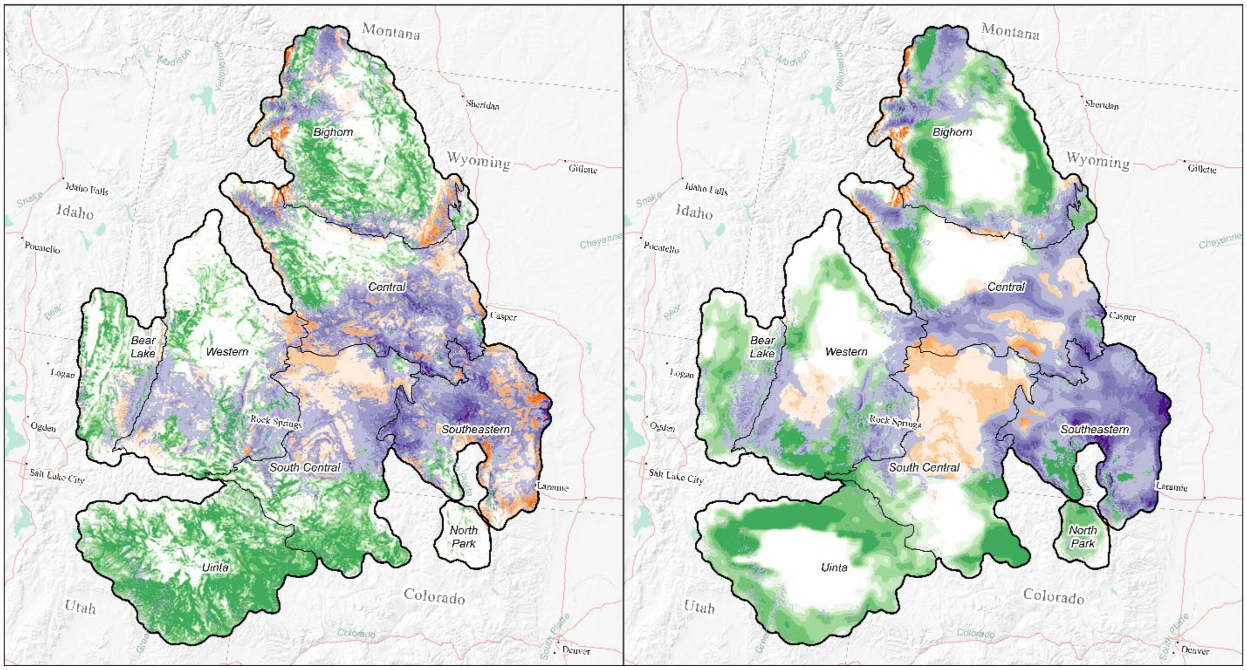
Wyoming and Uinta Basins Golden Eagle Conservation Strategy



Prepared for U.S. Fish and Wildlife Service Western Golden Eagle Team by the Wyoming Natural Diversity Database and Eagle Environmental, Inc.

Wyoming and Uinta Basins Golden Eagle Conservation Strategy

Version

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Disclaimer

The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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Acronyms and Abbreviations Used in This Report

AGL	Above Ground Level
APLIC	Avian Power Line Interaction Committee
AR	Anti-coagulant Rodenticide
BBS	North American Breeding Bird Survey
BCC	U.S. Fish and Wildlife Service Bird of Conservation Concern
BCR	Bird Conservation Region
BGEPA	Bald and Golden Eagle Protection Act
BLM	Bureau of Land Management
BMP	Best Management Practice
CGB	Central Great Basin Conservation Strategy Area
CI	Confidence Interval or Credible Interval
CV	Coefficient of Variation
CSA	Conservation Strategy Area
DOE	Department of Energy
ECPG	Eagle Conservation Plan Guidance
FO	Bureau of Land Management Field Office
GAP	National Gap Analysis Program
MBTA	Migratory Bird Treaty Act
MW	Megawatt
NBRA	Northern Basin and Range Conservation Strategy Area
NEPA	National Environmental Policy Act
NGO	Non-governmental Organization
NGP	Northern Great Plains Conservation Strategy Area
NPS	National Park Service
NSO	No Surface Occupancy
NWR	National Wildlife Refuge
OHV	Off-highway vehicle
PAC	Greater Sage-grouse Priority Areas for Conservation
PIF	Partners in Flight
RND	Relative Nesting Territory Density
SD	Standard Deviation
SE	Standard Error
SGCN	Species of Greatest Conservation Need
SOS	Strength of Selection
TNC	The Nature Conservancy
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
WEG	Wind Energy Guidelines
WGES	Western Golden Eagle Survey
WGET	U.S. Fish and Wildlife Service Western Golden Eagle Team
WGFD	Wyoming Game and Fish Department
WNv	West Nile Virus
WPC	Wind Power Class
WYDOT	Wyoming Department of Transportation
WYUB	Wyoming and Uinta Basins Conservation Strategy Area
WYNDD	Wyoming Natural Diversity Database

Scientific Names Used in This Report

Plants

Aspen (*Populus tremuloides*)
Cheatgrass (*Bromus tectorum*)
Cottonwood (*Populus* sp.)
Douglas fir (*Pseudotsuga menziesii*)
Engelmann spruce (*Picea engelmannii*)
Gamble oak (*Quercus gambelii*)
Greasewood (*Sarcobatus vermiculatus*)
Halogeton (*Halogeton* sp.)
Indian ricegrass (*Achnatherum hymenoides*)
Juniper (*Juniperus* sp.)
Limber pine (*Pinus flexilis*)
Lodgepole pine (*Pinus contorta*)
Mountain mahogany (*Cercocarpus* sp.)
Needle-and-thread grass (*Hesperostipa* sp.)
Plains cottonwood (*Populus deltoides*)
Ponderosa pine (*Pinus ponderosa*)
Rabbitbrush (*Chrysothamnus* sp.)
Russian thistle (*Salsola* sp.)
Saltbush (*Atriplex* sp.)
Subalpine fir (*Abies lasiocarpa*)
Western wheatgrass (*Pascopyrum smithii*)
Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*)

Birds

American white pelican (*Pelecanus erythrorhynchos*)
Bald eagle (*Haliaeetus leucocephalus*)
California condor (*Gymnogyps californianus*)
Chukar partridge (*Alectoris chukar*)
Dusky grouse (*Dendragapus obscurus*)
Eurasian collared dove (*Streptopelia decaocto*)
Ferruginous hawk (*Buteo regalis*)
Golden eagle (*Aquila chrysaetos*)
Greater sage-grouse (*Centrocercus urophasianus*)
Mourning dove (*Zenaida macroura*)
Rock pigeon (*Columba livia*)
Ring-necked pheasant (*Phasianus colchicus*)
Ruffed grouse (*Bonasa umbellus*)
Sharp-tailed grouse (*Tympanuchus phasianellus*)

Mammals

Badger (*Taxidea taxus*)
Beaver (*Castor canadensis*)
Black-tailed jackrabbit (Lepus
Black-tailed prairie dog (*Cynomys ludovicianus*)
Coyote (*Canis latrans*)
Desert cottontail (*Sylvilagus audubonii*)
Eastern cottontail (*Sylvilagus floridanus*)
Elk (*Cervus canadensis*)
Fox (*Vulpes* sp.)
Ground squirrel (*Urocitellus* spp.)
Long-tailed weasel (*Mustela frenata*)
Mule deer (*Odocoileus hemionus*)
Mountain Cottontail (*Sylvilagus nuttallii*)
Pocket gopher (*Thomomys* sp.)
Raccoon (*Procyon lotor*)
Pronghorn (*Antilocapra americana*)
Sagebrush vole (*Lagurus curtatus*)
Striped skunk (*Mephitis mephitis*)
Thirteen-lined ground squirrel (*Ictidomys tridecemlineatus*)
Uinta ground squirrel (*Urocitellus armatus*)
White-tailed deer (*Odocoileus virginianus*)
White-tailed jackrabbit (*Lepus townsendii*)
White-tailed prairie dog (*Cynomys leucurus*)
Woodrat (*Neotoma* sp.)
Wyoming ground squirrel (*Urocitellus elegans*)
Yellow-bellied marmot (*Marmota flaviventris*)

Other

Avian cholera (*Pasteurella multocida*)
Avian pox (*Avipoxvirus* sp.)
Plague causing bacteria (*Yersinia pestis*)
Blackfly (*Simulian* sp.)
Leucocytozoonosis causing hemosporidian blood parasite (*Leucocytozoon toddy*)
Mexican chicken bug (*Haematosiphon inodorus*)
Mosquito (*Culex tarsalis*)
Protozoan parasite causing Trichomonosis (*Trichomonas gallinae*)
Tuberculosis (*Mycobacterium avium*)
West Nile virus (*Flavivirus* sp.)

"The eagle ranges far and wide over the land, farther than any other creature, and all things there are related simply by having existence in the perfect vision of a bird."

– N. Scott Momaday, *House Made of Dawn*

Ecoregional Conservation Strategies for Golden Eagles

Diversification of U.S. energy supplies will require increasing reliance on landscape-scale assessments of development risk to vulnerable wildlife species. Vulnerability of Golden Eagles to collision with wind turbine blades, combined with legal protection under the Bald and Golden Eagle Protection Act, has stimulated considerable research into mortality risk and mitigation strategies for this species. Comprehensive conservation planning for this species, however, is lacking. In 2013, the U.S. Fish and Wildlife Service established the Western Golden Eagle Team (WGET) to develop landscape-scale conservation strategies to support management of Golden Eagles in the western U.S.

To account for geographic variation in golden eagle distribution, habitat associations, prey communities, and population limiting factors, WGET developed conservation strategies at the scale of Level III Ecoregions (Wiken et al. 2011). This enables the strategies to serve as landscape-specific assessments that can be scaled up to Bird Conservation Regions (Level II Ecoregions) and Flyways.

Each Ecoregional Conservation Strategy consists of two parts: a technical assessment of current information pertaining to Golden Eagles, and a regional conservation strategy for the species.

The Conservation Assessment provides information resources, data, and predictive models to support eagle management, including:

- Review and synthesis of published information, local research results, and current research on golden eagle populations, habitat associations, diet, prey communities, and population limiting factors;
- Results of ecoregion-specific predictive modeling of habitats used for breeding, wintering, and movement; and
- Results of ecoregion-specific analyses and modeling of threats such as electrocution, collisions with vehicles, and exposure to contaminants.

The Conservation Strategy is based on information and modeling results compiled in the assessment, and provides tools and management approaches for direct application in eagle conservation, including:

- Spatial prioritization modeling to identify areas of high resource value and higher risk;
- Ecoregion-specific risk assessments and decision support tools for energy development, mitigation, and eagle conservation planning; and

- Information to support integration with State, Flyway, Tribal, and other regional conservation planning efforts for golden eagles, as well as plans for other species of concern, such as greater sage-grouse.

Development and implementation of conservation strategies required collaboration of numerous stakeholders, including State and Federal agencies, research institutions, industry, Tribes, and NGOs. As work on each ecoregional strategy was initiated, WGET and partners strove to identify and coordinate with regional entities involved in eagle research and management. Our conservation strategies are intended to be complementary to State and Flyway management plans for golden eagles by providing new conservation planning tools and best-available information.

I. Conservation Assessment

The Conservation Assessment is a technical review of current information pertaining to golden eagles within the Wyoming and Uinta Basins region. The assessment provides information resources, data, and predictive models to support eagle management and identify key gaps in knowledge. These include review and synthesis of published information, local research results, and current research on golden eagle populations, including seasonal information on density, space-use, habitat associations, fecundity, diet, and prey communities, and population ecology, including regional status and limiting factors.

1. Introduction to Conservation Strategy Area

The area addressed by this assessment (Figure 1.1) includes the Wyoming Basin Ecoregion, as defined by the Commission for Environmental Cooperation (Wiken et al. 2011), with the addition of the Uinta Basin and Tavaputs Plateau area of northeastern Utah and northwestern Colorado, and the North Park basin of north-central Colorado. The latter two areas were added to the Conservation Strategy because golden eagle breeding habitat in these areas is more ecologically similar to the Wyoming Basin than their respective ecoregions. The combined Conservation Strategy Area (CSA) includes these three regions, with a 6.4-km (4-mi) spatial buffer used in models developed by WGET. Throughout this document, we refer to the component regions separately as the Wyoming Basin, Uinta Basin, and North Park, and to the combined CSA as the Wyoming and Uinta Basins (WYUB).

The WYUB is an 18.4 million-ha (184,505-km^2) area of the intermountain western U.S. The majority of the WYUB is in the state of Wyoming (72%, 133,613 km^2), with smaller areas extending south into Utah (14%, 26,337 km^2) and Colorado (11%, 20,443 km^2), north into Montana (1%, 2,129 km^2), and west into Idaho (1%, 1,982 km^2). The region is characterized by broad basins of sagebrush steppe and desert shrub vegetation, surrounded by forested mountains, and interrupted by smaller, isolated mountain ranges, ridge systems, and river valleys. High elevation, harsh climate, extensive public lands, and very low density of human settlement has left the WYUB with largely intact natural landscapes that support abundant wildlife populations.

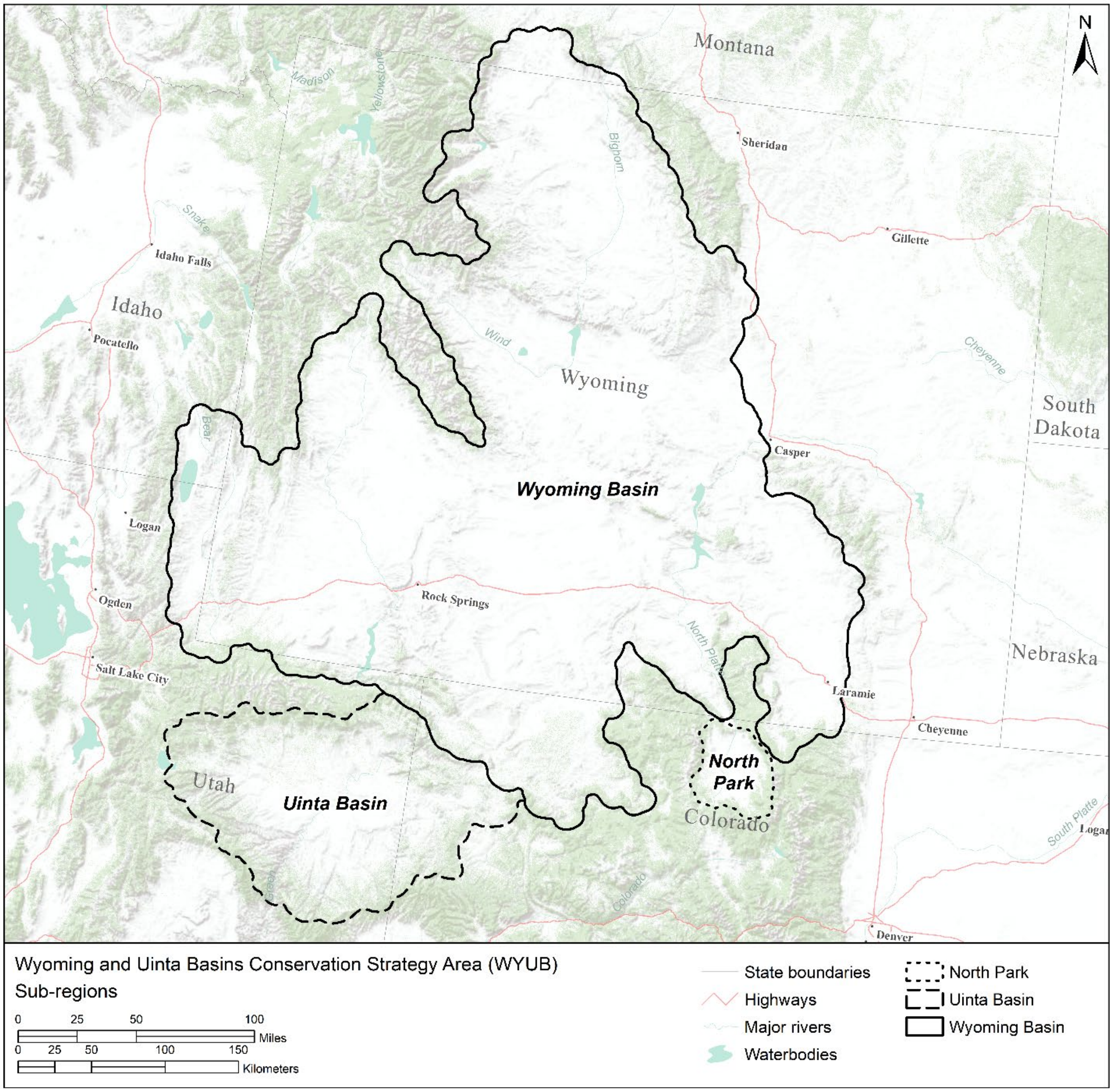

Figure 1.1. The Wyoming and Uinta Basins Conservation Strategy Area (WYUB), composed of the Wyoming Basin Ecoregion, Uinta Basin, and North Park. The WYUB covers 184,505 km^2 in parts of Colorado, Idaho, Montana, Utah, and Wyoming.

1.1. Geographic boundaries

The majority of the WYUB is composed of the Wyoming Basin Ecoregion (84%, 132,682 km^2). The borders of the Wyoming Basin are defined primarily by mountain ranges, with the Middle Rockies to the north and west, the Wasatch and Uinta Mountains to the southwest, and the Southern Rockies to the southeast. The prairies of the Northwestern Great Plains define lesser portions of the northern and eastern borders, and the arid tablelands of the Colorado Plateaus form a portion of the south-central boundary (Figure

1.1). The Uinta Basin (15% of WYUB, 23,285 km^2) extends from the southcentral portion of the Wyoming Basin west into Utah; its borders are defined by the Wasatch and Uinta Mountains to the north and west, and the Tavaputs Plateau to the south and east. The Uinta Basin is classified as part of the Colorado Plateau Ecoregion; however, we included it in this assessment because its rolling topography and arid shrubland vegetation are more similar to the Wyoming Basin than the more deeply dissected terrain and extensive juniper woodlands of the Colorado Plateau. North Park is a small (1% of WYUB, 2,302 km^2) basin adjacent to the southeastern portion of the Wyoming Basin. Part of the Southern Rockies Ecoregion, the borders of North Park are defined by the Park Range to the north and west, the Medicine Bow Mountains to the north and east, and the Rabbit Ears Range to the south. We included North Park in the WYUB because its open terrain and sagebrush steppe vegetation are more ecologically similar to the Wyoming Basin than the forested mountains that characterize the Southern Rockies Ecoregion.

1.2. Dominant geographic features

1.2.1. Topography

The landscape of the WYUB consists of a series of broad basins surrounded by mountain ranges. Elevation averages 2035 m (6677 ft), and ranges from <1100 m where the Bighorn River crosses the Montana border to >3600 m in the foothills of the Absaroka and Uinta Mountains. Pediments and piedmont plains extend from the slopes of the Rocky Mountains into the edges of the WYUB, and low mountain ranges, hills, buttes, scarp slopes, rims, hogback ridges, and badlands contribute to the diversity of terrain within its basins.

1.2.2. Climate

The climate of the WYUB is characterized by cold winters and warm summers. Annual precipitation averages 334 mm/yr (13 in/yr), and ranges from <150 mm/yr in low elevation desert basins to >1200 mm/yr in mountain foothills (Figure 1.2). Maximum annual average temperature, which correlates with the duration of the frost-free period, averages 13°C (56°F) and varies from >15°C in the lower elevations of the Uinta, Bighorn, and Wind River Basins to <5°C in the foothills of the Rocky Mountains (Figure 1.2). More precipitation falls as snow in the higher elevation, western portions of the region, while the lower and warmer basins to the northeast and south receive a greater fraction of precipitation as rain (Knight et al. 2014). The upper Green River Basin and North Park experience the coldest average annual minimum temperatures of <5°C, while the Tavaputs Plateau and Bighorn Basin have the warmest minimum temperatures of >1°C (Figure 1.2).

