Golden Eagle Nesting Ecology in the Bighorn Basin:

Influence of Landscape Composition, Energy Development and other Human Activity on Golden Eagle Nesting Distribution, Success, Productivity, and Diet

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INTRODUCTION

Golden eagles (*Aquila chrysaetos*) are protected under the Bald and Golden Eagle Protection Act (16 U.S.C. 668-668d). The Act expressly prohibits "taking" of eagles, including injuring, killing, or disturbing eagles in a way that causes nest abandonment or reduced productivity. Even short-term loss of adults or reduced productivity is of particular concern because it takes several years for eagles to reach sexual maturity, they typically produce only one or two offspring per reproductive effort, and they do not necessarily reproduce every year after reaching sexual maturity (Kochert et al. 2002). Golden eagle populations are believed to be declining through at least a portion of the species' range in the contiguous United States (Harlow and Bloom 1989, Kochert and Steenhof 2002, Kochert et al. 2002, Preston and Leppart 2004, Good et al. 2007, Farmer et al. 2008) due to a variety of anthropogenic factors. Habitat degradation, collisions with human structures, such as wind turbines, electrocutions, and human disturbance near nest sites are among the chief factors that negatively impact eagle populations.

Sagebrush-dominated ecosystems support most golden eagle nesting efforts in Wyoming. Loss or alteration of native sagebrush habitat due to invasion of exotic cheatgrass and associated large-scale fires (Kochert et al. 1999), residential and urban expansion (Boecker 1974, Scott 1985), and extensive agricultural development (Beecham and Kochert 1975, Craig et al. 1986) have negatively impacted eagle populations in intermountain basins and other lowlands through much of the West. Energy development, with its associated roads, well pads, wind turbines, and human activity, is another significant cause of sagebrush ecosystem alteration and potential impact on

golden eagle populations, especially in Wyoming and adjacent states (Madders and Walker 2002, Smith et al. 2010, Rowland et al. 2011, Pagel et al. 2013).

Golden eagles are also highly vulnerable to electrocution and collisions with utility lines associated with exurban expansion and energy development (Franson et al. 1995, Lehman et al. 2007, Lehman et al. 2010). Between 2007 and 2009, more than 200 golden eagles and scores of other raptors were killed after being accidently electrocuted in rural areas of Wyoming (T. Eicher, pers. comm.). Many of these incidents occurred along utility powerlines in or near oil fields and gas wells, including those in the Bighorn Basin, near Cody, Wyoming. Since 1991 there have been more than 1,000 documented eagle electrocutions across Wyoming, including at least 480 in the Bighorn Basin (T. Eicher, pers. comm.).

Recreational activity near golden eagle nests is another factor that can cause nest failure or reduced productivity (Scott 1985, Watson 1997, Watson 2010, Kochert et al. 2002). Disturbance can include repeated off-road biking or all-terrain vehicle use, hiking, rock-climbing, target shooting, as well as intentional approach toward nests (Steenhof et al. 2014). Abandonment is most likely during the early stages of nesting, depending on the type and duration of disturbance, but disturbance at any stage of nesting can negatively affect productivity.

Habitat loss and alteration, energy development, and motorized and non-motorized recreation are increasing in sagebrush-steppe ecosystems in the Rocky Mountain West and Intermountain Basins, especially in the Greater Yellowstone region (e.g., Preston 2006, Steenhof et al. 2014). Energy development is accelerating especially rapidly in Wyoming and adjacent states in response to demand and economic

opportunity. Across Wyoming, the number of oil wells increased by 73%, and the number of gas wells increased by 318% between 2000 and 2006 (Oakleaf et al. 2010). The importance of gaining a better understanding of golden eagle ecology and conservation issues was underscored during the National Golden Eagle Colloquium recently convened for federal and state agencies and eagle scientists (Pagel et al. 2010). Discussions at this colloquium stressed the need for both broad, regional and statewide landscape surveys to determine current status and distribution of golden eagles and more intensive, local studies to examine nesting dynamics of golden eagles in response to a variety of factors, including landscape composition, human activity, and independent fluctuations of weather and prey availability. These data are critical to establish a baseline context for evaluating golden eagle status and trends in relation to human activities decades into the future.

