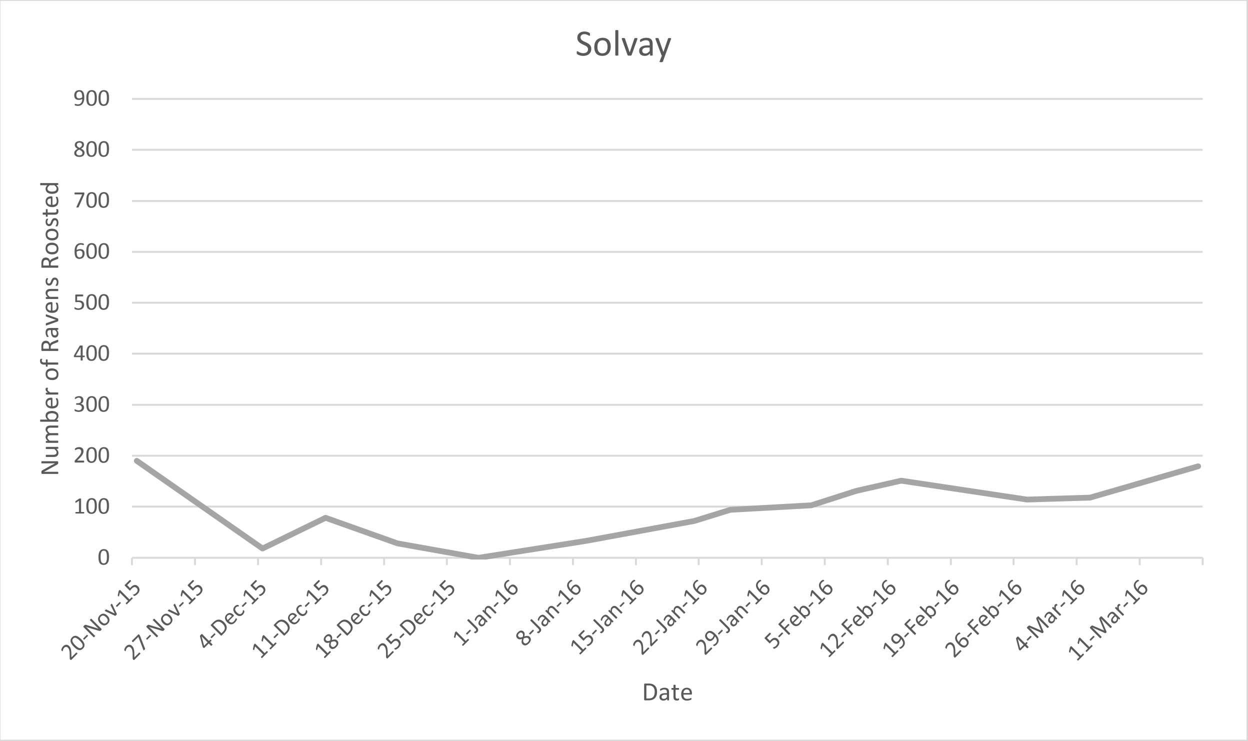

Table 1: Observed perpendicular distances of ravens from the roadway during point counts along the resource denial route. We began removing resources on 11 February 2016.