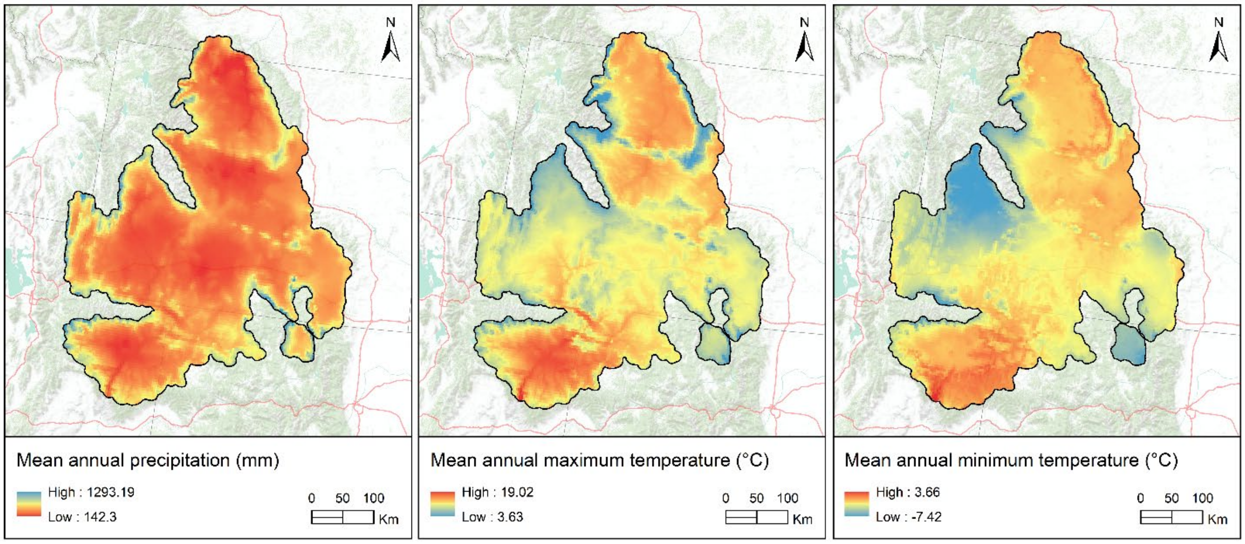

Figure 1.2. Climate of the Wyoming and Uinta Basins Conservation Strategy Area, 1981–2010: mean annual precipitation (left panel), mean annual maximum temperature (center panel), mean annual minimum temperature (right panel; PRISM Climate Group 2012).

1.2.3. Vegetation

Sagebrush steppe is the most common vegetative community in the WYUB (57% cover; Table 1.1 and Figure 1.3), and the Wyoming Basin has both the largest area and greatest proportion of sagebrush steppe of any ecoregion (Carr and Melcher 2015). Sagebrush steppe communities are dominated by Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*), but also include other sagebrush species and rabbitbrush (*Chrysothamnus* sp.). At elevations immediately above the sagebrush steppe, foothills shrub communities (2% cover) include mountain mahogany (*Cercocarpus* sp.) woodlands in the Wyoming Basin and Gamble oak (*Quercus gambelii*) and chaparral in the Uinta Basin. Below the sagebrush steppe, in the warmer low elevations, greasewood (*Sarcobatus vermiculatus*) and salt-desert shrub (*Atriplex* sp.) communities (8% cover) occur on poorly drained alkaline soils. Salt-desert shrublands in the Bighorn Basin are classified as a separate level-IV ecoregion, because of their greater contiguous area and more common conversion to agriculture than other salt-desert communities in the Wyoming Basin (Chapman et al. 2004). Grasslands (5% cover) occur throughout the WYUB in areas that are relatively well drained, but too dry to support sagebrush. These mixed grass prairie communities, which are more common closer to the eastern border with the Northwestern Great Plains Ecoregion, generally include needle-and-thread grass (*Hesperostipa* sp.), western wheatgrass (*Pascopyrum smithii*), and Indian ricegrass (*Achnatherum hymenoides*).

Although the WYUB is characterized by a lack of trees, coniferous forests, woodlands, and savannahs (6% cover) occur in limited areas. Limber pine (*Pinus flexilis*), ponderosa pine (*Pinus ponderosa*), and juniper (*Juniperus* sp.) forests grow above montane shrublands on dry mountain ranges, stands of aspen (*Populus tremuloides*) and other deciduous woodlands (3% cover) are scattered where snow accumulates on leeward slopes, and limited areas of coniferous forests that occur on the highest mountainous terrain include Douglas fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus flexilis*), and spruce-fir (*Picea* engelmanii and *Abies lasiocarpa*). Pinyon-juniper woodlands (4%) are more extensive in the Uinta Basin, especially on the Tavaputs Plateau. Lone juniper and pine trees occurring in moist micro-sites and relict cottonwoods (*Populus* sp.) associated with agricultural water impoundments and homesteads make up a small percentage of vegetation cover in the Wyoming Basin, but provide important nesting substrates for raptors. Riparian and wetland vegetation compose only a small part of the landscape (2% cover), but support biodiversity disproportionate to their area.

Non-native, exotic plant species occur throughout the WYUB (4% cover), including noxious weeds like cheatgrass (*Bromus tectorum*), halogeton (*Halogeton* sp.), and Russian thistle (*Salsola* sp.). Remaining areas are classified as barren or sparsely vegetated (3% cover); open water, ice, or snow (1% cover); developed (2% cover); or agriculture (3% cover). Overall, the native vegetation of the WYUB is more intact than most areas of the U.S. (Knight et al. 2014).

Table 1.1. Land cover in the Wyoming and Uinta Basins Conservation Strategy Area. Categories are groupings of existing vegetation types from LANDFIRE 1.4.0 (LANDFIRE 2016).

Category	Type	Area (km^2)	% of WYUB	Description
Shrublands	Sagebrush steppe	105,225	57	All classes of sagebrush vegetation
	Desert shrubland	13,959	8	Saltbush and greasewood shrublands, including rare desert shrub classes
	Other shrubland	4,459	2	Montane foothills shrublands, including mountain mahogany and chaparral
Forests and woodlands	Evergreen forest	10,863	6	All coniferous forest, woodland, and savannah, excluding pinyon-juniper
	Pinyon-juniper	8,069	4	Juniper woodlands with or without pinyon pine
	Deciduous woodland	4,710	3	Aspen forest and woodland, including Gambel oak and bigtooth maple classes
Anthropogenic	Exotic	6,541	4	Introduced vegetation, including annual and biennial forbland, annual grassland, and riparian woodland
	Agricultural	5,955	3	Western cool temperate pasture and hayland, with a lesser extent of wheat and row crop classes
	Developed	3,961	2	Urban areas and ruderal vegetation classes
Grassland	Grassland	8,971	5	All native grasslands
Other	Sparse-barren	5,929	3	Barren and sparsely vegetated systems
	Riparian and wetland	4,355	2	Woody and herbaceous riparian and wetland areas
	Water-Snow-Ice	1,507	1	Open water, snow fields, and glaciers
TOTAL		184,505	100	

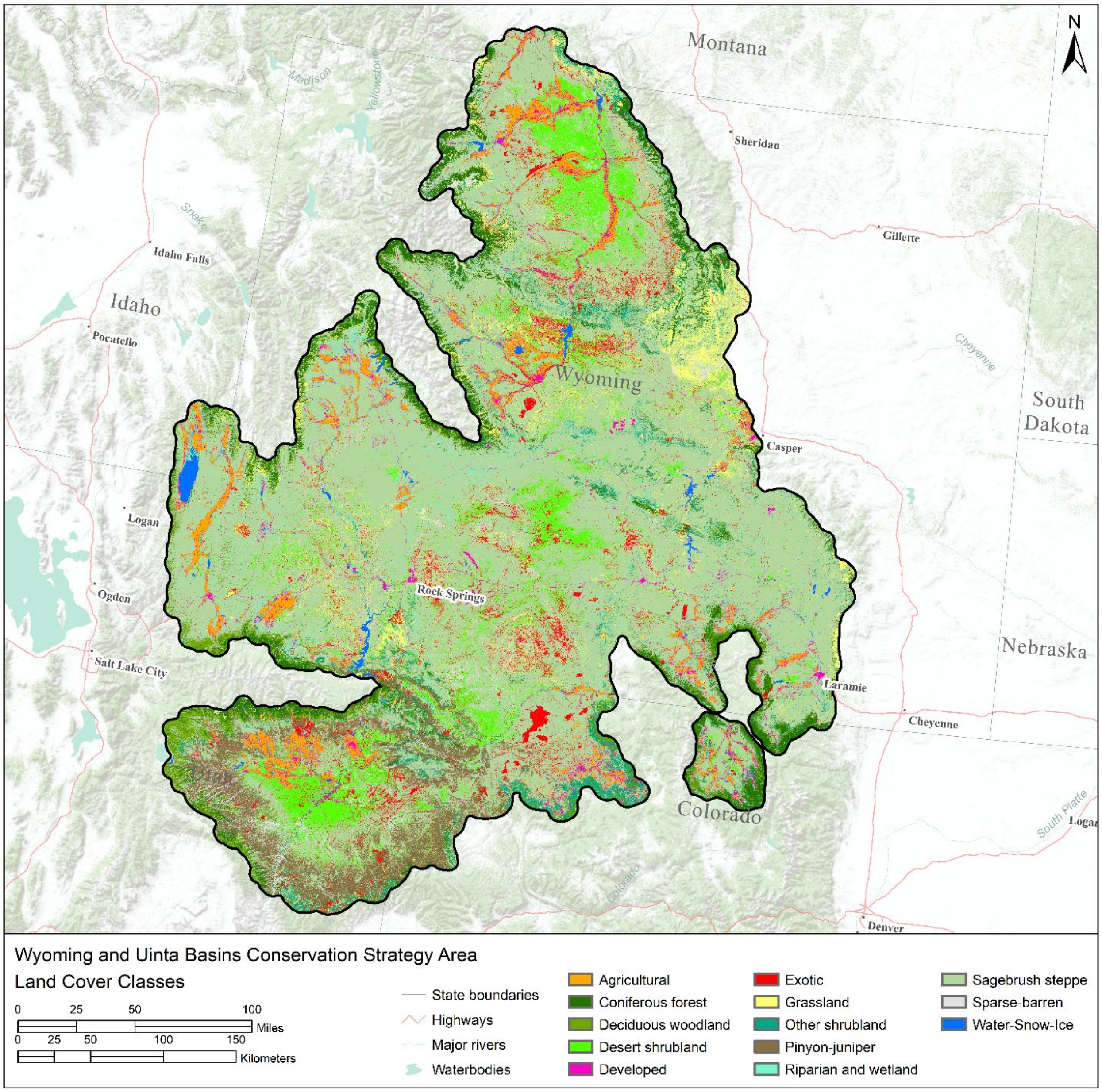

Figure 1.3. Land cover in the Wyoming and Uinta Basins Conservation Strategy Area. Categories are groupings of existing vegetation types from LANDFIRE 1.4.0 (LANDFIRE 2016).

1.2.4. Level-IV ecoregions

The patterns of topography, hydrology, climate, vegetation, and land use described above are the basis for the classification of the WYUB into level-IV ecoregions, which illustrate the key habitat types in the area (Chapman et al. 2004; Figure 1.4). The sub-regions of the WYUB are composed of 13 level-IV ecoregions and the 6.4-km buffer zone covers portions of an additional 24 level-IV ecoregions from the surrounding level-III ecoregions. The Wyoming Basin is classified into seven level-IV ecoregions: rolling sagebrush steppe, foothills shrublands and low mountains, sub-irrigated high valleys, salt desert shrub basins, Bighorn Basin, Bighorn salt desert shrub basins, and Laramie Basin. The Uinta Basin includes five level-IV ecoregions: semiarid benchlands and canyonlands, escarpments, northern Uinta Basin slopes, Uinta Basin floor, and shale desert and sedimentary basins. North Park is composed primarily of the sagebrush parks level-IV ecoregion, and also includes areas of crystalline mid-elevation forests, crystalline subalpine forests, and sedimentary subalpine forests.

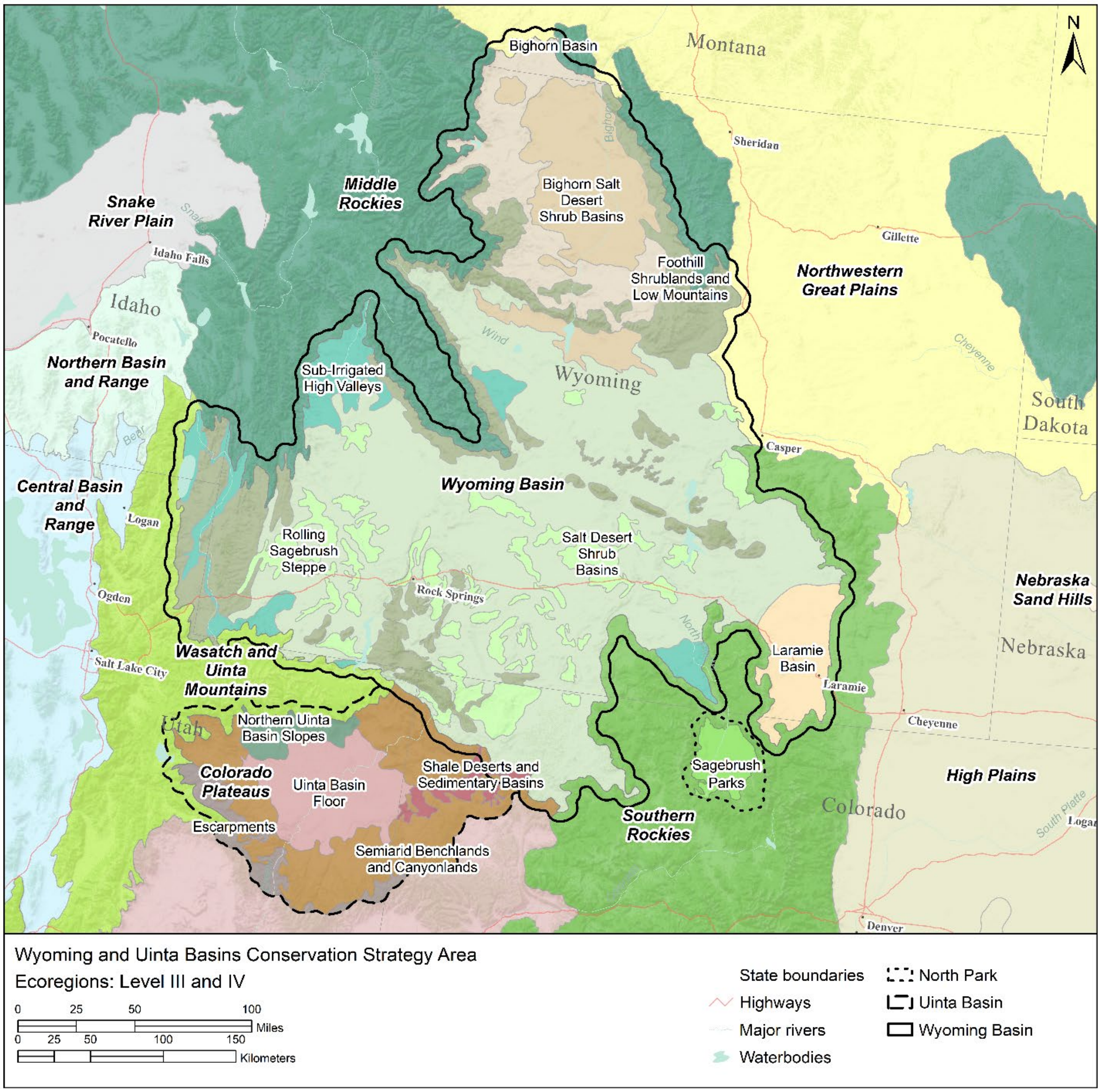

Figure 1.4. Level-IV ecoregions of the Wyoming and Uinta Basins Conservation Strategy Area (small plain text), with surrounding level-III ecoregions (large bold text; Chapman et al. 2004).

1.3. Surface management and development

1.3.1. Surface management

Surface management of the WYUB is dominated by the Bureau of Land Management (BLM; 49%) and private land owners (21%), with smaller areas under Forest Service (USFS; 11%), State (8%), Tribal (7%), or other (4%) management (USGS-GAP 2014; Table 1.2 and Figure 1.5). BLM lands occur in moderate-to-low elevation areas across the region, especially in the Wyoming Basin. Private lands are concentrated in river valleys, the southeastern Wyoming Basin, and western Uinta Basin. In a wide swath of "checkerboard" ownership along the I-80/Union Pacific Railroad corridor, ownership of 1-mi^2 sections alternates between private and BLM. The WYUB excludes most USFS land, which consists of National Forests in adjacent mountains that extends into the edges of the region. State trust lands, which originally occupied approximately two of every 36 mi^2, have been consolidated in some areas to support resource extraction or recreation. The WYUB includes portions of three Indian Reservations: the Eastern Shoshone and Northern Arapaho tribes of the Wind River Indian Reservation and the Ute Tribe of the Uintah and Ouray Reservation manage a total of >12,000 km^2, while a small portion (<200 km^2) of the Crow Indian Reservation is included in the northeastern edge of the WYUB.

Table 1.2. Agencies and entities responsible for surface management of the Wyoming and Uinta Basins Conservation Strategy Area, from the Protected Areas Database of the U.S. (version 1.3; USGS-GAP 2012). Some Bureau of Reclamation lands have been returned to Bureau of Land Management since these data were compiled.

Administrative Agency or Entity	Area (km^2)	% of WYUB
Bureau of Land Management	91,276	49
Private	39,088	21
Forest Service	20,662	11
State	13,842	8
Tribal	12,433	7
Bureau of Reclamation	2,959	2
National Park Service	1,805	1
Non-Governmental Organization	1,680	1
Fish and Wildlife Service	518	<1
Local Government	31	<1
Other, Unknown	102	<1
TOTAL	184,505	100

Compared to other areas of the western U.S., the WYUB contains relatively little land that is permanently protected from extractive uses (6%; GAP Land Status categories 1 and 2). Protected areas of the WYUB include portions of 13 National Wildlife Refuges, areas managed by the National Park Service (Bighorn Canyon National Recreation Area, Fossil Butte National Monument, and Dinosaur National Monument), USFS wilderness and

Research Natural Areas, BLM Wilderness Study Areas and Areas of Critical Environmental Concern, privately owned conservation properties and easements, and some State Parks, Conservation Areas, and Historic Sites. The majority of the land in the WYUB is managed for multiple use by Federal and State agencies (65%; GAP Land Status category 3), and the remaining area has no known management mandate (29%; GAP Land Status category 4 and all other private lands). Priority Areas for Conservation (PACs) of greater sage-grouse (*Centrocercus urophasianus*) afford a moderate level of land protection over a large area of the WYUB (68,625 km^2; 37%). While the future of PACs is uncertain and some extractive activities are permitted within their boundaries, their broad extent affords protection to golden eagle habitat (Carlisle et al. 2017).

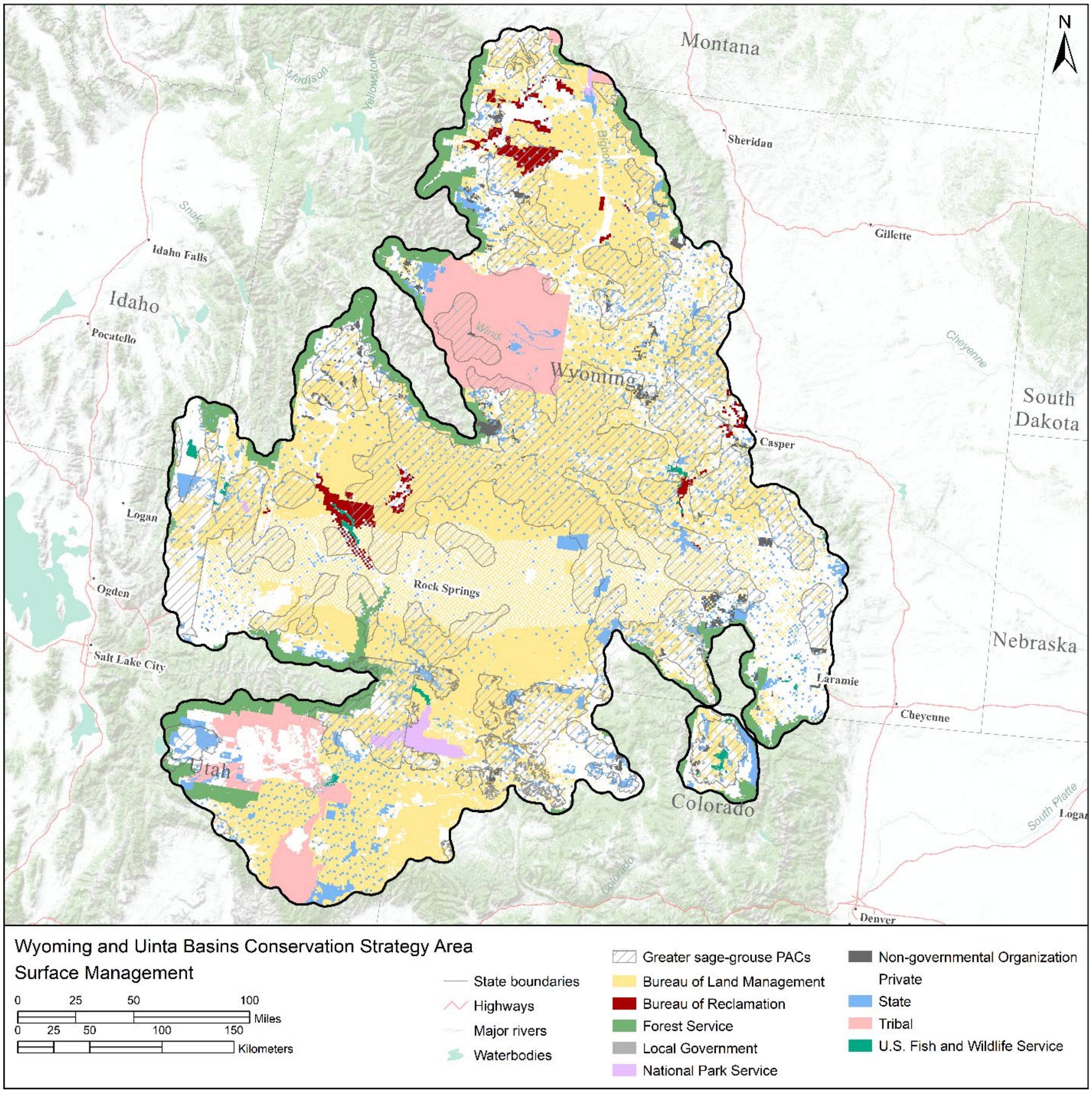

Figure 1.5. Agencies and entities responsible for surface management in the Wyoming and Uinta Basins Conservation Strategy Area, including greater sage-grouse Priority Areas of Conservation (PACs). Information from the Protected Areas Database of the U.S. (version 1.3; USGS-GAP 2012).