In 2009, the Draper Natural History Museum initiated a multi-year study to determine golden eagle nest occurrence and distribution, annual nesting territory occupancy, success, and productivity in a multiple land-use study site in Wyoming's Bighorn Basin. Our overarching goals are to establish a strong foundation to evaluate future golden eagle status in the study area in relation to environmental change and provide information and insights to help guide golden eagle management decisions in multiple-use landscapes across western North America. The study is being conducted over multiple years to help identify and partition the confounding effects of annual fluctuations in weather and prey availability and gain an understanding of human land-use patterns and trends. We are also integrating our scientific research with a diverse suite of educational programs to engage and inform the public regarding conservation of

raptors and other wildlife. This report provides a general summary of our efforts and results between 2009 and 2014.

STUDY AREA

The Bighorn Basin lies within the northeastern margin of the Greater Yellowstone Ecosystem, in northwestern Wyoming. It is a multiple use landscape of approximately 750,000 ha that contains large, virtually intact tracts of native sagebrush-steppe interspersed with diverse human-dominated tracts (Fig. 1).

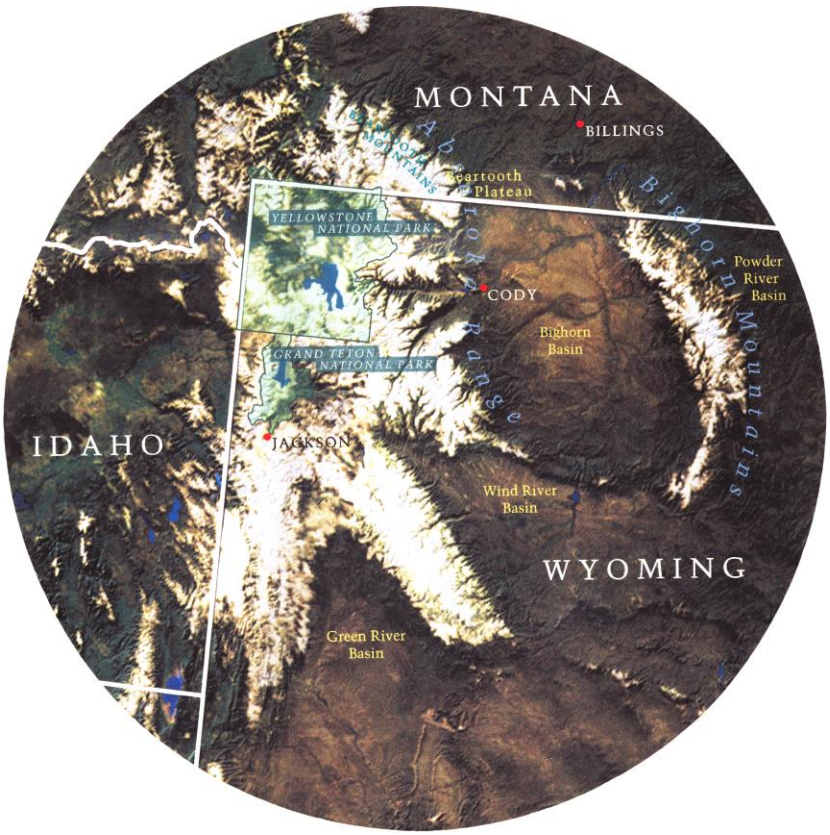

Figure 1. The Bighorn Basin in relation to adjacent geographic and political landscapes.

Except for a narrow gap to the northwest, the Basin is surrounded by high elevation ecosystems of the Beartooth and Pryor Mountains to the north, Bighorn Mountains to the east, Owl Creek Mountains to the south, and Absaroka Mountains to the west. Elevation varies from 1,100 – 1,800 m, and precipitation averages between 12 and

23 cm (USFS 2013). There are typically 90 – 120 frost-free days per year (Young et al. 1999). Flat and rolling terrain is broken sharply by sandstone outcroppings, cliffs, and ravines. Depending on local soil characteristics and topography, native vegetation is dominated by a complex of shrubs, e.g., big sagebrush (*Artemisia tridentata*), greasewood (*Sarcobatus vermiculatus*), saltbush (*Atriplex* spp.) and rabbitbrush (*Chrysothamnus* spp.), grasses, e.g., bluebunch wheatgrass (*Pseudoroegneria spicata*), prairie junegrass (*Koelaria macrantha*), and needle-and-thread (*Hesperostipa comata*), and forbs, e.g., scarlet globemallow (*Sphaeralcea coccinea*) and penstemon (*Penstemon* spp.), western yarrow (*Achillea millefolium*), and milkvetch (*Astragalus* spp.). Plains cottonwood (*Populus deltoides*) and willows (*Salix* spp.) occupy wetter drainages. Invasive species include cheatgrass (*Bromus tectorum*), knapweed (*Centaurea* spp.), tamarisk (*Tamarix* spp.), and Russian olive (*Elaeagnus angustifolia*).