1.3.2. Human development

The WYUB has a small human population (326,327 people, 1.13 people/km^2 at the 2010 census) that is largely concentrated in the towns of Laramie, Rock Springs, Green River, Evanston, and Riverton, Wyoming; Vernal, Utah; and Craig, Colorado (Center for International Earth Science Information Network 2017). The primary economic land uses in the region are agriculture and energy development. Agriculture in the WYUB is dominated by livestock grazing on untilled rangelands, with crop production limited by aridity at lower elevations, and cold temperatures and short growing seasons at higher elevations (Knight et al. 2014). Areas under cultivation (3%) are mainly Western cool temperate pasture and hayland associated with ranching operations, and a small area of wheat and row crops (LANDFIRE 2016). Energy development in the WYUB includes extensive petroleum and natural gas fields, industrial-scale wind energy facilities, and mining for coal, uranium, bentonite, trona, and other resources (Chapman 2014). Oil and gas development is concentrated in the Green River and Great Divide Basins of Wyoming, and the Uinta Basin of Utah and Colorado, with smaller developments in most basins of the region (Figure 1.6). The largest active coal mine complexes are located in the Great Divide Basin east of Rock Springs, Wyoming and in the vicinity of Craig, Colorado (Figure 1.6 A). Wind energy facilities are concentrated in southwestern Wyoming, and the Shirley and Laramie Basin area of southeastern Wyoming, which has the highest sustained wind speeds of any non-mountainous region of North America (Figure 1.6).

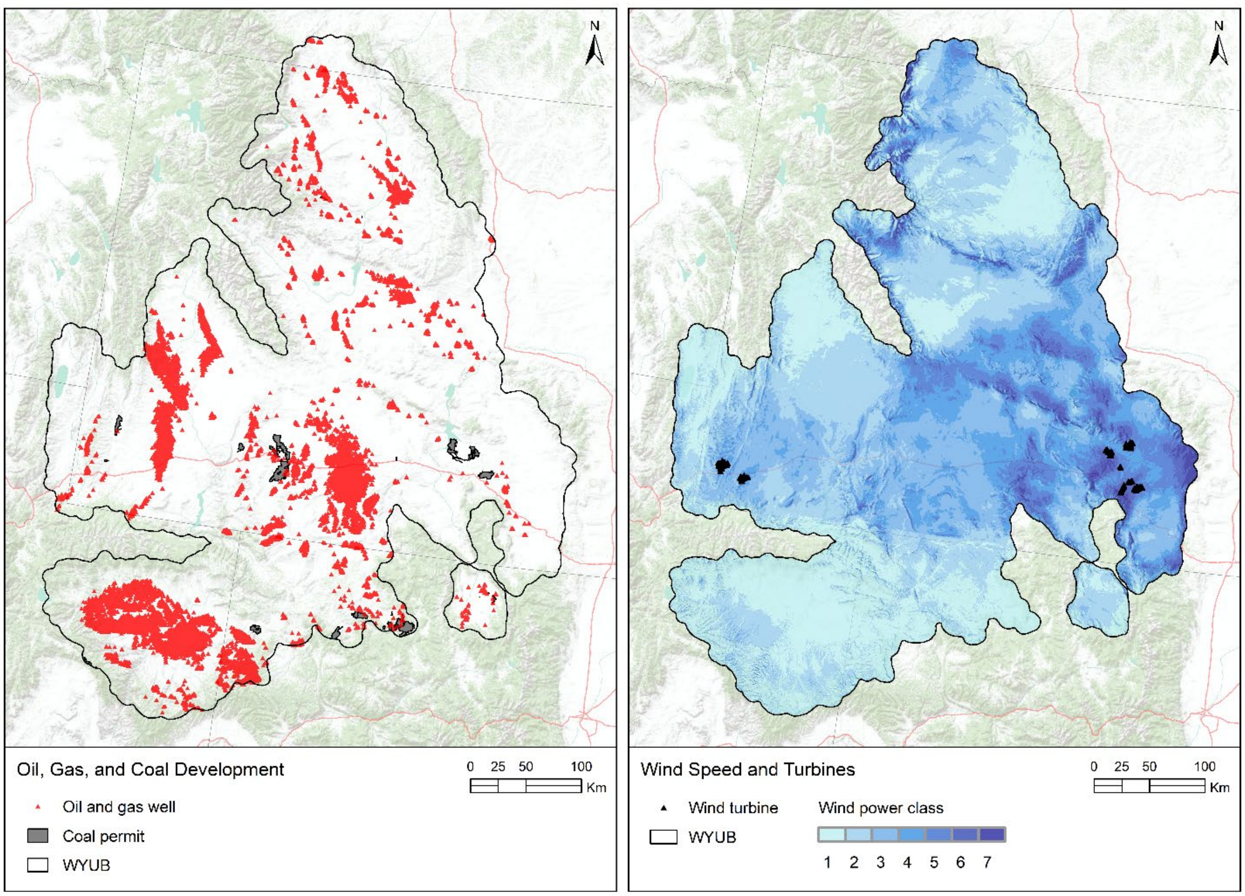

Figure 1.6. Energy development in the Wyoming and Uinta Basins Conservation Strategy Area (WYUB): active oil and gas wells and coal mine permit areas (left panel), and wind power classes and turbine locations (right panel).

2. Golden Eagle Populations

The WYUB supports a large and productive nesting population of golden eagles and provides habitat to residents and migrants outside the breeding season. Breeding populations benefit from extensive nesting habitat and abundant populations of small mammals, while wintering eagles exploit the region's plentiful ungulate populations. Compared to the breeding period, relatively little is known about golden eagle distribution and habitat during winter and migration. Additionally, very little information is available on movements of golden eagles in the WYUB, including space use of territorial pairs, dispersal movements of young originating in the region, and movement into the region from elsewhere. Ongoing efforts to collect and analyze telemetry data are expected to address these important data gaps in the future.

In this section, we summarize the state of knowledge on golden eagle populations in the WYUB by reviewing research on their density, space-use, habitat selection, fecundity, movements, diet, and winter-season ecology. We present spatial models developed by WGET to characterize habitat use of golden eagles during the breeding and winter seasons. This summary forms the foundation for identifying limiting factors to survival and fecundity in the following section on Population Ecology, as well as the spatial Conservation Prioritization, Spatial Risk Assessments, and recommended Regional Conservation Measures in the Conservation Strategy section. By summarizing all available data we aim to identify critical gaps in knowledge, facilitate comparisons with other regions, and establish benchmarks of demographic rates in the WYUB to support monitoring and management.

2.1. Breeding populations

Golden eagles breeding in the WYUB generally reside in the region year-round (Dunn and Ryder 1986, Kochert et al. 2002, Faulkner 2010). Monitoring of golden eagles in the WYUB has mostly occurred during the breeding season and has often been associated with regulatory compliance for development of the region's rich mineral resources. These monitoring efforts, which are typically short term and limited to project areas, have yielded copious records of nest locations, but less information on golden eagle ecology and population trends. General survey efforts by Federal (BLM, NPS, USFS, USFWS), State (Colorado Parks and Wildlife, Utah Division of Wildlife Resources, Idaho Fish and Game, Montana Fish Wildlife and Parks, Wyoming Game and Fish Department), and Tribal (Ute Tribe of the Uintah and Ouray Reservation Tribal Fish and Wildlife, Wind River Indian Reservation Tribal Game and Fish) agencies, NGOs (Bird Conservancy of the Rockies, Hawkwatch International), and citizen scientists have also generated many nest records. Information on golden eagle ecology in the region comes from several short- to medium-term intensive studies that included monitoring of demographic rates, habitat selection, and diet (Schmalzried 1976, Millsap 1978, Phillips et al. 1984, MacLaren et al. 1988, Young et al. 2010, Oakleaf et al. 2014, Preston et al. 2017b). Density estimates of individuals and nesting pairs are available for larger areas that include parts of the WYUB (Partners in

Flight Science Committee 2013, Nielson et al. 2014) and smaller areas within Wyoming (Phillips et al. 1984, Ayers et al. 2009, Young et al. 2010, Olson et al. 2015).

2.1.1. Abundance and density

Monitoring golden eagle population size and trend requires robust estimates of abundance. Although estimates of golden eagle abundance specific to the WYUB are not available, studies have been conducted to estimate abundance and density of breeding pairs in smaller study areas within Wyoming and individuals in larger areas that include the Wyoming Basin or Uinta Basin (Table 2.1).

Breeding pairs

Density of breeding pairs is a common index of population size and habitat quality for raptors (Bildstein and Bird 2007). Studies spanning portions of the WYUB have used various methods to locate golden eagle nests and estimate densities of breeding pairs. Phillips et al. (1984) estimated 3,381 (95% CI: 2,890–4,074) breeding pairs of golden eagles occurred in Wyoming, excluding approximately 20% of the state classified as marginal habitat. Seven of 12 regional study areas that contributed to the state-wide estimate were located in the Wyoming Basin; these areas covered 6,048 km^2 and had an average density of 1.75 breeding pairs/100 km^2 ((Phillips et al. 1984). Lower densities of occupied nests were documented over a 25-year period within a 3,215-km^2 study area that encompassed one of Phillips' survey areas near Medicine Bow, Wyoming. Densities reported were 1.56 breeding pairs/100 km^2 in 1978 (Oakleaf et al. 2014), an average of 0.89 breeding pairs/100 km^2 during 1997–2000, and 0.84 breeding pairs/100 km^2 in 2009 (Young et al. 2010). Ayers et al. (2009) conducted intensive aerial and ground-based surveys in a 783-km^2 area of southcentral Wyoming and found 16 occupied golden eagle nests in 1993 (2.04 breeding pairs/100 km^2), 0 in 1994, and 3 in 2008 (0.38 breeding pairs/100 km^2). Olson et al. (2015) used aerial surveys and distance sampling methods to estimate abundance of 258.5 (95% CI: 129.2–387.7) breeding pairs of golden eagles at a density of 0.36 breeding pairs/100 km^2 (95% CI: 0.18–0.54) within a 71,610-km^2 area of the Wyoming Basin in Wyoming.

While differences in density of nesting pairs likely reflect spatial and temporal variation in habitat quality and golden eagle populations, survey methodology and size of study areas also differed among studies. Olson et al. (2015) used probabilistic sampling and methods to account for imperfect detection across a broad area, while other studies attempted to census smaller areas that were not randomly selected. The study areas of Phillips et al. (1984) were distributed across Wyoming, but chosen due to mining applications (Oakleaf et al. 2014), and Ayers et al. (2009) selected a study area known for high densities of nesting raptors. The study area of Olson et al. (2015) was larger and determined by the breeding range of the ferruginous hawk, which likely included more low-suitability habitat and excluded some higher elevation areas used by golden eagles. With the exception of the estimates of Olson et al. (2015), breeding pair density in WYUB was generally higher than other study areas in the western U.S. summarized by Kochert et al. (2002): 1.52 pairs/100 km^2 in southwestern Idaho (Kochert 1972); 0.91 pairs/100 km^2 in Utah (Camenzind 1969);

0.78 pairs/100 km^2 in Montana (Reynolds 1969); and 0.40 pairs/100 km^2 in Nevada (Page and Seibert 1973).

Individuals

Monitoring of raptors is commonly focused on surveys of breeding adults associated with nests. However, estimates of abundance of individuals may offer a more complete index of golden eagle population size and trend because they capture all segments of the population, including juveniles, sub-adults, and floaters (Nielson et al. 2014).

The Wyoming Basin is located within and covers approximately 14% of Northern Rockies BCR (BCR 10; 951,561 km^2), with the remainder of the BCR composed of mountainous terrain in other ecoregions. Partners in Flight (PIF) estimated 14,000 golden eagles of all age classes occurred during the breeding season in BCR 10, based on data from the North American Breeding Bird Survey (BBS), 1997–2005 (Partners in Flight Science Committee 2013). The abundance estimate from PIF translates to an average density of 1.47 eagles/100 km^2 of all age classes during the breeding season in BCR 10 (Partners in Flight Science Committee 2013). Although data quality ranged from fair to poor, PIF also estimated breeding season abundance of golden eagles for the portion of each state within BCR 10, including 8,000 individuals in Wyoming, 2000 in Montana, 1,400 in Colorado, 190 in Idaho, and 70 in Utah (Partners in Flight Science Committee 2013). The Western Golden Eagle Survey (WGES), a systematic aerial survey of golden eagles in the western U.S. conducted by USFWS, provided annual estimates of abundance during the early post-fledging period within portions of BCRs in the western U.S. (Nielson et al. 2014). During 2006–2012, estimates from WGES suggested 6,431 (90% CI: 4,196–9,604) golden eagles of all age classes occurred in an approximately 500,000-km^2 portion of BCR 10 (Nielson et al. 2014). Annual density estimates from this survey ranged from 0.65 eagles/100 km^2 (90% CI: 0. 38–1.00) in 2014 to 1.63 eagles/100 km^2 in 2013 (90% CI: 0.94–2.46; Nielson et al. 2016a). Compared to adjacent BCRs, average density in BCR 10 was higher than the Great Basin (BCR 9) and Southern Rockies/Colorado Plateau (BCR 16), but lower than the Badlands and Prairies (BCR 17; Nielson et al. 2016a). Although PIF (2013) estimated higher golden eagle density in BCR 10, their estimate was within the range of annual estimates from WGES (Nielson et al. 2016a), suggesting general agreement among the two surveys, despite differences in time period, study area, and methodology.

The Uinta Basin makes up only 5% of the 518,550-km^2 Southern Rockies/Colorado Plateau BCR (BCR 16). PIF (2013) estimated 9,000 golden eagles of all age classes occurred during the breeding season in the BCR 16, with 5,000 in Utah and 2,000 in Colorado. The abundance estimate from PIF translates to an average density of 1.74 eagles/100 km^2 of all age classes during the breeding season in BCR 16 (Partners in Flight Science Committee 2013). Annual density estimates from the WGES for BCR 16 were lower, ranging from 0.31 eagles/100 km^2 (90% CI: 0.16–0.49) in 2008 to 1.00 eagles/100 km^2 in 2003 (90% CI: 0.60–1.40; Nielson et al. 2016a).

Table 2.1. Abundance and density of golden eagles from studies overlapping the Wyoming and Uinta Basins Conservation Strategy Area. Shown are unit (breeding pairs or individuals), study area name and size, years and season of data collection, estimated abundance and density, and source.

Unit	Area name	Size (km^2)	Years	Season	Abundance	Density (100 km^2)	Source
Breeding pairs	Ferruginous hawk range in Wyoming Basin	71,610	2010–2011	Breeding	258.5	0.36	Olson et al. 2015
	Wyoming Basin study areas	6,048	1976–1982	Breeding	106	1.75	Phillips et al. 1984
	Medicine Bow study area	3,215	1978 1997–2000 2009	Breeding	50 28.5 27	1.56 0.89 0.84	Young et al. 2010
	Southcentral Wyoming	783	1993 1994 2008	Breeding	16 0 3	2.04 0 0.38	Ayers et al. 2009
Individuals	BCR 10	951,561	1997–2005	Breeding	14,000	1.47	Partners in Flight Science Committee 2013
	BCR 10 (in U.S.)	499,984	2006–2012 [a] 2003–2015 [b]	Post-fledging	6,431[a]	0.65–1.63[b]	[a]Nielson et al. 2014, [b]Nielson et al. 2016
	BCR 16	516,755	1997–2005	Breeding	9,000	1.74	Partners in Flight Science Committee 2013
	BCR 16	471,584	2006–2012 [a] 2003–2015 [b]	Post-fledging	3,983[a]	0.31–1.00[b]	[a]Nielson et al. 2014, [b]Nielson et al. 2016

2.1.2. Spacing, home range, and core areas

The most common management action for golden eagles is restriction of disturbance around nest sites and core use areas. Information on nest spacing, home-range size and shape, and movement within core areas is, thus, important to inform management. In this section, we supplement limited information on golden eagle space use from the WYUB with data from other regions.

The minimum distance between adjacent territories or occupied nests of golden eagles is an indicator of relative habitat quality. Phillips et al. (1984) reported average nearest-neighbor distance between occupied nests of 5.29 km (range: 3.1–8.2) from seven study areas in the Wyoming Basin, while Preston et al. (2017b) documented smaller average distances of approximately 4 km and minimum of 1.4 km between territory centers. Nest spacing in the WYUB was similar to average nearest-neighbor distances summarized by Kochert et al. (2002) for southwest Idaho (4.3 km; Kochert 1972), Salmon Fall Creek, Idaho (4.39 km; Craig and Craig 1984), and Denali National Park, Alaska (6 km; Kochert et al. 2002).

Knowledge of regional variation in the size and shape of golden eagle home ranges and core areas is essential to inform buffer sizes for management of human disturbance; however, no studies of golden eagle space use specific to the WYUB are currently available. Breeding season home ranges of golden eagles in the western U.S. averaged 20–33 km^2 (Kochert et al. 2002) and a study from the adjacent Northwestern Great Plains Ecoregion reported breeding season home-range sizes of 26.1–54.0 km^2 (Tyus and Lockhart 1979). Year-round home ranges were 32.5 km^2 (range: 15.1–61.3 km^2) in the High Plains Ecoregion (Platt 1984) and 20.4 km^2 in the Northwestern Great Plains Ecoregion (Phillips and Beske 1982). An analysis of core area use across the western U.S. reported annual average core areas of 8.09 km^2 (80% CI: 7.50–8.69; Ross Crandall, Craighead Beringia South, personal communication).

2.1.3. Breeding habitat

The breeding range of golden eagles encompasses the major habitats of the western U.S., with the exceptions of dense montane forests and urban areas (Kochert et al. 2002). Within the WYUB, relative suitability of breeding habitat is influenced by availability of elevated nesting substrates, most frequently cliffs and rock outcroppings, adjacent to semi-open foraging habitats with abundant prey (Phillips et al. 1984, Tack and Fedy 2015, Dunk 2017). Studies from across the western U.S. suggest Wyoming and the WYUB provide continentally significant breeding habitat for golden eagles. Wyoming was the largest contiguous area of high-intensity use by golden eagles in western North America during late summer, owing to its lack of forested and developed areas, relatively high elevations and wind speeds, and moderate solar radiation (Nielson et al. 2016b). The high quality of breeding habitat across the Wyoming Basin was also evident in comparisons with relative nesting territory density (RND) models developed by WGET for other ecoregions (Dunk 2017). Compared to the other ecoregions in WGET's analysis, golden eagle nests in the Wyoming Basin occurred at higher densities even in areas classified as relatively low-suitability habitat. These results suggest greater overall breeding habitat quality for the Wyoming Basin ecoregion, compared to the other regions modeled by WGET.

Landscape characteristics

Golden eagles are a landscape-level species (Katzner et al. 2012a) that occur across the range of vegetation types and landforms in the WYUB. Accordingly, nesting records are known from all major habitat types within the region, including sagebrush steppe, salt desert shrublands, foothills shrublands and low mountains. Phillips et al. (1984) classified 80% of Wyoming as suitable nesting habitat for golden eagles, excluding only forests without openings, extensive croplands, and flat desert terrain. Given that land cover of forest, agriculture, and development each make up <5% of the WYUB, the only large areas excluded as nesting habitat under Phillips' definition are flat deserts lacking trees or anthropogenic substrates for nesting. Habitat suitability models also provide insight into landscape characteristics selected by breeding golden eagles. Models of relative nesting habitat suitability in the Wyoming portion of the Wyoming Basin developed by Tack and Fedy (2015) included variables representing topographic relief at fine spatial scales, and sparseness of vegetation and abundance of prey at broader scales. Similarly, RND models developed by WGET included fine-scale measures of relative topographic relief, and vegetation and climate characteristics at broader scales.