The large, relatively unbroken swath of sagebrush-steppe habitat in the Bighorn Basin provides important seasonal or year-round sustenance for wildlife native to the Greater Yellowstone Ecosystem. Prominent mammals using the Basin either year-round or seasonally include pronghorn (*Antilocapra americana*), mule (*Odocoileus hemionus*) and white-tailed deer (*O. virginianus*), elk (*Cervus elaphus*), bighorn sheep (*Ovis canadensis*), free-ranging horse (*Equus ferrus*), white-tailed prairie dog (*Cynomys ludovicianus)*, white-tailed jackrabbit (*Lepus townsendii*), desert cottontail (*Sylvilagus audubonii*), black bear (*Ursus americanus*), badger (*Taxidea taxus*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), and bobcat (*Felis rufus*). Occasionally, grizzly bears (*Ursus arctos*) wander into the Basin, and cougars (*Puma concolor*) occur persistently in

the area. Gray wolves (*Canis lupus*) range around and within the area, especially near livestock operations.

Prominent birds (seasonal or year-round residents) inhabiting the Basin include, sage thrasher (*Oreoscoptes montanus*), Brewer's sparrow (*Spizella breweri*), vesper sparrow (*Pooecetes gramineus*), lark bunting (*Calamospiza melanocorys*), western meadowlark (*Sturnus neglecta*), common raven (*Corvus corax*), northern flicker (*Colaptes auratus*) long-billed curlew (*Numenius americanus*), mountain plover (*Charadrius montanus*), golden (*Aquila chrysaetos*) and American bald eagles (*Haliaeetus leucocephalus*), red-tailed (*Buteo jamaicensis*), rough-legged (*B. lagopus*), and Swainson's hawks (*B. swainsoni*), prairie falcon (*Falco mexicanus*), great-horned (*Bubo virginianus*), long-eared (*Asio otus*), short-eared (*Asio flammeus*), and burrowing owls (*Athene cunicularia*). Ferruginous hawks (*Buteo regalis*) are uncommon breeders in the Bighorn Basin, and also scarce during winter and migration periods. The Bighorn Basin is among the world's remaining strongholds for greater sage-grouse (*Centrocercus urophasianus*) populations (Harrell 2008).

Land ownership in the Bighorn Basin is divided among private and public hands, with the majority of public land administered by the Bureau of Land Management. Land use includes urban and exurban residential development, significant oil and gas development, livestock grazing, and extensive motorized and non-motorized recreation. The Basin is one of the largest agricultural production areas of Wyoming (Young et al. 1999). The area is traversed by a maze of paved and unpaved transportation corridors. It is also an increasingly popular area for hunting and other outdoor recreation. The Bighorn Basin is experiencing a period of rapid environmental change in response to weather

fluctuations, increased recreational use, exurban residential sprawl, and significantly increased energy development, including the potential for wind energy development.

Our study area encompasses approximately 250,000 ha in the northwestern corner of the Bighorn Basin, near Cody, Wyoming. The area is bordered approximately by Powell and Lovell, Wyoming to the north, Meeteetse, Wyoming to the south, the western extent of the Buffalo Bill Reservoir to the west, and Greybull, Wyoming to the east. Vegetation, geomorphology, and human land use in our study area are representative of the Bighorn Basin as a whole.

METHODS

We have conducted helicopter and fixed-wing aerial surveys (Fig. 2) in mid-March to early April each year since 2009 to search for golden eagle nest territories and document whether any nest site within a territory was occupied (e.g., McIntyre 2002, McIntyre et al. 2006, Lehman et al. 1998). In 2014, we intensified our efforts in sections of the study we felt were underrepresented in previous surveys. The aerial surveys were repeated as necessary, and/or followed with ground observations to confirm nest status. A nest territory is defined as one or more alternate nests determined as being used or having been used by a single pair of eagles in a given year (Steenhof and Newton 2007). A nest territory was determined to be occupied if two adult eagles were observed within the area during

Figure 2. View of nest site during aerial survey.

nesting season, if there was evidence that one or more nests had been recently refurbished or used (i.e., fresh greenery or egg present), or if we confirmed the presence of egg(s), and/or nestling(s). We may have discounted some nests where eggs were laid and subsequently abandoned without any of the above in evidence. Because of our familiarity with nests and our practice of conducting repeated surveys and extended ground observations, we believe that we have discounted very few such nests. We conducted aerial surveys again in late June – early July to determine how many nests produced at least one chick reaching at least 51 days of age, or 80% of the average age at first flight (Steenhof 1987) and to record the number of chicks reaching at least 51 days of age. In 2014, volunteers contributed 299 hours of service and more than 1550 miles to monitoring nests and eagle behavior for the project. Volunteers have contributed an average of 342 hours and more than 2,000 travel miles per year to the project since 2009.

We initiated roadside surveys in 2010, and have continued these through 2014 to develop a relative index of abundance of leporids (i.e., white-tailed jackrabbits *Lepus townsendii*, cottontails *Sylvilagus* spp.). We established five, 5-mile (8.0 km) secondary roadside transects throughout the study area. Each transect was surveyed during one full moon night in each of three stages of the eagle breeding season, i.e., incubation, nestling, and fledgling stages. The surveys began between 2100 and 2200 hours Mountain Daylight Time during nights without precipitation and low to moderate wind conditions. Each transect was surveyed by two trained observers in a vehicle with headlights and a spotlight. Observers recorded each rabbit and hare observed within approximately 50 m of the road, and each survey lasted between 30 and 45 min. To assess nesting food

habits, we collected prey remains and pellets from a sample of nests (determined by accessibility) after chicks fledged or nests were abandoned.

In partnership with Dr. John Campbell and his students at Northwest College, Powell, Wyoming, we quantified selected landscape characteristics within a 1.5 km circle surrounding each of 36 nest territories using satellite imagery and Geographic Information Systems technology. The 36 nest territories were chosen because they have been monitored each year since 2009, providing adequate sample size needed for statistical analysis. Each circle is centered upon the occupied nest site within a given territory; if more than one alternate nest was occupied during the 2009 – 2014 breeding seasons, the circle was centered on a site equidistant among the occupied nest sites. In 2014, we conducted multivariate discriminant analyses to attempt to distinguish high productivity nest territories from low productivity nest territories with respect to the landscape characteristics.

We began capture/banding operations in 2010 to identify individual eagles and gain information on mortality and movements. We chose to mark birds with orange, anodized aluminum leg bands, each imprinted with a unique, white alphanumeric code (Fig. 3). In 2014, we collaborated with U. S. Fish

Figure 3. Orange anodized band placed on newly-fledged golden eagle. Note unique alpha-numeric code that can be read from a distance with binoculars and/or spotting scope.

and Wildlife Service to tag nestling and recent fledgling eagles with satellite transmitters.

RESULTS 2009-2014

General comments — Northwestern Wyoming received an unusual amount of moisture in 2014, with a long-lasting snowpack and frequent spring and summer rains. Temperatures were unusually cool through most of Spring and Summer, providing for exceptional vegetation height and density (Fig. 4).

Figure 4. Extraordinarily lush July vegetation in response to high moisture in the Bighorn Basin during Spring-Summer 2014.

We are currently compiling weather data from the National Oceanographic and Atmospheric Administration and National Weather Service for all years of the study, and will analyze the effects of weather on both eagle and leporid data in our final report and manuscripts prepared for peer-reviewed publications.

Golden eagle nest territory occupation, success, and productivity — We have now identified 70 distinct golden eagle nest territories that have been occupied at least one year between 2009 and 2014 inclusive. The number of nest territories surveyed has varied through the years of the study due to new discoveries and changing budgets and access. In some cases, we've adjusted numbers from previous reports with further review and

data cross-checks. Nest territories are distributed unevenly through the study area, conforming to the distribution of prominent sandstone outcrops and other topographic relief. Occupied nest success and productivity were highest in 2009, followed by declines during the next three years, and a moderate rebounds in 2013 and 2014 (Table 1).

Year	**Number of Nest Territories Monitored**	**Number of Nest Territories Occupied**	**Number of Occupied Nest Territories Producing at Least One Fledgling**	**Productivity**
2009	36	33 (92%)	24 (73%)	1.11
2010	55	43 (78%)	22 (51%)	0.79
2011	59	44 (75%)	14 (32%)	0.39
2012	61	48 (79%)	15 (31%)	0.31
2013	61	42 (69%)	15(36%)	0.41
2014	70	54 (77%)	23 (43%)	0.54

Table 1. Results of nest territory surveys 2009-2014.