Nest site characteristics

Monitoring and management of golden eagles is typically focused on nest sites. Nests are an ecologically meaningful sample unit because they are essential to reproduction, serve as activity centers in home ranges, and are likely to be reused for many years. The conspicuousness of large stick nests also makes them a practical sample unit for monitoring and management. Understanding the characteristics of nest sites used by golden eagles is, thus, essential to support effective monitoring and management. Although golden eagles breeding in the WYUB use a variety of nesting substrates with a range of heights and aspects, most nest sites are on cliffs >10m in height.

In the Wyoming Basin, the nest location database compiled by WGET included 15,100 records, 8,957 of which had information on nest substrate (Table 2.2); of those 62% were on cliffs. Although the WGET database likely included some duplicate records, the prevalence of nests on cliffs was consistent with other studies from the ecoregion: 98% (Preston et al. 2017b), 60% (MacLaren et al. 1988), 71% (Millsap 1978), 90% (Schmalzried 1976). Cliffs were also the predominant nesting substrate in the Uinta Basin: of 44 nest sites in the WGET database with information on substrate 36 (82%) were on cliffs. While cliffs were the most frequently used nest substrate in the WYUB, composition of samples from studies summarized here may have been biased because none used probabilistic sampling or accounted for variation in detectability of nests on different substrates. It is also important to note that nests in trees and on the ground are expected to be underrepresented in these samples because they are more difficult to detect.

Table 2.2. Nesting substrates of golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area. Shown are source, percentage of nests by substrate, and total number of nests with information on substrates.

Source	Percentage of nests by substrate					Total Nests
	Cliff	Rock outcrop or erosional feature	Tree	Nesting platform or other human-made	Other	
WGET database: Wyoming Basin	62%	8%	5%	5%	20%	8,957
WGET database: Uinta Basin	82%		7%		11%	44
Preston et al. (2017b)	98%		2%			83
MacLaren et al. (1988)	60%	3%	34%		3% [a]	30
Millsap et al. (1978)	71%	10%	15%	2%	2% [a]	48
Schmalzried (1976)	90%		10%			31

[a] ground nest

Height above ground of golden eagle nests in the WYUB averaged >10 m and ranged from 2–40 m. Millsap (1978) reported mean nest height of 14.33 m, with all nests above 4.57 m. MacLaren et al. (1988) found that golden eagle nests had an average height of 11.23 m (SE: 1.25, range: 3.05–39.62), which was significantly higher than nests of sympatric raptor species. Schmalzried (1976) reported that cliff nests ranged from 2–24 m above ground, while nests in trees were 10–12 m in height. Wallace (2014) found a strong positive relationship between nest height and occupancy for golden eagles in Wyoming: the probability that a site was reused increased from 0.28 to 0.98 as nest height increased from 2–15 m, and was >0.99 for nests from 15–30 m. Higher sites may offer nesting eagles a better vantage point to detect and deter avian predators, provide greater protection from disturbance, and wind conditions that facilitate take-off (Wallace 2014).

Aspect of golden eagle nest sites in the WYUB showed no clear pattern: MacLaren (1988) documented a bimodal distribution of nest aspects, with 47% facing northwest and 33% southeast, and suggested these exposures protected nestlings from intense sun and wind. Millsap (1978) reported that northeastern aspects were avoided and nests with western exposures were most productive. Northern populations of golden eagles tend to favor nest sites with southern exposures because they receive more solar radiation, while southern populations use a range of aspects, depending on local conditions and availability (Kochert et al. 2002). Consistent with other populations at middle latitudes, golden eagles in the WYUB likely select varied nest aspects to adapt to the wide range of weather conditions in the region, which range from harsh wind and winter weather early in the breeding season to intense heat and sun during the brood-rearing period.

Alternative nest sites maintained within breeding territories attract golden eagles, serve as activity centers, and are likely to be reused (Millsap et al. 2015). Few studies in the WYUB reported the number of alternative nests, likely due to the difficulty of mapping breeding territories and detecting unoccupied nests. Schmalzreid (1976) found an average of 2.4 alternative nests (range: 1–6) in 13 breeding territories in the Laramie Basin. Studies from other regions summarized by Millsap et al. (2015) reported similar or greater average number of alternative nests: <2.0 in Montana (McGahan 1968), 2.4 in Sweden (Tjernberg 1983), 3.4 in Britain (Watson 2010), 4.5 in Scotland (Watson 2010), and 6.9 in Idaho (Kochert and Steenhof 2012).

Photo gallery

The following photos are intended to represent the range substrates used by golden eagles nesting the WYUB.

Figure 2.1. Typical golden eagle nest on sandstone cliff in the Bighorn Basin. Photo by Charles Preston.

Figure 2.2. Incubating golden eagle in a nest on sandstone cliff in the Bighorn Basin near Powell, Wyoming. Photo by Dale Stahlecker.

Figure 2.3. Incubating golden eagle (top) and alternative nest (bottom) in Uinta County, Wyoming. Photo by Megan Ruehmann.

Figure 2.4. Incubating golden eagle (right) and alternative nest (left) in Uinta County, Wyoming. Photo by Megan Ruehmann.

Figure 2.5. Occupied golden eagle on nest on communication tower in the Great Divide Basin west of Rawlins, Wyoming. Photo by Dale Stahlecker.

Figure 2.6. Occupied golden eagle on nest in cottonwood tree in Uinta County, Wyoming. Photo by Megan Ruehmann.

Figure 2.7. Occupied golden eagle on nest in Douglas fir tree in Uinta County, Wyoming. Photo by Megan Ruehmann.

2.1.4. Relative nesting territory density model

Nesting habitat is an essential resource for reproduction and persistence of golden eagle populations. To understand the distribution and characteristics of golden eagle nesting habitat in the WYUB, WGET developed a model of Relative Nesting territory Density (RND). This presence-background species distribution model predicted the relative density of golden eagle nesting territories across the region by relating locations of known nests to habitat variables using the software MaxEnt (Phillips et al. 2006). The RND model is one of three key data products supporting the Conservation Strategy, together with models of winter habitat use and movement. Here we provide a brief summary of modeling methods and focus on results describing the attributes of golden eagle nesting habitat in the WYUB. We use these model results in subsequent sections on breeding priority areas and spatial risk assessments for the WYUB. Details of modeling methods are available in Dunk et al. (in review).

Model development

Training data for the model included 948 nest locations in the Wyoming Basin, thinned from 15,100 by clustering nest sites within 3-km into putative breeding territories and filtering records with inaccurate location information, dates prior to 1974, or human-made substrates. We consulted regional experts to select a suite of 31 variables predicted to be associated with golden eagle nesting habitat, for which we estimated the mean and standard deviation at 6 spatial extents within a 20-km buffer around the nest sample. We used a multi-stage variable screening process to select a model that had high predictive power and generalized well across the ecoregion. After developing the model in the Wyoming Basin, we projected the results to the Uinta Basin and North Park, and evaluated the performance of the model with samples of 128 and 8 nest locations, respectively.

The model output predicted RND in 120 × 120-m cells. To more accurately represent the larger area of core habitat required to support breeding golden eagles, we smoothed the AAF surface using a weighted Gaussian kernel generated using the 80% upper confidence interval of the grand mean core area size (Ross Crandall, Craighead Beringia South, personal communication). Assuming a circular mean core area size of 8.69 km^2, the diameter would be approximately 3320-m, which is approximately 27 120-m pixels. This approach, which extended the influence of high-suitability pixels into the surrounding core area while emphasizing pixels closer to the center, was based on our assumption that habitat use and exposure to risk by golden eagles would be greatest in the core area around nests.

Results

The final model included 14 covariates representing attributes of topography, vegetation, climate and weather, and human development (Table 2.3). Predictors representing topography contributed most to the model (69%), followed by vegetation (23%), climate and weather (5%), and human development (3%). Evaluation metrics showed the model had high predictive power in the Wyoming Basin, and also performed well when projected to the Uinta Basin and North Park (Dunk 2017).

Relative density of golden eagle nesting territories was most strongly related to variation in terrain steepness at a fine (120-m) spatial extent around nest sites (60.7% contribution) and average percent cover of sagebrush at a broad (6.4-km) spatial extent (10.4% contribution). Twelve other covariates each contributed less than 5% to the overall performance of the model (Table 2.3).

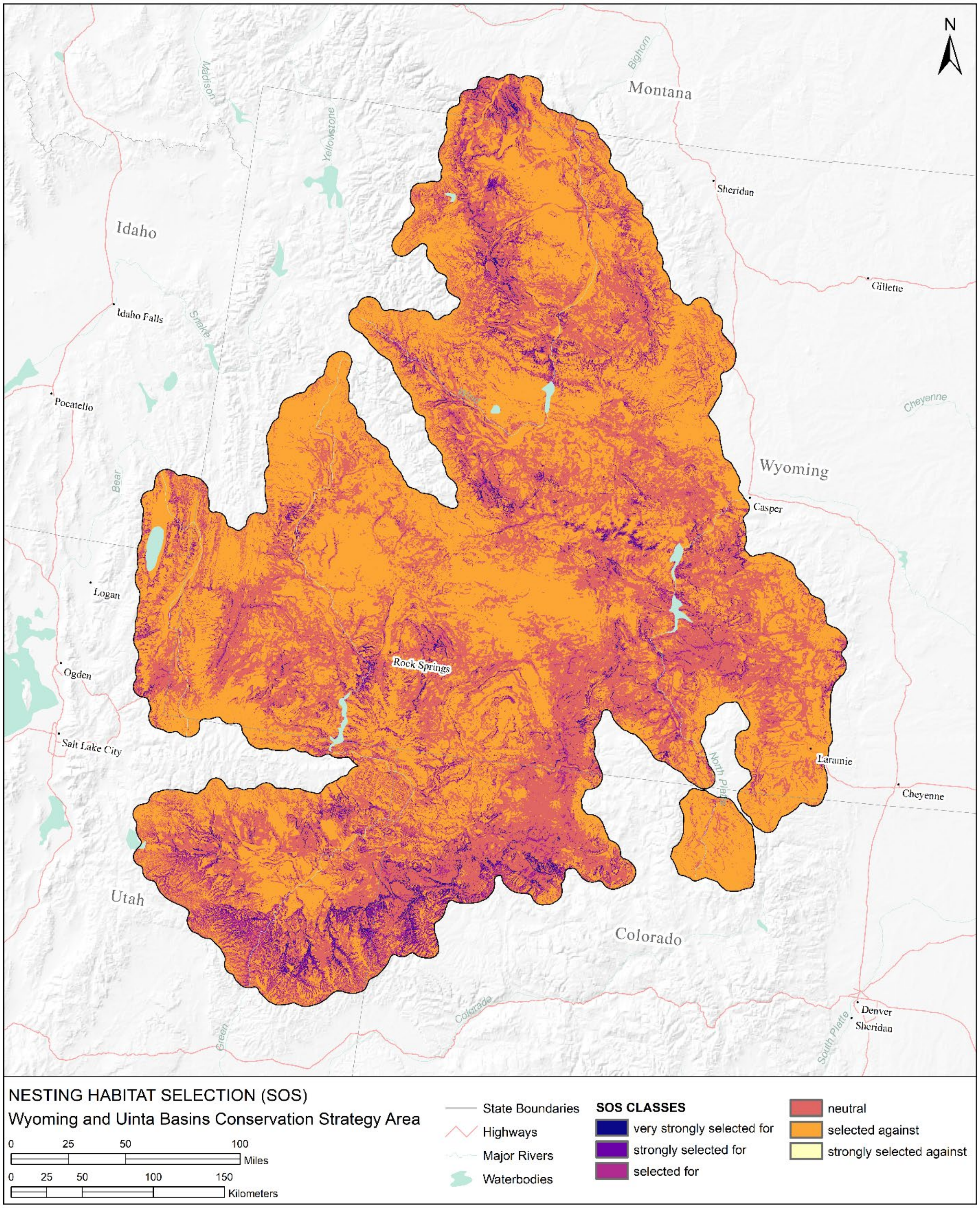

Figure 2.8. Predicted relative density of golden eagle nesting territories in the Wyoming and Uinta Basins Conservation Strategy Area. Displayed as relative strength of selection (SOS).

Table 2.3. Variables contributing to model of relative density of golden eagle nesting territories in the Wyoming Basin Ecoregion. Shown are variable name, base covariate description, size of neighborhood in which variable was evaluated (Scale), focal statistic within neighborhood, and percent contribution to the model. Detailed descriptions of variables and model development are available in (Dunk et al. in review).

Name	Description	Scale	Focal Statistic	% Contribution
steep1_120m_sd	Terrain steepness index	120 m	Standard deviation	60.7
sage1c_4mi_mn	Percent cover of all sagebrush areas from Landfire EVT 1.3	6.4 km	Mean	10.4
sage1c_05km_sd	Percent cover of all sagebrush areas from Landfire EVT 1.3	0.5 km	Standard deviation	4.6
climate2c_2mi_mn	Degree-days > 5d Celsius from Rocky Mountain Research Station climate data	3.2 km	Mean	4.3
slope1_05km_sd	Terrain slope index	0.5 km	Standard deviation	3.8
ndvi1b_05km_sd	Normalized Difference Vegetation Index (NDVI) for May 17-June 17 averaged over 11 years (2003-2013).	0.5 km	Standard deviation	3.3
led1_120m_mn	Local Elevational Difference (LED) index	120 m	Mean	3.2
urban1_4mi_sd	All developed areas from NLCD 2011 landcover [30m]	6.4 km	Standard deviation	3.1
ponderosa1c_4mi_sd	All ponderosa pine areas from Landfire EVT 1.3	6.4 km	Standard deviation	2.2
slope1_05km_mn	Terrain slope index	0.5 km	Mean	1.5
alfalfa3b_2km_sd	Alfalfa from NASS Cropland Data Layer, 2008-2009	2 km	Standard deviation	0.9
grass1_2mi_mn	Grassland and herbaceous from NLCD 2011 landcover	3.2 km	Mean	0.9
upliftoro1_4mi_mn	Index of orographic uplift calculated following Bohrer et al. 2012. Uplift is maximized when wind direction is perpendicular to the terrain aspect, and minimized when parallel.	6.4 km	Mean	0.7
greasewood1c_4mi_mn	All saltbush-greasewood areas from Landfire EVT 1.3	6.4 km	Mean	0.5

Discussion

The single strongest influence on relative density of golden eagle nesting territories in the Wyoming Basin was fine-scale (120-m) variation in terrain steepness. Other aspects of fine-scale topography influenced RND to a lesser degree: relative nest densities were higher in areas with greater average slope, variation in slope, and local elevational difference within 120–500 m. These results describe the steep and variable terrain that provides the cliffs, rock outcrops, and erosional features commonly used by nesting golden eagles in the WYUB and other regions (Kochert et al. 2002).

The second strongest influence on relative density of golden eagle nesting territories was broad-scale (6.4-km) cover of sagebrush. Sagebrush is the dominant vegetation type in the WYUB and this result is consistent with the known preference of golden eagles to nest adjacent to foraging areas with relatively smooth terrain and native vegetation (Kochert et al. 2002, Crandall et al. 2015). Other attributes of vegetation had weaker relationships with RND at a range of spatial scales: at a broad scale (6.4-km), RND was lower in areas with greater cover of greasewood and more variation in cover of ponderosa pine. Although greasewood vegetation offers habitat for some prey species, extensive greasewood communities tend to occur at lower elevations in the interior of arid basins (e.g., Bighorn Basin, Great Divide Basin) where lack of elevated nest substrates and lower primary productivity may limit nesting by golden eagles. The weak negative effect of variation in ponderosa pine cover on RND was limited to areas in the mountain foothills around the edges of the Wyoming Basin. Given that very few nests in the sample were in pine trees, this variable likely captured a combination of elevation, landscape position, and forest cover in areas where cliffs and rock outcrops suitable for nesting occurred. At moderate spatial extents (2 km–3.2 km), RND was higher in areas with less area of grassland and more variation in cover of alfalfa. Evidence for avoidance of habitats with greater area of grassland is inconsistent with use of prairie habitats by golden eagles in the WYUB and neighboring regions (e.g., Northwestern Great Plains Ecoregion); however, this variable explained only a small amount (<1%) of variation and may have little biological meaning in the WYUB beyond contributing to predictions in local areas. Similarly, alfalfa cover made a small contribution to the model (<1%) and has a limited distribution in the WYUB, where it is restricted to areas along major rivers (e.g., Bighorn River, Wind River, Yampa River), sub-irrigated valleys (e.g., Bear River Valley, Saratoga Valley), and isolated irrigation projects (e.g., Eden, Wyoming). Several vegetation variables were weakly related to RND at finer scales (500 m), including greater variation in sagebrush cover and an index of green vegetation (NDVI); both may have reflected greater variation in vegetation cover associated with rough terrain in the immediate vicinity of nest sites.

Relative density of golden eagle nesting territories was weakly influenced by climate and weather: RND was higher in areas with more degree days >5° C at a 3.2-km scale, suggesting nesting golden eagles avoided the coldest areas of the Wyoming Basin, like the centers of mountain ranges. Orographic uplift, the currents created when air is forced over landscape features, had a weak positive influence on RND at a broad (6.4-km) scale. Orographic lift is greatest in areas where high wind speeds occur perpendicular to terrain aspect and enables golden eagles to fly with less energetic cost (Bohrer et al. 2012). Previous research suggested high average wind speeds contributed to the quality of golden eagle habitat in Wyoming (Nielson et al. 2016b) and our results confirm that favorable wind patterns are a habitat resource for this species.

Relative nesting territory density was lower in areas with greater variation in human development within 6.4 km. Human settlement is relatively sparse in the WYUB and this variable encompassed all levels of development intensity from "Open Space" to "High Intensity" (Fry et al. 2011). Rather than suggesting an association of nest sites with urbanized areas, the positive relationship of relative nesting territory density with variability in the cover of developed areas reflects higher RND in areas with less continuous patterns of development. This result is, thus, consistent with previous research suggesting golden eagles are unlikely to nest in close proximity to human settlements and benefit from moderate heterogeneity in land cover (Kochert et al. 2002).

The narrow range of conditions in the Wyoming Basin Ecoregion may have limited the influence of variables associated with golden eagle nesting habitat at broader scales and in other areas. For example, golden eagles in the western U.S. are known to largely avoid nesting in forests (Kochert et al. 2002, Nielson et al. 2016b), however RND showed no clear pattern relative to forest cover in the Wyoming Basin. This is likely due to the lack of forest in the ecoregion, where continuous coniferous forests occur only on isolated mountain ranges (e.g., Rattlesnake Hills), the Tavaputs Plateau, and the foothills of the Rocky Mountains. Similarly, studies at broader scales found that elevation was a good predictor of golden eagle habitat (Kochert et al. 2002, Nielson et al. 2016b), whereas the lowest and highest RND bins in the Wyoming Basin differed by only 145 m elevation. This result likely reflects both the small range of variation in elevation in the Wyoming Basin and the availability of elevated substrates for nesting in even the lowest elevation areas of the ecoregion. Consistent with results for other golden eagle populations at mid-latitudes (Kochert et al. 2002), we found no evidence of selection for nest aspect.

Applications and Limitations

Maps of predictions from this model are powerful tools with potential applications for prioritization of landscapes for conservation and mitigation, as well as informing design of future surveys and monitoring efforts in the WYUB. However, the data and methods used to generate this model place some limitations on its interpretation and applications. RND values represent relative density of nesting territories within the ecoregion and do not predict actual locations of golden eagle nest sites. Although the model predicted habitat suitability within 120-m^2 cells, caution should be used in applying model predictions for management at fine spatial scales. The model is based on nest locations and predicts habitat suitability at a relatively fine scale; however, mapped predictions underestimate the spatial extent of habitat that is actually required to support breeding by golden eagles. Covariates in the model should not be interpreted to represent the ecological niche of nesting golden eagles; results represent correlations with relative density of nesting territories, rather than a mechanistic model of golden eagle breeding habitat selection.

Training data did not include nests on human-made substrates; therefore, caution should be used when applying the model in areas where golden eagles are known to nest on power poles, artificial platforms, oil and gas tanks, and other infrastructure. These include areas of energy development in the Green River, Washakie, Great Divide, and Uinta Basins. Nests on trees were included in the training data, however they are likely under-represented in the sample due to their lower detectability. Caution should thus be used when applying the model in areas where suitable nesting habitat may occur in lone trees, riparian gallery forests, or coniferous forests.

Predictions from this model are most useful for regional- and landscape-scale conservation planning. Examples of these applications are included below in the sections on Conservation Prioritization and Spatial Risk Assessments.