Food Habits — We collected more than 200 prey items from 11 golden eagle nests at the conclusion of the 2014 field season. This brings the total of prey items collected and analyzed since 2009 to more than 700 (Fig. 5).

Figure 5. A sample of prey remains from one golden eagle nest in 2014.

As in all previous years, cottontails were by far the most frequently occurring prey species collected from eagle nests in 2014 (Table 2).

Year	Cottontail	Jackrabbit	Pronghorn	Prairie Dog	Other Mammals	Greater Sage-grouse	Great Horned Owl	Other Birds	Other
2009 (n=1)	40 (91%)	0	0	0	1 (2%)	0	1 (2%)	1 (2%)	1 (2%)
2010 (n=3)	68 (77%)	2 (2%)	3 (3%)	1 (1%)	4 (5%)	1 (1%)	1 (1%)	7 (8%)	1 (1%)
2011 (n=4)	87 (76%)	2 (2%)	8 (7%)	0	5 (4%)	0	2 (2%)	10 (9%)	0
2012 (n=5)	71 (60%)	18 (15%)	13 (11%)	0	3 (3%)	6 (5%)	1 (1%)	6 (5%)	0
2013 (n=7)	91 (61%)	15 (10%)	5 (3%)	1 (1%)	15 (10%)	1 (1%)	1 (1%)	18 (12%)	2 (1%)
2014 (n=11)	145 (71%)	15 (7%)	8 (4%)	4 (2%)	4 (2%)	7 (3%)	7 (3%)	15 (7%)	0

Table 2. Summary of annual collection of nest prey remains (n = number of nests where prey remains were collected.

Other frequently-occurring prey included pronghorn fawns, white-tailed jackrabbits, and a wide variety of birds, such as common raven, northern flicker, and western meadowlark. Final identification, enumeration, and analysis of 2009 - 2014 prey remains is ongoing, and will be presented in final report and in manuscripts prepared for peer-reviewed publication.

Leporid surveys — We completed all rabbit and hare surveys as scheduled in 2014. Across all routes and seasons, we recorded a total of 53 cottontails and 8 jackrabbits. In contrast to our anecdotal observations and expectations given increases in eagle occupied nest success and productivity, both cottontail and jackrabbit indices were lower in 2014 than in 2013. Unlike past years, March was the most productive survey month across all routes. We recorded the fewest leporids in June. It is noteworthy that a much greater proportion of leporid observations occurred on or near the roadways in 2014 compared with previous years of the study.

Relationship between productivity and landscape characteristics — We completed preliminary digitization and calculation of landscape variables (Table 2)

1.	**Distance to nearest building**
2.	**Distance to nearest 4-lane highway**
3.	**Distance to nearest 2-lane paved highway**
4.	**Distance to nearest gravel road**
5.	**Distance to nearest graded dirt road**
6.	**Distance to nearest 2-track road**
7.	**Distance to nearest ATV trail**
8.	**Total length of roadways**
9.	**% Tree cover**
10.	**% Shrub cover**
11.	**% Grass cover**
12.	**% Bare/rocky ground**
13.	**Nearest oil/gas pad**

Table 2. List of landscape variables used in preliminary discriminant analysis.

associated with the 36 nest areas we have monitored continuously since 2009. For the exploratory analysis, we categorized each of the nest territories (Fig. 6) as high productivity (>5 young produced since 2009; n = 7), medium productivity (2 – 4 young produced since 2009; n = 22), or low productivity (<2 young produced since 2009, n = 7). All percentage data were transformed to improve normality using arcsin-square root transformation. Multivariate discriminant analysis (Morrison 2004) was used to determine which variables or suite of variables best discriminate among high, medium,