2.1.5. Fecundity

Successful reproduction is essential to the persistence of golden eagle populations. Accordingly, golden eagle monitoring commonly involves tracking rates of occupancy, breeding success, and productivity at nests within territories (Bildstein and Bird 2007). Such data provide baselines of productivity necessary to assess population status and impacts of disturbance, while regionally-specific information on breeding phenology can inform timing of seasonal restrictions on activity near nest sites. Long-term declines in fecundity can occur in response to habitat conversion (Steenhof et al. 1997) or chronic disturbance (Steenhof et al. 2014), while inter-annual changes track climatic variation (Wiens et al. 2018), fluctuations in prey abundance (Preston et al. 2017a), and short-term disturbance (Spaul and Heath 2016). Fecundity of golden eagles in the WYUB has been documented by seven studies spanning 1976–2017 (Table 2.5). Fecundity varied widely among years, but was broadly similar to other regions. Although no long-term trends in fecundity were apparent, most studies were short-term and not designed to detect trends.

Territory occupancy

Recent studies have used methods to estimate occupancy probabilities that account for imperfect detection, while older studies calculated occupancy as the percentage of occupied territories. One study estimated detection-adjusted occupancy probabilities for golden eagle breeding territories in the WYUB: Wallace (2014) reported mean annual occupancy probabilities of 0.69 in 2012 and 0.80 in 2013 that ranged from 0.28–0.99 as a function of nest height for 57 golden eagle territories in Wyoming. Preston et al. (2017b) reported a similar un-adjusted occupancy rate of 0.86 (range: 0.71–0.92) for an average of 45 territories in the Bighorn Basin during 2009–2017. Occupancy from studies in the WYUB was slightly lower than rates reported in long-term studies from other regions, including 0.87 in Denali National Park, Alaska (range: 0.80–0.94; McIntyre and Schmidt 2012), and 0.90 in Idaho (range: 0.83–1.00; calculated from Table 1 in (Steenhof et al. 1997)). Care should be taken in comparing occupancy rates due to differences in methods and sizes of study areas.

Breeding success

Breeding success of golden eagles in the WYUB (Table 2.5), defined as the percentage of occupied territories that raised ≥1 young to fledgling age (Steenhof and Newton 2007), ranged from an average of 57.9% (range: 32%–88%) in the Bighorn Basin during 2009–2017 (Preston et al. 2017b) to 88% near Medicine Bow, Wyoming during 1981–1982 (MacLaren 1986). Young et al. (2010) documented a decline in breeding success in southern Wyoming over 32 years from 76.5% in 1976, to 56% during 1997–2000, and 44% in 2009. While the results of Young et al. (2010) suggest a decline from the mid-1970s to the 2000s, a study conducted nearby in the Laramie Basin in 1975 reported nest success of only 50% (Schmalzried 1976). Long-term studies from other regions also documented wide annual and regional variation in breeding success, including 32–80% over 23 years in Idaho (mean: 60%; Steenhof et al. 1997) and 42–82% over 10 years in Alaska (mean: 71%; McIntyre and Schmidt 2012).

Reproductive rates

Reproductive rates of raptors are commonly expressed as the number of young reaching fledging age per occupied nest or successful nest (Steenhof and Newton 2007). Productivity of golden eagles nesting in the WYUB was broadly comparable to other regions. An average of 0.85 young per occupied nest (range of means: 0.51–1.20) reached fledging age from five studies spanning 40 years (Table 2.5). This was similar to the average of 0.83 young per occupied nest (range of means: 0.66–1.08) from five long-term studies across the Western U.S. summarized by Kochert et al. (2002) and higher than the average of 0.55 young per occupied nest (SE: 0.087) from 12 studies included in a meta-analysis by USFWS (U.S. Fish and Wildlife Service 2016). An average of 1.41 young per successful nest reached fledging age from three studies in the WYUB (Table 2.5), which was intermediate between averages for populations in northern (1.38 fledglings/successful pair) and temperate latitudes (1.56 fledglings/successful pair) summarized by Kochert et al. (2002).

Breeding phenology

Three studies documented breeding phenology of golden eagles in the WYUB. In the Laramie Basin, Schmalzried (1976) reported egg laying between March 23 and April 4, hatching from May 2 to May 31 and fledging from July 15 to August 7. In southcentral Wyoming, Millsap (1978) documented an earlier phenology, with laying from March 11 to April 4, hatching from April 7 to May 18, and fledging from June 12 to July 11. In the Bighorn Basin, Preston et al. (2017b) reported hatching between April 25 and May 2, and fledging between June 10 and August 2. Nesting stages in the WYUB averaged slightly later than other studies in lower-48 states, yet considerably earlier than Alaska and Canada (Kochert et al. 2002). Although many monitoring activities have the potential to yield data on nesting phenology, this information is rarely summarized in reports and publications. Given the value of these data to inform seasonal stipulations for nest protection and track potential effects of climate change on breeding phenology, we encourage investigators to record and report them.

Table 2.4. Nesting phenology of golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area. Shown are source, and date ranges of nesting stages.

Author (Date)	**Nesting Stage**		
	Egg Laying	**Hatching**	**Fledging**
Preston et al. (2017b)	–	April 25–May 2	June 10–August 2
Millsap et al. (1978)	March 11–April 4	April 7–May 18	June 12–July 11
Schmalzried (1976)	March 23–April 4	May 2–May 31	July 15–August 7
Average	March 26	May 4	July 9

Table 2.5. Fecundity of golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area. Shown are source, study location, study area size, years of data collection, average number of territories monitored, and fecundity parameters. Breeding success was defined as percentage of occupied territories that raised ≥1 young to fledging age, and productivity was defined as number of young known to have fledged or reached fledging age per occupied nest.

Study					Success	Productivity	
Source	**Location**	**Size (km^2)**	**Years**	**Territories monitored**	**Per occupied nest**	**Per occupied nest**	**Per successful attempt**
Preston (2017b)	Bighorn Basin, WY	2,500	2009–2017	45	58%	0.84	1.43
Wallace (2014)	Ferruginous hawk range in Wyoming	114,217	2012–2013	57	69%, 80%	–	–
Oakleaf (1978) in Young et al. (2010)	Medicine Bow, WY	3,215	1978	Unknown	76%	0.90	–
Young et al. (2010)	Medicine Bow, WY	3,215	1997–1999, 2009	25.5	60%	0.78	1.38
MacLaren (1986)	Medicine Bow, WY	712	1981–1982	21	88%	1.20	1.35
Millsap (1978)	Southern WY	2,740	1978	46	–	–	1.50
Schmalzried (1976)	Laramie Basin, WY	4,999	1975	14[a]	50%	0.51	–

[a] Sample included n = 6 nests in the Southern Rockies Ecoregion.

2.1.6. Breeding season diet

Breeding performance of golden eagles is influenced by abundance and availability of food, including live-captured prey and carrion (see Prey resource limitation). While the WYUB hosts a diverse prey community, dietary studies suggested golden eagles breeding in the region relied on a small number of primary prey species and had a slightly narrower dietary breadth compared to other regions of the western U.S. (Bedrosian et al. 2017). Breeding season diet of golden eagles in the WYUB has been documented by five studies spanning 1943–2015. All studies analyzed nest contents to quantify frequency of prey groups, two studies estimated biomass of prey (MacLaren et al. 1988, Preston et al. 2017a), and two studies measured relative abundance of prey species (Schmalzried 1976, Preston et al. 2017a).

Diet of breeding golden eagles in the WYUB was composed primarily of cottontails (*Sylvilagus* spp.) and jackrabbits (*Lepus* spp.) of the family Leporidae (hereafter leporids; Table 2.6). Although one study found greater combined frequency of ground squirrels (*Urocitellus* spp.) and prairie dogs (*Cynomys* spp.) of the family Sciuridae (hereafter sciurids), leporids still made up the majority of biomass (MacLaren et al. 1988). These results are consistent with evidence for the predominance of leporid prey in the diet of golden eagles across their range (Bedrosian et al. 2017). Within the category of leporids, there was variation in importance among groups: two studies documented diets consisting primarily of cottontails (Arnold 1954, Preston et al. 2017a), one documented mostly jackrabbits (Schmalzried 1976), and another found slightly fewer jackrabbits than cottontails (Millsap 1978). The second most frequent prey items recorded in each study included other leporid species, sciurids, various birds, and sage-grouse; the third most frequent prey items were pronghorn fawns (*Antilocapra americana*), various birds, sciurids, waterfowl, and unidentified species (Table 2.6). The opportunistic nature of predation and scavenging by golden eagles was evident in the wide range of species that appeared infrequently in their diets, including other rodents (thirteen-lined ground squirrel, *Ictidomys tridecemlineatus*; yellow-bellied marmot, *Marmota flaviventris*; beaver, *Castor canadensis*; woodrat, *Neotoma* sp.; pocket gopher, *Thomomys* sp.; sagebrush vole, *Lagurus curtatus*), carnivores (coyote, *Canis latrans*; fox, *Vulpes* sp.; long-tailed weasel, *Mustela frenata*; badger, *Taxidea taxus*; striped skunk, *Mephitus mephitis*; raccoon, *Procyon lotor*), adult and neonatal pronghorn and mule deer (*Odocoileus hemionus*), domestic sheep and bovids, birds (passerines, waterfowl, corvids, and raptors), reptiles, and fish. Although golden eagles consumed diverse species, both studies that conducted prey surveys found golden eagles selected leporids disproportionately to their relative abundance (Schmalzried 1976, Preston et al. 2017a). Studies across the range of the golden eagle have documented a similar pattern, in which animals from a broad range of taxa are consumed opportunistically, but diets are composed primarily of locally abundant medium-sized prey (i.e., leporids; Bedrosian et al. 2017).

Average dietary breadth in the WYUB (mean: 3.66, range: 1.91–4.63, SD: 1.09) was slightly lower than elsewhere in the western U.S. (mean: 4.09, range: 1.36–12.27, SD: 2.41). The narrowest dietary breadth in the WYUB (1.91) occurred in the northwestern portion of

Bighorn Basin, where diet of golden eagles was composed primarily of cottontails (Preston et al. 2017a). This study was conducted during a cyclic low in jackrabbit populations, and availability of sciurids may also have been limited because white-tailed prairie dog populations had declined from historical levels and Wyoming ground squirrels do not occur in the study area (Preston et al. 2017a; Harrell and Marks 2009). Other differences in breadth and composition of golden eagle diet among studies likely resulted from a similar combination of temporal variation in prey abundance and spatial variation in prey occurrence.

Sample sizes of prey remains and nests were limited in all studies, as were sizes of study areas and coverage of the WYUB. The most intensive studies were conducted in the Bighorn and Laramie Basins, areas unique enough within the Wyoming Basin to be defined as separate level-IV ecoregions (Chapman et al. 2004), with few or no samples from the Green River, Wind River, Bear River, Great Divide, or Powder River Basins. Available studies may have underestimated the importance of smaller prey species (e.g., sciurids and smaller birds) because analysis of nest contents and pellets are biased toward the bones of larger prey (Simmons et al. 1991, Marti 2007). Additionally, biomass of prey is a more realistic measure of diet composition than prey frequency and should be used when possible. Future studies in under-represented areas of the WYUB using unbiased methods such as field observations and remote cameras to measure biomass of prey could improve understanding of golden eagle diet in the region. Studies should also link diet composition to abundance of prey species, habitat composition within territories, and breeding success.

Table 2.6. Results from studies of golden eagle diet in the Wyoming and Uinta Basins Conservation Strategy Area. Shown for each study is frequency (%) of prey groups, with number of individual prey items in parentheses, total prey items, and dietary breadth.

Prey group	**Sub-group or species**	**Study**				
		Preston (2017b)	**MacLaren (1988)**	**Millsap (1978)**	**Schmalzried (1976)**	**Arnold (1954)**
Leporids	All Leporidae	80% (1127)	39.5% (221)	70.7% (41)	46.9% (60)	57.5% (69)
	Jackrabbit (*Lepus* spp.)	7% (103)	–	24.1% (14)	42.2% (54)	20.0% (24)
	Cottontail (*Sylvilagus* spp.)	73% (1024)	–	46.6% (27)	4.7% (6)	37.5% (45)
Sciurids	All Sciuridae	3%				
	Urocitellus spp. ground squirrel		18.2% (102)	12.1% (7)	21.9% (28)	9.2% (11)
	White-tailed prairie dog (*Cynomys leucurus*)		27.3% (153)	10.3% (6)	0.8% (1)	0
Pronghorn	Pronghorn (*Antilocapra americana*)	4% (51)				
Other mammals	Other mammals	6% (82)	6.1% (34)	0	7.0% (9)	5.0% (6)
Birds	All birds	9% (127)				
	Greater Sage-grouse (*Centrocercus urophasianus)*		0	3.4% (2)	6.3% (8)	17.5% (21)
	Waterfowl (Anseriformes)		0	1.7% (1)	15.6% (20)	0.8% (1)
	Other birds		8.6% (48)	0	1.6% (2)	0
Other	Other / unidentified	1% (17 snakes)	0.4% (2)	1.7% (1)	0	10.0% (12)
Total		1404	560	58	128	120
Dietary Breadth [a]		1.91[c]	4.63 [b]	3.31	4.10	4.33

[a] Dietary breadth (B) calculated using Levin's formula: $B = 1/\sum p_i^2$, where p_i is the frequency of each prey species' occurrence among nest remains.
[b] From MacLaren et al. (1988).
[c] From Preston et al. (2017a).

2.1.7. Prey community

The WYUB is characterized by broad expanses of sagebrush steppe habitat. Not surprisingly, the major prey species of golden eagles in this region are all associated with a mix of shrub and grassland vegetation in moderately sloping terrain (APPENDIX: Prey Group Summaries). Jackrabbits and cottontails, the primary prey of golden eagles, depend on shrubs for hiding cover and forage (Chapman and Willmer 1978, Simes et al. 2015). Although jackrabbits occur in areas with higher percent cover of sagebrush than cottontails, both species are broadly associated with large amounts of native shrub habitat (Hanser et al. 2011). Wyoming ground squirrels occur in areas with lower percent cover of sagebrush than leporids (Johnson et al. 1996) and white-tailed prairie dogs are associated with even sparser shrub cover and more bare ground (Keinath 2004). Among alternate prey species, sage-grouse, occur in areas with moderate sagebrush cover (15–25% breeding, 10–30% winter; Connelly et al. 2000), while pronghorn fawns use areas with slightly less cover (~14%; Alldredge et al. 1991). Waterfowl are the only prey group not directly associated with shrub-steppe habitat.

Leporids, ground squirrels, sage-grouse, and pronghorn are distributed relatively evenly across the region, whereas prairie dogs and waterfowl occur in clusters. Prominence of leporids as prey may be due in part to the evenness of their distribution across suitable golden eagle breeding habitat. Similarly, importance of spatially clustered prey, like prairie dogs may be limited during the breeding season when golden eagles are restricted to central-place foraging from nest sites. However, in territories where they occur, clustered species may compose the majority of diet for golden eagles (e.g., black-tailed prairie dogs; Phillips and Beske 1990). Species with limited distributions in the region (e.g., black-tailed jackrabbit, black-tailed prairie dog, Uinta ground squirrel) are complemented by more widely distributed species in the same genus (e.g., white-tailed jackrabbit, white-tailed prairie dog, Wyoming ground squirrel). Other notable patterns in prey distribution include the absence of Wyoming ground squirrels from the Bighorn Basin (Keinath et al. 2010a) and the largest known colony complex of white-tailed prairie dogs in the Shirley Basin of Wyoming (Seglund et al. 2004).

Abundance of prey varies dynamically among years and seasons. Fluctuations are cyclical for cottontails (Fedy and Doherty 2011), and likely jackrabbits (Steenhof et al. 1997, Bartel et al. 2008, Hansen et al. 2017), while present-day abundance of prairie dogs, ground squirrels, and sage-grouse likely reflect substantial declines from historical levels (Johnson et al. 1996, Connelly et al. 2004, Keinath 2004). Seasonal variation in abundance and activity of prey species also affects their availability to golden eagles: leporids are active year-round (Lim 1987, Hansen and Bedrosian 2017), while most sciurids estivate during late-summer, hibernate during winter, and reach peak activity and abundance in mid-summer (Clark 1970;1973). The peak in activity of sciurids corresponds to the brooding and post-fledging periods of golden eagles and these species may, thus, be an important food source for nestlings and fledglings. Similarly, availability of pronghorn fawns beginning late in May corresponds with the brooding period (Preston et al. 2017a). The role of sciurids in golden eagle diet is further complicated by anthropogenic threats: prairie dog colonies experience dramatic fluctuations in abundance and occupancy from plague (*Yersinia pestis*), and abundance of prairie dogs and ground squirrels may be locally limited by control as agricultural pests and sport shooting (Seglund et al. 2004). These anthropogenic threats have likely reduced abundance and fragmented distributions of sciurids, thereby diminishing their reliability as a buffer for breeding season diet of golden eagles during cyclic declines in leporid abundance. Waterfowl also have a naturally patchy distribution that has likely been altered by human activities. The hydrology of the WYUB has been modified by damming, grazing, and mining, resulting in both loss and creation of water bodies (Knight et al. 2014); however, the effects of these activities on historical distribution and abundance of waterfowl are not well understood. In addition to waterfowl, sage-grouse and pronghorn are more abundant near water sources in the late summer and early fall, and cottontails are associated with riparian areas and intermittent water sources. Management to conserve and enhance water resources in sagebrush steppe ecosystems may provide benefits to golden eagles and their prey.

Prey populations in the WYUB could be negatively affected by threats that transform large areas of native shrubland and grassland habitat, like wildfire, invasion of exotic plant species, sustained intensive livestock grazing, and agricultural tillage. Catastrophic wildfire has affected only a limited portion of the WYUB compared to neighboring regions; however, risk of wildfire is expected to increase as the continued spread of invasive annual grasses is facilitated by climate change (Bradley 2009). In addition to direct habitat loss, habitat fragmentation and disturbance from anthropogenic development (e.g., energy development, exurban expansion, mining) and associated infrastructure (e.g., roads, power lines) can negatively affect some prey species (see Prey Group Summaries). Evidence from neighboring regions suggests golden eagles breeding in sagebrush habitats can shift their diets when abundance of primary prey declines (Steenhof and Kochert 1988, Heath and Kochert 2015, Watson and Davies 2015). Although widespread population declines of primary prey have not yet occurred in the WYUB, golden eagle territories with a mix of habitats supporting a diverse prey community are expected to be most resilient to future disturbance. Sources of heterogeneity in shrub-steppe breeding habitat of golden eagles could include a mix of shrub and grassland vegetation, smooth and rough terrain, sciurid colonies, and water features.

2.2. Movements and migration

Golden eagles are a highly mobile species with a complex life-history and population structure (Watson 2010). Movement behavior of eagles varies among age-classes and seasons, with some individuals remaining in a relatively localized area year-round and others ranging widely (Kochert et al. 2002). In this section, we summarize the limited information available on directed, long-distance movements of golden eagles in the WYUB, as distinct from the localized space-use patterns of territorial adults. Golden eagles engage in long-distance, directed movements during various life-stages and seasons, beginning with 1st-year dispersal of fledglings from natal territories (McIntyre et al. 2008, Murphy et al. 2017). After initial dispersal, pre-breeding eagles may range widely across the continent until they reach sexual maturity at 4 or 5 years of age (Soutullo et al. 2008). After establishing a breeding territory, adult eagles continue to make directed movements within territories, which increase in size during the non-breeding season (Domenech et al. 2015). Adult eagles from other regions migrate into the WYUB during the non-breeding season, including long-distance migrants from Alaska and Northern Canada and short-distance migrants from other parts of the western U.S. (Bedrosian et al. 2018a). Some migrants settle in the WYUB during the non-breeding season, while others simply pass through during spring and fall (McIntyre et al. 2008). Pre-breeding eagles from the WYUB and other regions move within and through the region while prospecting for territories and settling (Steenhof et al. 1984). Additionally, non-territorial adults, or “floaters”, comprise a poorly understood segment of the population with the potential to move between regions (Hunt 1998, Caro et al. 2011).

Despite being recognized as a continentally important area for golden eagles, very little information is currently available on movements of golden eagles in the WYUB. Recent efforts to study golden eagles using satellite telemetry will provide much needed insights into patterns of movement and migration in the WYUB; however, only preliminary analyses by WGET and other researchers (Mike Lockhart, Wildlands Photography and Bio-Consulting, personal communication) were available at the time of publication. Please see future revisions of this report for information, including migration risk assesments. Available data on movement and migration of golden eagles in the region come from band recoveries, counts at migration observation sites, and a small number of studies using satellite telemetry, including preliminary results of WGET migration models.