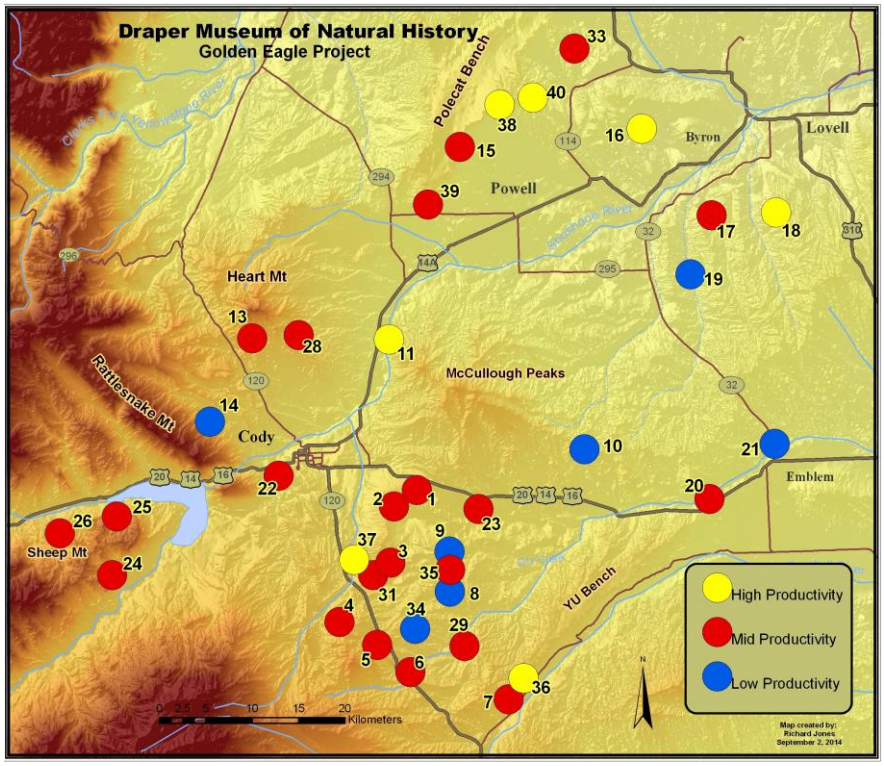

Figure 6. Distribution of high, mid, and low productivity nest territories.

and low productivity territories. In summary, the first two discriminant functions together were capable of discriminating high from low productivity sites in 100% of the cases, but could not consistently discriminate between high and medium or low and medium territories. Highly productive sites were characterized by more distant and less dense roadways and a mixture of shrubby and open ground. Low productivity sites were

characterized as having numerous roadways, especially 2-track and all-terrain-vehicle trails, near nest sites and dominated by relatively homogeneous shrub cover. We are currently expanding and refining this analysis and preparing manuscripts including the results of this and other analyses for submission to peer-reviewed journals.

Banding operations — We captured 11 recently fledged eagles from nine successful nests and fitted each with a USGS silver leg band and a uniquely coded, orange leg band. Additionally, we collaborated with U. S. Fish and Wildlife Service contractors to capture four nestling and recently fledged eagles that were fitted with USGS silver leg bands and platform transmitter terminal (PTT)/GPS satellite transmitters (Fig. 7).

Figure 7. Attaching satellite transmitter to nestling golden eagle.

As of early January 2015, all four birds were alive and transmitting well. Three of these birds have stayed in the general vicinity of our study area within 80 km of Cody. The fourth bird has travelled well outside the study area, moving more than 130 km south of Cody.

Scientific outreach — Our team published two abstracts and presented papers at two international science conferences (North American Congress for Conservation Biology, in Missoula, MT and Raptor Research Foundation, in Corpus Christi, TX, in

2014). The papers summarized some of our 2009-2013 activities and analyses. Additionally, we were asked to participate in two workshops organized by the U. S. Fish and Wildlife Service to present our preliminary findings related to golden eagles in the Bighorn Basin and discuss the challenges and opportunities of studying and conserving golden eagle populations in light of increased wind energy and other development in western North America. These discussions led to the collaborative effort to place PTT transmitters on 4 birds from our study area.

Public educational outreach — We conducted three field trips and delivered seven public lectures, including a total of more than 250 participants, to help participants learn about our study and the dynamics of golden eagle and sagebrush-steppe ecology. In addition, we taught a 2-day, youth Discovery Camp workshop for 8 middle-school students who learned to observe nesting eagles safely from a distance, identify eagle prey remains, and conduct roadside rabbit/hare surveys (Fig. 8). The students also learned basics of raptor trapping and banding, and how eagles and raptors interact with other animals and elements of the sagebrush-steppe environment. I also submitted an article updating progress on our project for Points West magazine, currently in press, and the project has received recent media coverage from Billings Gazette.

Figure 8. Students in Eyes on Eagles Discovery Class observe eagles near nest in Bighorn Basin study area while instructors keep eyes on other students.