2.2.1. Movements of locally produced young

No data were available on movements of locally produced young in the WYUB. Analyses of band recovery data from across the U.S. suggested median natal dispersal distances of 46 km, with 80% of golden eagles dispersing <100 km from their natal territory (Millsap et al. 2014). Estimates from satellite telemetry of golden eagles in the Southwestern U.S. found differences by sex, with shorter average natal dispersal distances of 41.2 km for males compared to 63.8 km for females (Murphy et al. 2018). While successful long-distance dispersal events are known to occur, most pre-breeding-age golden eagles in the Colorado Plateau and Southern Rocky Mountains stayed within 120 km of their natal nest sites, and those attempting longer-distance dispersal had significantly lower survival rates (Murphy et al. 2017). These results suggest young produced in the WYUB are likely to settle in the region or neighboring regions. Studies to address the lack of knowledge on dispersal patterns and survival of juvenile and sub-adult golden eagles from the WYUB should be a research priority.

2.2.2. Movements of territorial adults

Few data were available on directed, long-distance movements of territorial adults in the WYUB. A migration study that included one golden eagle from southeastern Wyoming described a migration corridor extending northward from the Greater Yellowstone Ecosystem (see Movement into the region from elsewhere).

2.2.3. Movement into the region from elsewhere

Several studies documented movement of juveniles into the WYUB from other areas: a nestling banded in southern Idaho was recovered in southwestern Wyoming (Steenhof et al. 1984), two nestlings banded in Denali National Park, Alaska, migrated to the WYUB to winter in the Big Horn Basin and Wind River/Hanna Basin areas, and another Alaska juvenile that wintered in southcentral New Mexico passed through the WYUB on fall and spring migrations (McIntyre et al. 2008).

Counts from a migration observation site operated by HawkWatch International (HWI) on Commissary Ridge, near Kemmerer, Wyoming, documented an average of 253 golden eagles annually from 2002–2015 (Oleyar 2017). Among 8 count sites operated by HWI, Commissary Ridge had the second highest total golden eagle count in 2015 and 2016, and third highest in 2014 (Hawks and Oleyar 2015, Oleyar 2016;2017).

Bedrosian et al. (2018b) evaluated overlap of migration tracks from golden eagles (n = 66) captured in Alaska, Montana, the Four Corners region, and one eagle from southeastern Wyoming. Although the relevance of their study to the WYUB is limited because most migration routes did not extend south of the Greater Yellowstone Ecosystem, they identified a high-use Fall migration corridor in the Bighorn Basin on the eastern edge of Yellowstone National Park that extended down the Wind River Range, before dispersing in the low-lying terrain of the Green River and Great Divide Basins. No concentration areas occurred in the WYUB during spring. Notably, no eagles in their sample passed east of the Bighorn Mountains or Laramie Range, suggesting the Fall season migratory corridor that extended down the Rocky Mountain Front in Montana connected through the interior basins of the WYUB via Yellowstone and the Wind River Range, rather than following the eastern front of the Rocky Mountains in Wyoming (Bedrosian et al. 2018a). Fall migration habitat models for all raptors in the state of Wyoming developed by the Wyoming Natural Diversity Database (WYNDD) and The Nature Conservancy (TNC; Pocewicz et al. 2013) showed a similar pattern: migration habitat was concentrated west of the Bighorn Mountains and Laramie Range in the isolated mountain ranges and basins of the WYUB. These results suggest golden eagles and other raptors migrating down the Rocky Mountains are more likely to pass through the WYUB, including low-elevation areas of the Green River and Great Divide Basins, than the Great Plains.

2.2.4. Migration models

WGET developed models of spring and fall migration using satellite telemetry data from long-distance migrant eagles (Jessi Brown, unpublished data). Future versions of this document will include more detailed information and risk assessments using these models, but only preliminary drafts were available at the time of publication. Separate seasonal models suggested that eagles used different habitat for migration during spring (Figure 2.9) and fall (Figure 2.10). The fall model was broadly consistent with previous efforts to model migration habitat in the region during that season (Pocewicz et al. 2013, Bedrosian et al. 2018b). It suggested fall migrants followed the eastern portion of the Greater Yellowstone region to the Wind River Range before dispersing into the central basins, and used the western mountains of the Greater Yellowstone region more than the eastern front range formed by the Bighorn and Laramie ranges. Overall use of the WYUB was higher in fall than spring. During spring, density was higher outside the WYUB in Utah's Wasatch Range and the western portion of the Greater Yellowstone region. Further evaluation and integration of these models into risk assessments will be valuable to identify how migration paths overlap potential hazards, like wind energy development.

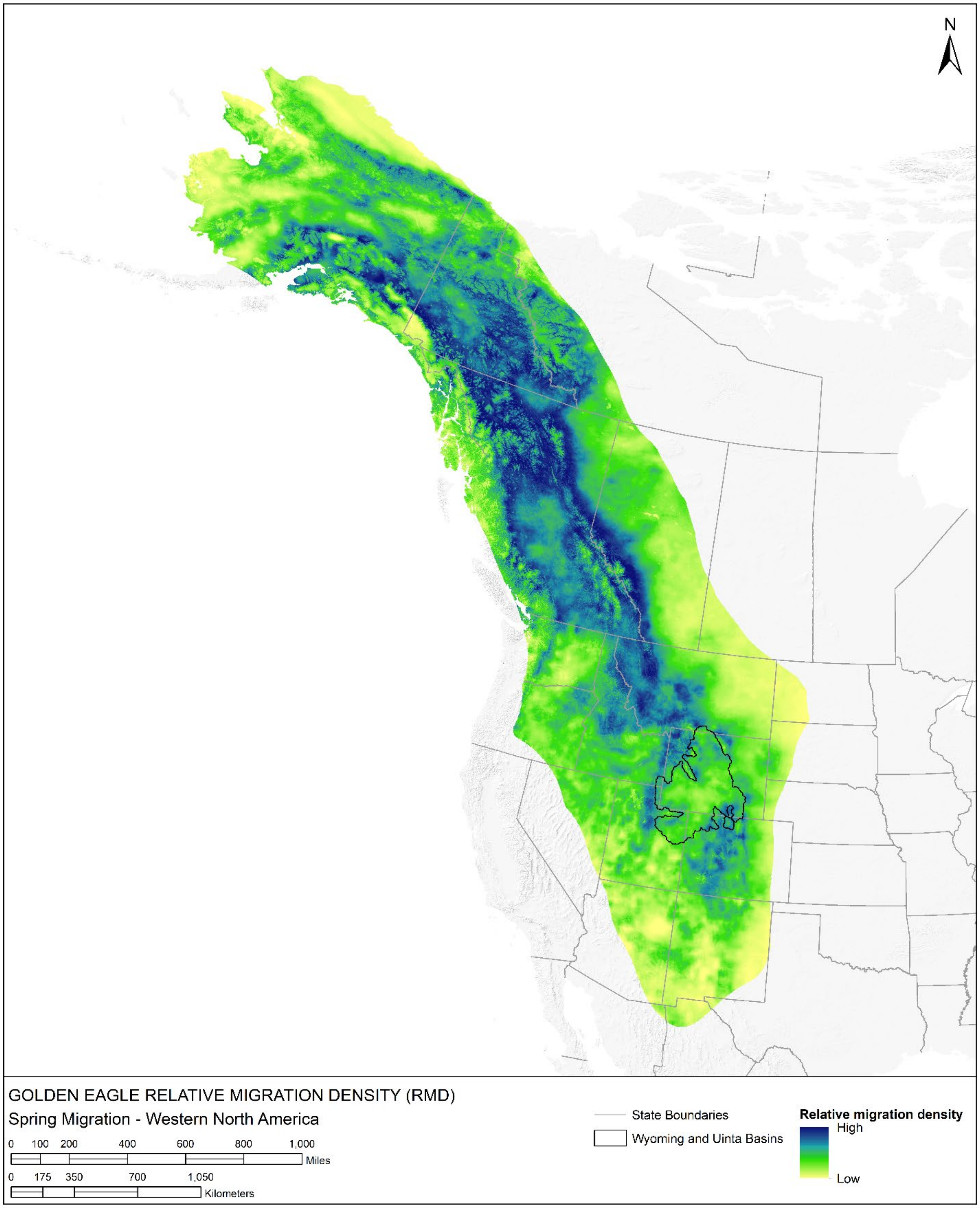

Figure 2.9. Predicted relative density of migrating golden eagles during spring in Western North America, including the Wyoming and Uinta Basins Conservation Strategy Area.

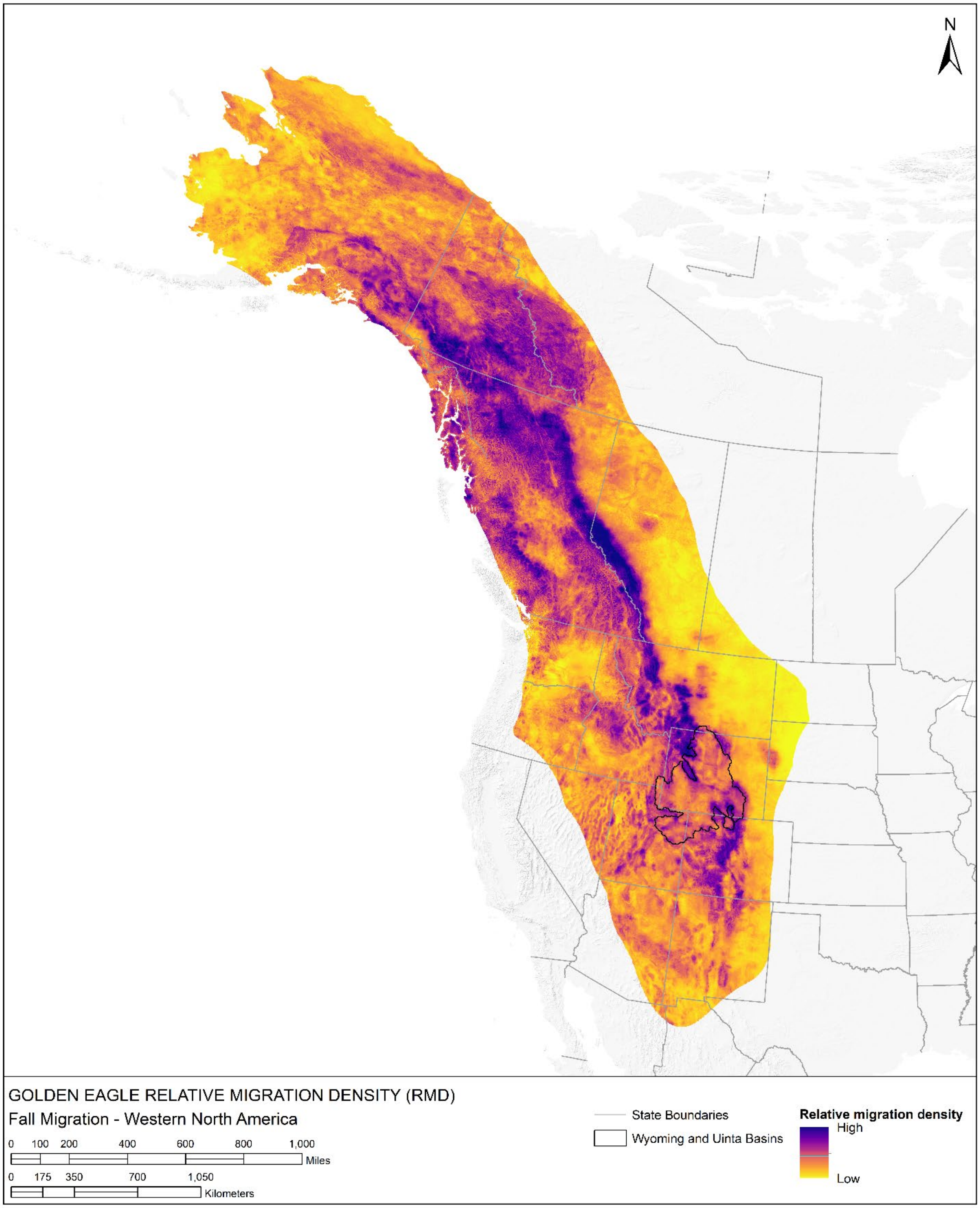

Figure 2.10. Predicted relative density of migrating golden eagles during fall in Western North America, including the Wyoming and Uinta Basins Conservation Strategy Area.

2.3. Winter ecology and distribution

Most studies of golden eagles in the WYUB have focused on adults during the breeding season, while a smaller number have investigated winter-season abundance, diet, and space use. The winter season for migrant golden eagles is defined as the period of relatively localized movement between the directed movements of fall and spring migration (Kochert et al. 2002). For resident eagles, the winter season is not distinct from the non-breeding season, which is defined as the period of increased home-range size following the post-fledging dependency period and before courtship begins for the next breeding season. In the western U.S., migration occurs from mid-September through late-November (McIntyre et al. 2008), while the non-breeding season begins as early as mid-August and may end by early January.

The non-breeding/winter season for golden eagles in the WYUB is characterized by an increase in population size with the arrival of southern migrants, greater use of lower elevation areas when mountains are covered in snow, and a shift in diet to include more ungulate carrion. A large-scale analysis of movement data confirmed two distinct population segments of eagles in the region: the sedentary population in the combined area of the Northern Rockies and Badlands and Prairies BCRs and the migratory population that moves from Alaska to the Northern Rockies during winter (Brown et al. 2017). The population of golden eagles wintering in the WYUB is a combination of resident adults, juveniles dispersed from territories in the WYUB and neighboring regions, short-distance altitudinal migrants that move downslope from adjacent mountainous regions, and long-distance southern migrants and dispersing juveniles from populations in Alaska and northern Canada (McIntyre et al. 2008). Resident breeders show fidelity to wintering areas (Kochert et al. 2002), although home ranges are larger and more variable than during the breeding season (Domenech et al. 2015). Little is known about winter-season space use and habitat selection for other population segments, including southern migrants, dispersing juveniles, sub-adults, and floaters.

Research on golden eagles during winter presents challenges: resident adults range more widely and are less easily distinguished by association with nest sites, diet studies are more difficult without the ability to focus on prey delivered to nests, and the addition of migrants increases the complexity of the population. A detailed understanding of the winter ecology of golden eagles in the WYUB will require further study of population structure, as well as diet, movement, and habitat use among eagles of different age-classes and migration strategies. Winter is a season when a continental perspective on eagle ecology and conservation is imperative because management in the WYUB has implications for breeding populations of golden eagles from distant regions.

2.3.1. Abundance and density

Abundance of golden eagles in the WYUB is expected to increase during winter due to an influx of southern migrants from Alaska and northern Canada, and altitudinal migrants from neighboring regions. Estimates of winter-season golden eagle density specific to the WYUB were not available to test this assumption; instead, systematic surveys were conducted in larger areas, including the state of Wyoming, BCR 10, and BCR 16 (Table 2.7). Higby (1975) conducted extensive aerial transect surveys during January of 1972–1973 in a 78,000-km² area of Wyoming that excluded major mountain ranges and covered the extent of the WYUB in the state, as well as portions of the Northwestern Great Plains and High Plains Ecoregions. Results from this survey were used to estimate abundance of 11,069 golden eagles of all age-classes in 1972 and 9,046 (95% CI: ±1,448) in 1973 (Wrakestraw 1973), which translate to densities of 1.42 eagles/100 km² in 1972 and 1.16 eagles/100 km² in 1973. Forty years later in 2014, the WGES survey (described above) was conducted during mid-winter, resulting in similar estimates within the extent of BCR 10 in the U.S.: density of 1.34 eagles/100 km² (90% CI: 0.84–1.96) and abundance of 6,689 eagles (90% CI: 4,178–9,821; Nielson and McManus 2014). Estimates were lower in BCR 16, which includes the Uinta Basin: density of 1.00 eagles/100 km² (90% CI: 0.62–1.49) and abundance of 4,734 eagles (90% CI: 2,932–7,012). Consistent with an influx of southern migrants, golden eagle density during winter 2014 was greater than summer 2013 in all regions surveyed (BCR 9, BCR 16, BCR 17), except BCR 10, where winter density was 21% lower (Nielson and McManus 2014). The implications of these results for seasonal changes in population size in the WYUB are unclear, however, because BCR 10 outside the Wyoming Basin includes extensive mountainous and forested habitats where density of golden eagles likely decreases during winter.

Smaller-scale surveys have documented local wintering concentrations of golden eagles in parts of the WYUB. Winter season surveys of golden eagles in Moffat County, Colorado were initiated in response to an observed increase in the number of wintering eagles during the mid-1980s. Road-based surveys from 1988–1996 documented 0.23 eagles/km (mean: 30 eagles/yr, range: 20–45), which was greater than densities from road-based surveys in most other regions (Beaver and Roth 1997). Moffat County is known to be part of a wintering concentration area for golden eagles (Liza Rossi, Colorado Park and Wildlife, personal communication) that extends into the Utah portion of the Uinta Basin, where injury or mortality of >10 golden eagles per winter from vehicle collisions along highway 40 is common (Brian Maxfield, Utah Division of Wildlife Resources, personal communication). Similarly, Idaho Fish and Game identified the Bear River Valley as an important wintering area, where mortality from vehicle collisions is an issue for golden eagles feeding on road-killed mule deer and elk (*Cervus canadensis*) along highway 30 (Idaho Department of Fish and Game 2017). Annual one-day surveys conducted during mid-winter 2015–2017 on the Wind River Indian Reservation documented 3–5 golden eagles per year (Art Lawson, Wind River Tribal Game and Fish Department, personal communication).

Table 2.7. Winter-season abundance and density of golden eagles from studies including portions of the Wyoming and Uinta Basins Conservation Strategy Area. Shown are study area name and size, year, estimated abundance and density, and source.

Area	Size (km^2)	Year	Abundance	Density (100 km^2)	Source
Wyoming	78,000	1972	11,069	1.42	Wrakestraw (1973)
Wyoming	78,000	1973	9,046	1.16	Wrakestraw (1973)
BCR 10 (in U.S.)	499,984	2014	6,689	1.34	Nielson and McManus (2014)
BCR 16	471,584	2014	4,734	1.00	Nielson and McManus (2014)

2.3.2. Habitat use

At a broad scale, golden eagles use similar habitat during the breeding and non-breeding seasons (Nielson and McManus 2014). In the WYUB, golden eagles likely shift their distribution downward in elevation, as deep snow covers isolated mountain ranges within the region and surrounding mountain foothills. The extent to which the winter distribution of golden eagles shifts in response to availability of ungulate carrion along roads is unknown. However, it is widely presumed that this and other food resources play a greater role in determining local and regional distributions during winter when prey are scarce and golden eagles are less strongly tied to breeding territories (Kochert et al. 2002, Idaho Department of Fish and Game 2017).

2.3.3. Winter-season habitat use model

To characterize the distribution of golden eagles during winter, WGET developed a model of relative winter density (RWD) based on location data from golden eagles tracked with GPS telemetry (Jessi Brown and David Laplante, unpublished data). The model related golden eagle telemetry locations to environmental variables to predict relative probability of use in 3-km^2 cells across most of the western U.S. during December–February. Training data from 556 eagles were filtered to include 42,265 locations classified as sedentary and remove directed long-distance movements. Candidate predictor variables included 240 indexes representing variation in vegetation, landcover, topography, wind and uplift, and climate. These base variables were summarized at 5 spatial scales from 3 km to 20 km by mean and standard deviation, where appropriate.

Predictions from this model provide a broad-scale characterization of winter-season habitat use by golden eagles that include all age-classes, sexes, breeding statuses, and migration strategies. Results should, thus, be interpreted as the relative probability of use by all golden eagles, rather than any sub-group, and within the context of the of the entire western U.S. Additional analyses are in progress to produce ecoregional models of winter use specific to the WYUB and other conservation strategy areas. Until such models are available, we have used predictions from RWD model for conservation prioritization and risk assessment in the WYUB. Compared the breeding habitat (RND) model, however, predictions from the RWD model must be interpreted in the broader context of golden eagle habitat use in the western U.S. and may be less accurate at the ecoregional scale.

Overall, model results suggested golden eagles wintered in areas of the western U.S. with open, flat terrain broken by elevated features, moderately warm weather, and strong winds. The final model included 15 covariates representing attributes of topography, vegetation, hydrology, climate, and weather (Table 2.8). Predictors representing climate and weather contributed most to the model (48%), followed by topography (28%), and vegetation (24%). Winter use was most strongly related to broad-scale variation in the proportion of open, flat areas (20.6% contribution) and the amount of solar radiation reaching the ground during winter (10.1% contribution). Vegetation and landcover variables related to winter use included gross primary production (8.7% contribution), variation in shrub cover (7.6% contribution), proportion of crop landcover (5.4% contribution), and variation in grass landcover (2.5% contribution). Climate variables related to winter use included the average (8.3% contribution) and variation (4.0% contribution) in the number of degree days >5°C and mean annual precipitation amount (3.0% contribution). Wind-related variables included the average strength of North-South winds (6.2% contribution), variation in the daily thermal energy gradient (6.1% contribution), maximum turbulence (5.7% contribution), and minimum strength of East-West winds (4.8% contribution). In addition to open, flat areas, winter use was influenced by the proportion of U-shaped valleys (5.0% contribution) and topographic wetness (1.8% contribution).

In the WYUB, concentrations of high-use winter habitat were predicted in the Laramie, Saratoga, upper Wind River, lower Green River, and Bighorn Basins, as well as the southern slope of the Uinta Mountains, and the northern Shirley Basin (Figure 2.9). A detailed discussion of the distribution of winter habitat in the WYUB is included below under Winter priority areas, and a comparison of winter and breeding habitat in the Conservation Prioritization section.

Table 2.8. Variables contributing to model of relative winter-season habitat use by golden eagles in the western U.S. Winter was defined as December–February. Shown are variable name, base covariate description, size of neighborhood in which variable was evaluated (scale), focal statistic within neighborhood (mean or standard deviation), and percent contribution to the model. Detailed descriptions of variables and model development are available in (Brown et al. 2018).

Name	Description	Scale	Focal Statistic	% Contribution
Open, flat areas	Variation in proportion of Weiss plains landform 5: open, flat areas	20 km	SD	20.6
Winter solar radiation	Amount of light reaching the ground during the winter	3 km	Mean	10.1
Primary productivity	Gross primary productivity	3 km	Mean	8.7
Degree days >5°C	Number of degree days >5°C	3 km	Mean	8.3
Shrub cover	Variation in shrub cover	5 km	SD	7.6
N-S wind strength	Magnitude of North-South winds 30m above surface	3 km	Mean	6.2
Thermal energy	Variation in daily thermal energy gradient index	3 km	SD	6.1
Turbulence	Turbulent kinetic energy: maximum variable winds	3 km	Mean	5.7
Cropland	Proportion of crop landcover	20 km	Mean	5.4
U-shaped valleys	Proportion of Weiss landform 3: U-shaped valleys	15 km	Mean	5.0
Minimum E-W wind strength	Minimum magnitude of East-West winds 30 m above surface	3 km	Mean	4.8
Degree days >5°C	Variation in number of degree days >5°C	3 km	SD	4.0
Precipitation amount	Annual precipitation	3 km	Mean	3.0
Grass cover	Variation in grass cover	5 km	SD	2.5
Wetness	Variation in topographic wetness index	20 km	SD	1.8

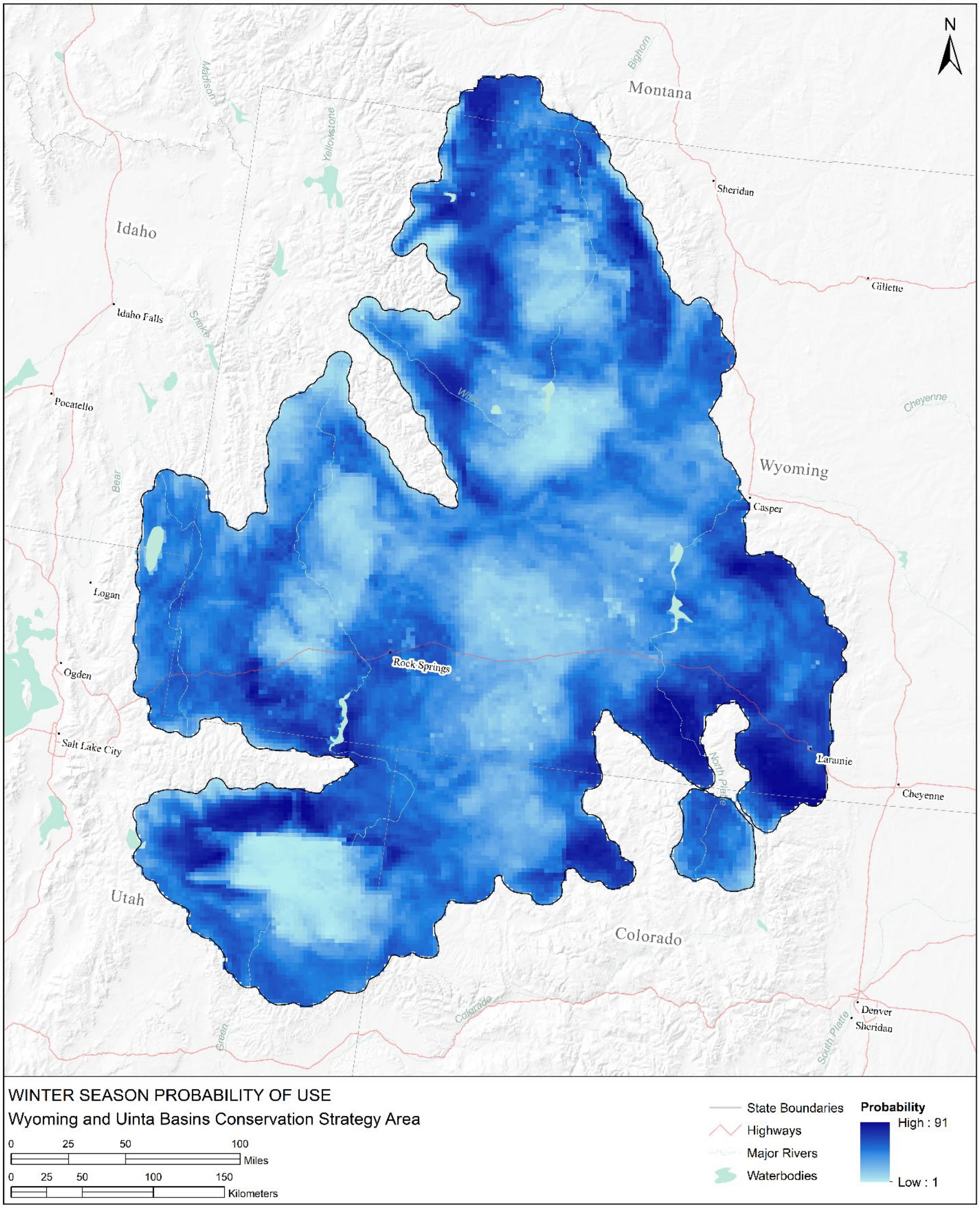

Figure 2.11. Predicted probability of use by golden eagles during winter (December–February) in the Wyoming and Uinta Basins Conservation Strategy Area.

2.3.4. Winter diet and prey communities

Little information is available on the winter-season diet of golden eagles, due in part to the difficulty of observing food habits outside the breeding season (Bedrosian et al. 2017). Developing a better understanding of golden eagle winter-season diet may be important to maintaining populations, because reproductive success in the breeding season is influenced by winter body condition (Newton 2010). Furthermore, an improved understanding of winter diet and foraging ecology could inform efforts to reduce mortality from collisions with motor vehicles while feeding on road-killed carrion, which is a substantial source of mortality for golden eagles during winter (Riginos et al. 2017).

It is generally assumed that the diet of golden eagles shifts in winter from capturing live prey to scavenging carrion, including road- and winter-killed ungulates (Kochert et al. 2002). Evidence for increased exploitation of ungulate prey during winter in the WYUB includes examples of golden eagles feeding on roadkill (Idaho Department of Fish and Game 2017) and occasionally killing live pronghorn (Goodwin 1977, Deblinger and Alldredge 1996, Beckmann and Berger 2005). Pellets collected at winter roosts used by bald eagles (*Haliaeetus leucocephalus*) and golden eagles on Pine Mountain west of Casper, Wyoming were composed mainly of pronghorn antelope hair, and contained hair and bone from other species likely taken as carrion (mule deer and domestic sheep), as well as plant material and soil likely consumed while feeding on carrion (Bagdonas et al. 1985). However, pellets also contained remains of species common to the breeding season diet of golden eagles, like jackrabbits, cottontails, and prairie dogs (Bagdonas et al. 1985). Reliance of golden eagles on carrion may increase during severe winters (Woodgerd 1952, Hayden 1984) and may also be influenced by the composition of the local prey community. For example, black-tailed prairie dogs are available as prey during the winter because they remain active above ground, whereas white-tailed prairie dogs and Wyoming ground squirrels hibernate. Golden eagles in areas with hibernating sciurid species, like the WYUB, may thus rely more heavily on carrion than eagles in areas with non-hibernating sciurids, like the neighboring Northwestern Great Plains Ecoregion.

3. Population Ecology

In this section, we review evidence for trends in the golden eagle population in the WYUB and identify factors with the potential to limit survival and fecundity in the region. Our review is focused on hazards that are caused by humans and have the potential to be addressed through management actions. We describe the mechanisms behind each hazard, provide available evidence of the magnitude of risk in the WYUB, and describe spatial and temporal patterns in risk to support the risk assessments and regional conservation measures presented in the Conservation Strategy section.

3.1. Status and trend

Golden eagle populations in the western U.S. are stable or possibly declining (U.S. Fish and Wildlife Service 2016). Models using data from the North American Breeding Bird Survey (BBS) and the WGES (described above) suggested populations were stable during 1968–2014 (Millsap et al. 2013, U.S. Fish and Wildlife Service 2016), while demographic models project a gradual decline due to human caused mortality (U.S. Fish and Wildlife Service 2016). Although estimates specific to the WYUB are not available, the population trend was stable in the Northern Rockies Bird Conservation Region (BCR 10) that encompasses the Wyoming Basin and the Southern Rockies/Colorado Plateau Bird Conservation Region (BCR 16) that includes the Uinta Basin and North Park (U.S. Fish and Wildlife Service 2016). Initial work by Millsap et al. (2013) provided some evidence for an increasing trend in population size in BCR 10 and a decreasing trend in BCR 16; however, subsequent analyses including data through 2014 suggested populations were stable (U.S. Fish and Wildlife Service 2016). Recent analysis of WGES data by age-class reported stable trends for juvenile eagles in BCR 10 and BCR 16 from 2006–2015 (Nielson et al. 2016a). Although the Wyoming Basin covers only 27% of the area of BCR 10 in the U.S., it represented the largest area of high-intensity use by golden eagles in BCR 10 and the western U.S. (Nielson et al. 2016b). Changes in status of golden eagles in the Wyoming Basin may, therefore, have disproportionate impacts on population trends for this species across BCR 10 and adjacent regions. Fall migration counts of golden eagles conducted at Commissary Ridge, near Kemmerer, Wyoming, by Hawkwatch International showed no apparent trend in passage rates of golden eagles during 2002–2016 (Oleyar 2017).

The apparent stability of the population of golden eagles in the western U.S. over the past 45 years has still allowed for trends in abundance and other demographic rates over shorter time periods and at smaller scales. For example, regional declines have been reported in productivity in north-central Utah, and in the number occupied nesting territories in southwestern Idaho, northeastern Colorado, and Southern California (Kochert et al. 2002). In the WYUB, two studies reported declines in the number of occupied nests: Young et al. (2010) documented a decline in occupied nesting territories within a 3,215-km^2 study area near Medicine Bow, Wyoming from 50 in 1978, to an average of 28.5 from 1997–2000, and 27 in 2009. Oakleaf et al. (2014) resurveyed 96 historical golden eagle territories in 2009 within a larger area overlapping the study area of Young et al. (2010) and found only 25 occupied sites. Although these studies were pre- and post-construction surveys of a wind farm, the decline in territory occupancy occurred before construction of the wind farm and the authors speculated it was related to low leporid abundance (Oakleaf et al. 2014). Ayers et al. (2009) reported declines in the number of occupied golden eagle nests in a 783-km^2 study area north of Baggs, Wyoming from 16 in 1993, to 0 in 1994, and 3 in 2008. The authors attributed this decline to historically low leporid abundance in the late 2000s, rather than extensive oil and gas field development that occurred within and adjacent to the study area (Oakleaf et al. 2014). While these studies suggest the possibility of local declines in nest occupancy within the WYUB, neither time series is continuous enough to separate long-term trends from inter-annual fluctuations. Moreover, the relatively small size of the study area of Ayers et al. (2009) and the nest-occupancy based approach used in both studies make it difficult to separate local declines from shifts in distribution.

3.2. Population limiting factors – Direct effects on survival

Golden eagles are a long-lived species with low fecundity and delayed sexual maturity (Watson 2010). For golden eagles, like other species with "slow" life histories (Sæther 1987), adult survival is the most critical factor influencing population performance (Tack et al. 2017). Although recent historical trends in the western U.S. appear to have been stable (Millsap et al. 2013), demographic models suggest current levels of human-caused mortality experienced by golden eagles in North America will cause a population decline (U.S. Fish and Wildlife Service 2016). In this section, we review factors known to have direct effects on survival of golden eagles, focusing as much as possible on direct evidence from the WYUB. The factors included in our review are based on sources of mortality identified by USFWS (2016), an expert elicitation conducted by Brown (2014), and our review of literature on potential hazards to golden eagles in the WYUB (Table 3.1).

Table 3.1. Factors affecting survival and fecundity of golden eagles in the WYUB evaluated in this report, with links to spatial risk assessments, and recommended regional conservation measures.

Demographic rate affected	Category	Hazard	Spatial Risk Assessment	Regional Conservation Measures
Survival	Energy Infrastructure	Electrocution	Yes	Yes
		Wind Resource Development	Yes	Yes
		Oil and Gas Development	Yes	Yes
		Mining and Power Generation		Yes
	Collisions	Motor vehicles	Yes	Yes
		Transmission structures		Yes
	Contaminants	Lead	Yes	Yes
		Anticoagulant Rodenticides		Yes
		Others		Yes
	Disease and Parasites	West Nile virus		Yes
		Others		Yes
	Persecution	Direct persecution		Yes
		Poaching		Yes
Fecundity	Prey	Habitat loss from wildfire		Yes
		Habitat loss and modification from energy development	Yes	Yes
	Disturbance	Recreation (OHVs, hikers)		Yes
		Construction		Yes
		Vehicle traffic		Yes

3.2.1. Energy Infrastructure

Due to the low human population density and resource-extraction economy of the WYUB, energy infrastructure makes up the majority of the human footprint in many areas of the region. Renewable and conventional energy development present unique sources of mortality for golden eagles (e.g., collision with wind turbines), while other infrastructure and activities hazardous to golden eagles are common to all forms of energy development (e.g., roads, vehicle traffic, and power lines). This section is focused on energy infrastructure with direct effects on survival of golden eagles, including electrocution, collision with wind turbines and transmission structures, oil and gas development, mining, and power generation. Indirect effects on survival of golden eagles from disturbance associated with energy development are addressed in the Disturbance section.

Electrocution

Electrocution on power infrastructure is among the leading causes of mortality for golden eagles in North America (U.S. Fish and Wildlife Service 2016) and around the world (Lehman et al. 2007). Golden eagles are more vulnerable to electrocution than smaller species because their greater wingspan and body length increase the likelihood of making connections between an exposed energized wire or component and another exposed wire or component of different electric potential (Dwyer et al. 2015). Most electrocutions occur on distribution lines, rather than transmission lines, due to the closer spacing of equipment and greater abundance of distribution poles across the landscape (APLIC 2006). Avoidance and mitigation of avian electrocutions has been the focus of collaboration among government and industry, including the formation of the Avian Power Line Interaction Committee (APLIC; http://www.aplic.org). Compared to other hazards to golden eagles, more research has been dedicated to understanding the magnitude and prevention of electrocution. Retrofitting power poles is, thus, the only currently approved form of compensatory mitigation to offset programmatic take of golden eagles (U.S. Fish and Wildlife Service 2013).

Electrocution of golden eagles was first documented in the WYUB in the 1970s (Boeker and Nickerson 1975, Benson 1982) and has been the focus of subsequent research (e.g., Lehman et al. 2010, Dwyer et al. 2016) and mitigation efforts (e.g., Harness 2000, Slater and Smith 2010, Mojica et al. 2018). Although the magnitude of golden eagle electrocution is difficult to quantify, because most electrocutions are not detected (Harness and Wilson 2001), estimates using data from golden eagles tracked with telemetry suggest 504 individuals (95% CI: 124–1,494) die from electrocution annually in North America (U.S. Fish and Wildlife Service 2016). In Wyoming, electrocution was suspected as the cause for 10 of 73 (14%) golden eagle mortalities processed by Wyoming State Veterinary Laboratory during 1997–2016 (Terry Creekmore, Wyoming Game and Fish Department, personal communication). Although the latter reports are opportunistic, they highlight the fact that electrocution is likely a substantial source of mortality for golden eagles in the WYUB. Several important studies of raptor electrocution have been conducted within the WYUB in and around the Rangely Oil Field in northwestern Colorado: Lehman et al. (2010)

estimated electrocution rates of 0.0036–0.0066 golden eagle deaths/pole/yr in the service area of the Moon Lake Electrical Association in the Uinta Basin during 2001–2003, while Harness (2000) focused on identifying dangerous pole configurations and retrofitting methods. Research in Wyoming suggested electrocution risk was greater for juvenile and sub-adult eagles (Mojica et al. 2018), and influenced by a complex interplay of factors, including habitat and topography, season, prey abundance, pole design, and others (Benson 1982).

Despite widespread retrofitting efforts, dangerous poles persist in the landscape. This is due in part to the vast number of distribution lines, but also because retrofitting is typically done by individual electrical utilities, which leaves some service areas unaddressed. The Wyoming and Uinta Basin are serviced by 26 electric utility providers with service areas ranging from <2 km^2 for small municipal utilities and cooperatives to >70,000 km^2 for large multi-state power companies. Regional coordination across utilities is needed to identify and prioritize retrofitting in areas with the greatest risk (Dwyer et al. 2016). Although mapped locations of distribution poles with configurations dangerous to golden eagles are generally not available, density of poles can be used as a surrogate for electrocution risk (Dwyer et al. 2016). To inform spatial prioritization of retrofitting efforts, WGET and EDM International developed a model of power pole density for the states of Wyoming and Colorado, and demonstrated that it could be overlaid with data on golden eagle habitat to identify areas of elevated risk (Dwyer et al. 2016, EDM International 2017). The model suggested densities of distribution poles were greatest in areas with more roads, more oil and gas wells, and relatively flat terrain (Dwyer et al. 2016). In the WYUB, this included areas around towns, oil and gas fields, and pivot irrigation (Dwyer et al. 2016). In this report, we overlay the pole density model with seasonal models of golden eagle habitat to identify areas of the WYUB where power pole retrofitting could provide maximum conservation benefit (see Electrocution Risk Assessment).

Wind resource development

Collision with turbine blades at wind energy facilities is recognized as a substantial and increasing source of mortality for golden eagles (Smallwood and Thelander 2008, Pagel et al. 2013). Turbine-strike mortality can affect individuals from a broad area around wind energy facilities (Katzner et al. 2017b) and has the potential for population-level impacts to golden eagles (Beston et al. 2016, but see Hunt et al. 2017). As wind resource development increases in North America (Wiser and Bolinger 2016), research to inform effective mitigation (U.S. Fish and Wildlife Service 2016, Allison et al. 2017) has focused on understanding the behavioral and environmental factors that influence exposure of golden eagles to turbine strikes (May 2015, Hunt and Watson 2016), and developing methods to estimate rates of collision (New et al. 2015) and mortality (Huso et al. 2016). Results suggest risk of turbine-strike is influenced by numerous factors that include the location and design of wind energy facilities (Katzner et al. 2012b), height and blade length of turbines (Loss et al. 2015), season (Pagel et al. 2013), and degree of overlap with other resources important to golden eagles, like prey, nest sites, perches, and updrafts (Hunt and Watson 2016).

The state of Wyoming is among the areas of North America with the greatest potential for on-shore wind energy development: Wyoming contains >50% of areas with the highest ranked wind capacity in the continental U.S. (wind power classes 6 and 7), and the southeastern portion of the Wyoming Basin is the largest contiguous area where average annual wind speeds exceed 8.5 m/second (Elliott et al. 1987). By contrast, wind speeds in the Uinta Basin are generally at or below the level required for commercial development with current technology (wind power class <3; Elliott et al. 1987). Given projected increases in development of wind power resources in Wyoming by an order of magnitude over the next decade (U.S. Department of Energy 2015), effective avoidance and mitigation of turbine-strike mortalities will be critical to maintaining golden eagle populations in the region (U.S. Fish and Wildlife Service 2016).

There are currently 12 wind energy facilities operating in the Wyoming Basin and none in the Uinta Basin or North Park (Figure 1.6; Biewick and Jones 2012, Diffendorfer et al. 2014). Wind energy development in the Wyoming Basin is concentrated in an approximately 1000-km^2 area around Medicine Bow, Wyoming, where 9 windfarms comprising 431 turbines began operation during 1999–2010. Two additional facilities comprising 147 turbines were built in the southwestern corner of the state near Evanston in 2003 and 2008. Future wind resource development in the region is likely to be extensive: the Choke Cherry and Sierra Madre Wind Energy Development south of Rawlins, Wyoming, will be the largest on-shore wind energy facility in North America with up to 1000 turbines (U.S. Bureau of Land Management 2012).