DISCUSSION

The lands within and adjacent to Bureau of Land Management holdings in the northwestern portion of Wyoming's Bighorn Basin support a significant population of nesting golden eagles. All of the nest sites we've discovered in our study area are cliff sites, although we are aware of at least two tree nests in an agricultural region our study area that were occupied as late as 2007. Large trees are very rare in our arid study area. Most large trees are plains cottonwoods located in a few narrow drainages. These drainages support several red-tailed hawk nests. As we have become more familiar with the study area, we have discovered additional golden eagle nest areas each year, even after adjusting for redundancies. This argues for the importance of long-term studies and caution in drawing inferences from short-term data. Some golden eagle nest areas are difficult to locate in remote, varied terrain.

While nesting success and productivity were similar in 2009 and 2010, we detected a marked decline in these parameters in 2011 and 2012, before detecting a rebound in 2013. The rebound continued in 2014. The nesting declines in 2011 and 2012, and the rebound detected in 2013 coincided with the decline and rebound in numbers of leporids detected in our surveys initiated in 2010. However, in 2014, eagle reproductive parameters increased while the numbers of leporids we detected in our surveys decreased. Anecdotally, however, we noted increased leporid encounters while on foot in the study area and increased rabbits and hares observed dead on the road in 2014 compared with 2013. Our surveys may not have detected an increase due to the extraordinary height and density of vegetation from June through July. To gain additional information regarding annual leporid, particularly cottontail, fluctuations, we will turn to hunter bag surveys compiled by the Wyoming Game and Fish Department, and include these data in future reports and publications.

Again, this underscores the importance of long-term, geographically-focused studies to help understand golden eagle ecology and population dynamics and to create an appropriate baseline range for golden eagle breeding populations in a given area. Leporids, especially cottontails, have been by far the most important eagle prey items identified from nest remains. Though clear interpretations or cause-and-effect relationships are premature with the data currently in hand, these results are suggestive that leporid availability typically drives golden eagle reproduction in a given year, and may thus exert a profound influence on golden eagle population dynamics in the Bighorn Basin. If this is true, energy development and other human activities in the Basin that

influence leporid abundance and availability could exert an important indirect influence on the golden eagle population, even when they don't impact eagle nesting sites directly.

Our preliminary analysis of the relationship between golden eagle productivity and landscape characteristics suggests that golden eagles are most productive in areas with little off-highway traffic that also include a mosaic of shrubby and bare ground. Our results are thus consistent with the findings presented by Steenhof et al. (2014) indicating a negative effect of off-road-vehicle activity to golden eagle productivity. Productivity in these our high-productivity areas may be higher due to less anthropogenic nest and habitat disturbance and greater availability of primary prey. In 2010, we observed several instances of target-shooting immediately under an occupied golden eagle nest near a well-used two-track road. The nesting eagles fledged young after target-shooting occurred under the active nest. However, this nest area, known to be active and productive during the previous two years, has not been occupied since we first documented target-shooting. Two other nest areas, productive in prior years, were abandoned during years with off-road vehicle use near active nests and have not been occupied since we first observed off-road vehicle traffic at these sites. We will continue to document recreational and other human activity near nests to eventually provide a quantitative analysis of the relationship between nest area occupation/activity/success/productivity and increased human foot traffic, off-road vehicle use, and other activity.

Cottontails tend to thrive in areas with a mixture of shrub cover, grasses, and bare ground/rocky outcrops (e.g., Chapman and Wilner 1978, Brown and Krausman 2003, Bock et al. 2008), and they are presumably more vulnerable to eagles as they move

through the more open areas of a mosaic landscape. In our preliminary analyses, nest territories intermediate in productivity could not be distinguished as a group from either high or low productivity territories. This may point to individual variability in ability to produce young, whereby some eagle pairs are able to produce marginally better than others even in poor quality territories while other eagle pairs cannot produce at the highest levels even in high quality territories. We will continue to refine our understanding of the relationships between landscape characteristics and eagle productivity with additional observations and analyses.

There is no indication that another prey species can replace the critical importance of cottontails and jackrabbits in golden eagle diet in our study area. Prairie dogs and other ground squirrels are important primary or secondary prey in the diet of golden eagles in other regions (Kochert et al. 2002), but are relatively uncommon in the Bighorn Basin (pers. observation). Harrell and Marks (2009) reported a 71% decline in area occupied by prairie dogs between the mid-1980s and the early 2000s in the northern Bighorn Basin. Direct persecution (shooting and poisoning) and especially sylvatic plague (*Yersinia pestes*) are generally considered the primary causes of prairie dog decline. The decline may be reversed in the future if plague vaccines can be delivered to prairie dogs on a large scale in the Bighorn Basin.

Greater sage-grouse are rabbit-sized and fairly common in the study area, but have been detected only rarely in our prey remains. This may be due to the grouse effectively using the relatively dense sagebrush cover in our study area during summer (e.g., Dinkins et al. 2012, Greene 2013) or may indicate that grouse remains are somehow underrepresented in nest prey remains. Presumably, adult sage-grouse are most

vulnerable to aerial attack during lekking bouts in relatively open sites. Golden eagles are often cited as predators on sage-grouse (Wiley 1973, Hartzler 1974, Bradbury et al. 1989, Gibson and Bachman 1992), and have even been cited as the principal diurnal predator of adult sage-grouse (Boyko et al. 2004). But observations of successful eagle predation are scarce, and sage-grouse remains are not typically reported as a significant component of golden eagle nesting diet by researchers studying golden eagle food habits (Kochert et al. 2002). The sage-grouse lekking period in our study area ends just after eagle nestlings appear, and therefore sage-grouse killed by eagles before very late sage-grouse courtship may not be brought back to the eagle nest for nestling consumption. The extent to which golden eagles successfully prey on greater sage-grouse merits further, directed study. Our study thus far provides no support for the tacit assumption that eagles are significant sage-grouse predators during the nesting season.

Little is known about leporid or other potential eagle prey cycles in the Bighorn Basin, but Fedy and Doherty (2011) reported what appears to be roughly an 8-year boom-and-bust population cycle for both cottontails and greater sage-grouse in Wyoming. Anecdotal reports from wildlife officials, local landowners, and residents suggest that white-tailed jackrabbits also exhibit regular fluctuations, but on the order of a 10-12-year cycle. We hypothesize that eagle nest success, and productivity will increase with increases in leporid numbers, barring any exceptional weather pattern or environmental disturbance. Additionally, we hypothesize that eagle diet breadth will shrink as leporids become more available. We will test these hypotheses with additional data collected in the following years.

STATUS OF PROJECT AND FUTURE WORK

We were able to meet all of our objectives in 2014 and presented papers at major scientific conferences and workshops. We intend to submit our first series of manuscripts on eagle diet and relationships among eagle productivity, weather, and leporid abundance (e.g., Steenhof et al. 1997) for peer review during the next several months. We attracted additional support and collaborators for this project in 2014 that will allow us to complete all of our baseline project objectives through 2017. During the next three years, we will focus our monitoring efforts on the 70 nest territories that we have documented as being occupied at least one year since 2009. We also intend to focus more attention on leporid abundance, distribution, and habitat use within the study area, and document prey deliveries to selected nests with remote cameras. We will continue to collaborate with USFWS to follow the movements of eagles from our study area tagged with satellite transmitters. Additionally, we hope to begin deploying a network of remote camera traps at carcasses during winter 2014-2015 to attempt to identify the origin of overwintering birds that have been banded or otherwise marked in our study area and in other breeding grounds. We will also trap and mark overwintering birds to help document the breeding origin of birds using our study area during winter months. These data are important to creating a broader understanding of how changes in our study area might affect birds breeding elsewhere, as well as how these changes might affect our breeding and resident birds. In 2015, we will seek funding to partner with the University of Wyoming Berry Center for Conservation Biodiversity to analyze DNA from shed eagle feathers (e.g., Rudnick et al. 2005) to better understand demographics of our study population. We're also working with the UW Haub School for Environment and Natural Resources, private

land owners, Rocky Mountain Power, BLM, and other partners to use this project as a platform for an overarching program revolving around human dimensions in wildlife conservation and management in the Greater Yellowstone Ecosystem. Our partnership with Yellowstone National Park and Craighead Beringia South to communicate and collaborate on a broad picture of golden eagle nesting ecology across a major portion of the Greater Yellowstone Ecosystem between the Bighorn Basin and Livingston, Montana will also continue.

Our public education programming has become very popular with local and even national audiences, and we will continue to seek funding opportunities to expand our audiences via our website and through K-12 ecological science curricula related to the eagle project. In 2015, we will begin to explore the possibility of creating a travelling exhibition and/or broadcast documentary focusing on our study and more broadly the cultural and ecological significance of the golden eagle in the American West and the challenges they are facing in the 21st century.

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