Wind Energy development in Wyoming has been concentrated in Carbon, Converse, and Albany Counties. In addition the Choke Cherry and Sierra Madre Wind Energy Development, several new wind energy facilities with >1800 MW total capacity are currently proposed to be in operation in these counties by the end of 2020 (Patricia Sweanor, U.S. Fish and Wildlife Service, personal communication). Transmission capacity is currently a limiting factor to the extent and location of developments; however, the Gateway West Transmission Line Project (http://www.gatewaywestproject.com/) would substantially increase access to high-voltage transmission along a corridor between Glenrock, Wyoming, and Melba, Idaho. The route approximately follows the I-80 corridor across western Wyoming, then turns north towards Glen Rock, passing through the area of concentrated wind energy development in the southeastern Wyoming Basin. While the majority of development will likely be concentrated in the southeastern WYUB, projects have been proposed in other areas. For example, a 120-turbine wind project is currently proposed in the portion of the WYUB in Montana (Shawn Stewart, Montana Fish, Wildlife and Parks, personal communication).

Data on turbine-strike mortalities are not publicly available for most wind energy facilities in the WYUB. Available data for the region are limited to model-based estimates of mortality. Bay et al. (2016) estimated mortality rates of 0.65 eagles/yr for the Foote Creek Rim Phase I windfarm (69 turbines) and 0.36 eagles/yr for Foote Creek Rim Phases II and III (36 turbines). The BLM Final Environmental Impact Statement (FEIS) for the Choke Cherry and Sierra Madre Wind Energy Development predicted take of 40–64 golden eagles/yr for the full project (1000 turbines), which was reduced to 10–14 golden eagles/yr for Phase I (500 turbines) in the USFWS FEIS (U.S. Fish and Wildlife Service 2016) following changes to design and mitigation documented in the Eagle Conservation Plan (Power Company of Wyoming 2015). In addition to mortality from turbine-strikes, wind energy development also entails construction of new roads and power lines that could increase risk of mortality from vehicle collisions and electrocution, and increased human activity that could reduce productivity and overall fitness (May 2015).

Despite the abundance of both wind and golden eagles in the WYUB, spatial hazard analyses have identified some areas where wind speeds suitable for commercial development have minimal overlap with undisturbed wildlife habitat (Fargione et al. 2012) and golden eagle nesting habitat (Tack and Fedy 2015). As of 2012, however, only 0.002% of installed turbines and 3% of proposed turbines in Wyoming were located in areas classified as having low impacts to wildlife habitat (Fargione et al. 2012); results from this study are available as an online decision support mapping tool: http://www.lowimpactwind.tnc.org/). Historical siting of wind energy developments in areas of high potential for conflict with golden eagles is due in part to a lack of understanding of the overlap of golden eagle habitat and wind resources; however, wind energy siting decisions are also influenced by numerous other factors, including access to transmission capacity and energy markets; local, State, and Federal incentives; land ownership and management; approval by industrial siting commissions; conflicts with other wildlife species (e.g., greater sage-grouse) and resource values (e.g., view sheds); and public opinion. Owing to the difficulty of predicting many of these factors, most studies have used wind speed as a proxy for development potential. In this report, we take an approach to risk assessment similar to that of Tack and Fedy (2015), and extend the assessment to include habitats used for wintering (see Wind Resource Development Risk Assessment).

Collisions with transmission structures

Collisions with transmission lines and structures are sources of mortality for golden eagles, but little is known about their magnitude, proximate causes, or avoidance measures. There were at least 8500 km of transmission lines in the Wyoming proportion of the WYUB in 2012, spanning the major basins of the region, with concentrations in the southwestern portion of the state and along the I-80 corridor (Lindstrom 2012). Raptors in the WYUB are attracted to transmission structures because they offer elevated substrates for perching and nesting in otherwise open landscapes (Slater and Smith 2010). Attraction to distribution poles is associated with increased risk of electrocution, but its relationship to risk of collision has not been studied. Erickson et al. (2005) estimated that collision with power transmission structures accounted for 13.7% of anthropogenic mortalities of all bird species in North America. Most collisions are with guy-lines for transmission structures because they are lighter weight and more difficult for birds to see than transmission lines and towers (Jenkins et al. 2010). Risk is greatest for large land and water birds and smaller fast-flying species, with falcons being the group of raptors most affected (Jenkins et al. 2010). For raptors, diagnosis of mortalities from collisions with power lines is complicated by the possibility of electrocution or shooting, both of which are also associated with power poles (Lehman et al. 2010). Further research is necessary to understand and reduce the risk of collisions with transmission structures to golden eagles in the WYUB.

Oil and gas development

There were 32,748 active oil and gas wells in the WYUB in 2016 (COGCC 2016, MTBOG 2016, UDOGM 2016, WOGCC 2016), following a regional natural gas boom in the 1990s and 2000s during which the number of wells in the region more than doubled (Copeland et al. 2009). Oil and gas wells occur in all regions of the WYUB, with major fields in the Great Divide Basin, Uinta Basin, and upper Green River Basin, where the Jonah and Pinedale Anticline fields are among the densest in the western U.S. (Hethcoat and Chalfoun 2015). While the extraction of oil and gas is not a direct threat to survival of golden eagles, development involves infrastructure and activities with the potential to increase other hazards with known negative impacts. Distribution lines that power oil and gas wells increase risk of electrocution (Lehman et al. 2010); golden eagles are at risk of drowning in waste pits in oil fields (Trail 2006); and roads built in previously undeveloped areas, as well as expansion and improvement of existing road networks, increases risk of eagle-vehicle collisions and facilitates access for persecution of eagles and their prey (e.g., white-tailed prairie dogs; U.S. Bureau of Land Management 2007). Vehicle traffic, human presence, and activities associated with construction and maintenance of oil and gas fields may also cause disturbance to golden eagles that can reduce individual fitness and reproductive success (see Disturbance–Energy Development).

Few studies have documented direct mortality of golden eagles associated with oil and gas developments in the WYUB or elsewhere. In the WYUB, raptor electrocution rates were 2.5–3.0 times higher in the Rangely Oil Field than surrounding areas of the Uinta Basin due to a high density of dangerous poles (Lehman et al. 2010). No studies have investigated persecution of wildlife in oil and gas fields, but anecdotal evidence suggests greater risk of shooting for raptors (Zach Wallace, Wyoming Natural Diversity Database, unpublished data). An estimated 840,000 birds of all species die annually in the U.S. from drowning in oil pits, approximately 8% of which are birds of prey (Trail 2006). Although drowning of golden eagles in oil pits has not been documented in the WYUB, it has occurred in other areas (Trail 2006), and uncovered oil pits in the region are a hazard to the species.

In this report, we present a spatial hazard analysis identifying areas where seasonal habitat of golden eagles overlaps areas with higher oil and gas development potential (see Oil and Gas Development Risk Assessment), and spatial models of electrocution risk that can be applied to prioritize retrofitting efforts in existing oil and gas developments (see Electrocution Risk Assessment).

Mining and power generation

Numerous mines and 49 mine plants in the WYUB produce coal, sand, gravel, gold, bentonite, soda ash, phosphate, gypsum, limestone, and other resources (U.S. Geological Survey 2005). There are 7 coal, 3 natural gas, 15 hydroelectric, and 3 other power plants operating in the region (U.S. Energy Information Administration 2017). Like oil and gas development, mining and power generation involve activities and infrastructure that may be hazardous to golden eagles. Roads, vehicle traffic, and distribution and transmission lines associated with mining and power generation are possible sources of mortality for golden eagles, while habitat loss from surface mining and disturbance from vehicle traffic, human presence, and activities associated with construction and maintenance of mines and power plants can affect breeding and foraging golden eagles (see Disturbance). Mine highwalls create temporary cliffs that golden eagles have used as nest sites (Postovit et al. 1982, Fala et al. 1985). Operation permits for many coal mines in the WYUB require monitoring of raptor nests and prey, and the resulting data represent some of the longest-term studies of golden eagles in the region (Lorraine Keith, BLM Rock Springs Field Office, personal communication). However, monitoring of mortality is not included in these requirements, and the relatively small number of nests within each mine area makes these data impractical for trend analysis.

3.2.2. Collisions with vehicles

Collisions with motor vehicles are a major source of mortality for golden eagles (Russell and Franson 2014, U.S. Fish and Wildlife Service 2016) that has increased over the past century (Lutmerding et al. 2012). In the WYUB, vehicle collision mortality of golden eagles is mainly associated with feeding on road-killed ungulates during winter (Riginos et al. 2017). Eagle-vehicle collisions likely occur to some extent in all seasons and may be associated with factors other than feeding on road kill, and with road kill other than ungulates (Riginos et al. 2017). Removal of carcasses from highways may reduce risk of vehicle collision mortality for golden eagles feeding on road kill (U.S. Fish and Wildlife Service 2013) and has been suggested as a possible form of compensatory mitigation to offset programmatic take at wind energy facilities (Allison et al. 2017).

Communications with regional biologists in the WYUB suggested vehicle collisions were widespread and occurred most often during winter along secondary highways when eagles were feeding on and flushing from road-killed ungulates. Idaho Fish and Game identified vehicle collision as a threat to golden eagles feeding on road-killed mule deer and elk along highway 30 in the Bear River Valley (Idaho Department of Fish and Game 2017). Of 18 road-killed golden eagles reported to Idaho Fish and Game in the WYUB from 2011–2017, all occurred between mid-December and early March, 4 were noted as directly associated with deer carcasses, and 2 with road-killed jackrabbits (Becky Abel, Idaho Fish and Game, personal communication). Injury or mortality of >10 golden eagles per winter from vehicle collisions is common along highway 40 in the Uinta Basin (Brian Maxfield, Utah Division of Wildlife Resources, personal communication), and regional biologists in Wyoming identified higher-risk areas along WY-287 North of Rawlins (Heath Cline, BLM Rawlins Field Office, personal communication) and highway 30 in the Green River Basin (Lorraine Keith, BLM Rock Springs Field Office, personal communication).

An analysis of deer collision records collected by the Wyoming Department of Transportation (WYDOT) revealed “hotspots” of deer-vehicle collision in the state (Teton Science Schools 2016). Riginos et al. (2017) overlaid the deer-vehicle collision model with models of golden eagle habitat to identify seasonal concentrations of collision risk (Figure

3.1). Assuming deer-vehicle collision rates as a surrogate for risk of eagle-vehicle collision, the results of their analysis could be used for spatial prioritization of roadkill removal to maximize benefit to golden eagles. Eagle-vehicle collision risk varied by area and season, with the highest risk in the southwestern and northwestern Wyoming Basin during fall and spring, and smaller hotspots in the southeastern area of the region during summer (Figure 3.1). Several collision hotspots were apparent within the WYUB, including areas in the Bighorn Basin (Hwy 14-ALT between Cody and Lovell, Hwy 20 between Greybull and Wind River Canyon), Wind River Basin (Hwy 287 around Dubois, Hwy 789 between Riverton and Shoshoni, Hwy 287 and 789 around Lander), upper Green River Basin (the Pinedale area on Hwy 191 between Daniel Junction and Boulder, Hwy 189 between La Barge and Big Piney), lower Green River Basin (portions of I-80 between Evanston and Lyman, Hwy 189 between I-80 and the Carter Cutoff, Hwy 30 East and West of Kemmerer), Bear River Valley (Hwy 89 from Evanston to the Utah Border, Hwy 30 North of Cokeville), Hwy 789 North of Baggs, and smaller areas around other towns in southern Wyoming (Green River, Rock Springs, Farson, Rawlins, Saratoga, Arlington, and Laramie).

A model of eagle-vehicle collisions suggested removal of road-killed carcasses could be an effective strategy to reduce eagle mortality in Wyoming (Lonsdorf et al. 2018). Increasing carcass removal effort from 0 to 5 times per month was predicted to reduce eagle mortality by 30% in a given area (Lonsdorf et al. 2018). The greatest potential mitigation benefits were on roads with lower traffic volumes (i.e., 15–35 vehicles per hour), higher densities of road-killed carcasses, and where current carcasses removal effort was low (Lonsdorf et al. 2018). Within the state of Wyoming, the counties with the highest predicted number of annual golden eagle deaths (Bighorn, Carbon, Fremont, Lincoln, Sublette) and expected mortality probability (Bighorn, Hot Springs, Lincoln, Uinta) were all in the Wyoming Basin, with substantially lower risk for counties in eastern Wyoming (Lonsdorf et al. 2018).

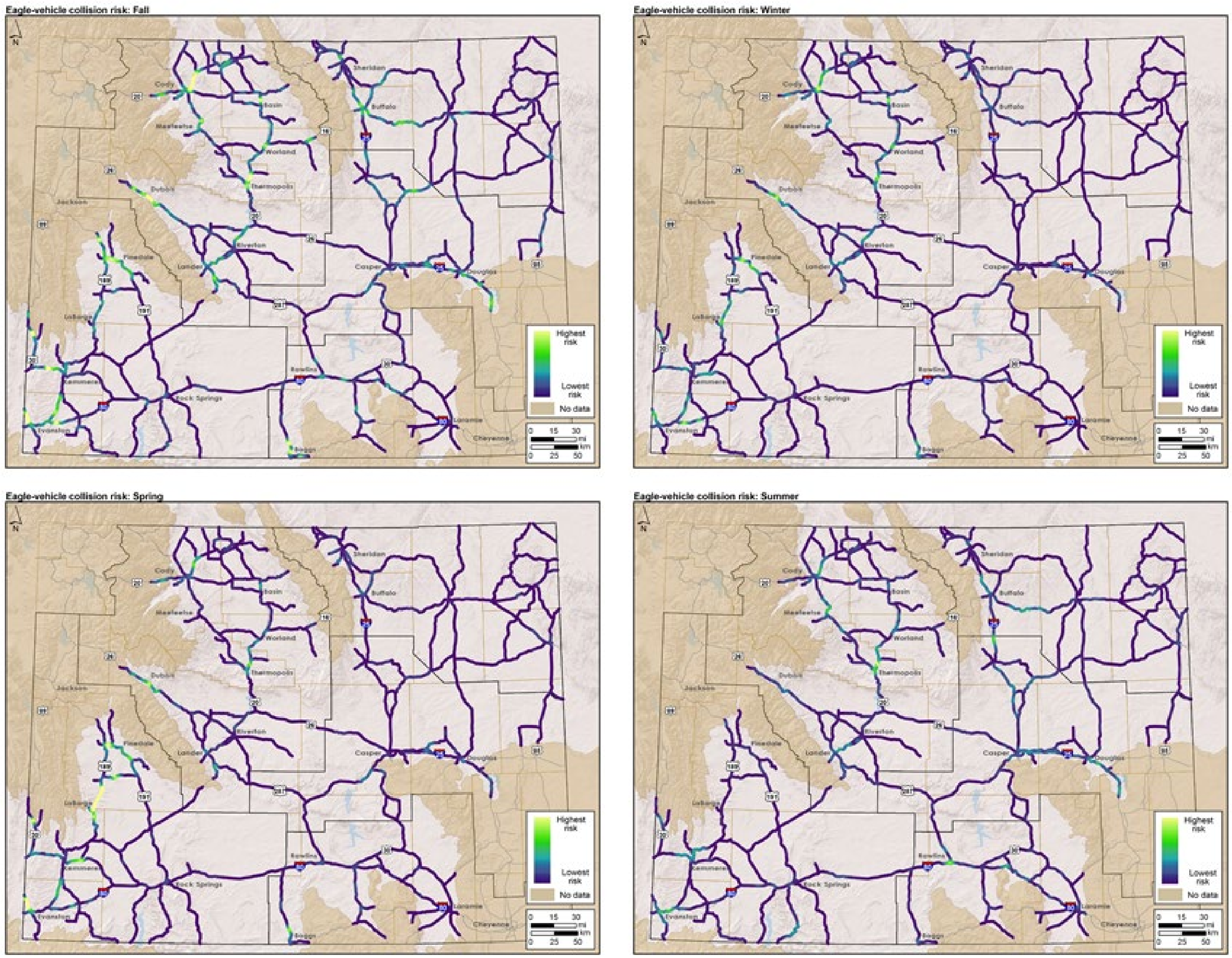

Figure 3.1. Relative risk of eagle-vehicle collisions during fall (October–November, upper left panel), winter (December–February, upper right panel), spring (March–April, lower left panel), and summer (June–August, lower right panel) in Wyoming, from Riginos et al. (2017).

Golden eagles occasionally collide with aircraft, although this is likely not a major source of mortality. During 1990–2013, 14 golden eagle strikes with aircraft were reported to the Federal Aviation Administration in the Intermountain West Region (Washburn et al. 2015). Most collisions in the western U.S. occurred at low flight altitudes, with 81% below 305 m above ground level (AGL) and none above 915 m AGL (Washburn et al. 2015). Data specific to the WYUB were not available, but 25% of reported collisions in the western U.S. occurred in Colorado, 8.3% in Utah, 4.2% in Montana, 4.2% in Idaho, and none were reported in Wyoming (Washburn et al. 2015). While the WYUB includes portions of states with reported golden eagle-aircraft collisions, the majority of collisions are expected to occur at larger airports outside the WYUB.

Risk of wildlife-train collisions is generally unknown for most wildlife in the United States, but can be greater than vehicle collisions (Dorsey et al. 2015). Ungulates and other wildlife are regularly struck by trains, which can lead to eagle-train collisions when eagles are feeding on carrion. For example, train collisions are the leading cause of mortality for white-tailed sea eagles in Germany (Krone et al. 2002). Trains that transport agricultural products, such as grain, can attract wildlife and increase risk of collisions (Dorsey et al. 2015), but all train types pose a wildlife collision risk.

3.2.3. Contaminants

Exposure to environmental contaminants is a significant threat to persistence of golden eagle populations. Contaminants account for an estimated 20% of golden eagle deaths annually in North America, including 1,025 (95% CI: 316–2,266) from poisoning and 160 (95% CI: 10–867) from lead toxicosis (U.S. Fish and Wildlife Service 2016). In Wyoming, poisoning was confirmed as the cause of death for 5 of 73 (7%) golden eagles processed by Wyoming State Veterinary Laboratory during 1997–2016 and suspected in 9 (12%) additional cases (Terry Creekmore, Wyoming Game and Fish Department, personal communication). The extent of exposure and population-level impacts to Golden Eagles from most contaminants remain poorly understood in the region. Exposure to some contaminants may be limited to isolated, local incidents, while others are recognized as extensive hazards with population-level impacts.

Lead

Lead poisoning is a widespread and persistent hazard to golden eagles in North America (Craig et al. 1990, Stauber et al. 2010, Russell and Franson 2014). The primary pathway of exposure is through lead bullet fragments and shotgun pellets ingested by golden eagles scavenging on animals killed by hunters (Herring et al. 2017, but see Katzner et al. 2017a). In the WYUB, sources of lead-laden carrion include hunting of big game animals and upland game birds, shooting of prairie dogs and ground squirrels for recreation and pest control, and shooting of coyotes for predator control. Estimates based on telemetered golden eagles suggest lead toxicosis accounts for 3% mortalities annually in North America (U.S. Fish and Wildlife Service 2016), while rates from studies using opportunistically recovered eagle carcasses were higher, ranging from 10–44% (Kochert et al. 2002). In Wyoming, lead toxicosis was the confirmed cause of death for 1 of 73 (1.4%) golden eagles processed by

Wyoming State Veterinary Laboratory during 1997–2016 and suspected in 2 additional cases (Terry Creekmore, Wyoming Game and Fish Department, personal communication). Consistent with the telemetry-based results, a simulation model of lead poisoning in Wyoming projected 3.2% (80% CI: 1.2–9.2%) of the golden eagle population in the state would die from lead poisoning during one hunting season (Cochrane et al. 2015). In addition to mortality from toxicosis, sublethal exposure to lead is pervasive in golden eagles: studies of free-flying eagles documented elevated blood lead levels in 46% of individuals (Craig and Craig 1998), and detectable levels of lead in the blood of 85% (Harmata and Restani 1995) and 99% (Craig and Craig 1998). Sublethal lead burdens can reduce growth and survival of nestlings (Herring et al. 2016) and impair flight and balance (Ecke et al. 2017), thereby increasing risk of injury from other hazards like collision (Herring et al. 2017) and electrocution (Golden et al. 2016). Effects of sublethal lead poisoning may also be additive with other contaminants, diseases, and parasites, contributing to weakened immune function, illness, loss of coordination, and starvation (Herring et al. 2017).

Few restrictions exist on the use of lead ammunition for hunting and recreational shooting in the WYUB. Federal law requires the use of non-toxic shotgun pellets for hunting waterfowl in all states. Non-toxic shot is required when hunting game birds or small game on the Table Mountain State Wildlife Habitat Management Area in Wyoming, but no other regulations on the use of lead ammunition exist in the portions of the WYUB in Colorado, Idaho, Montana, Utah, or Wyoming.

Large numbers of big game animals are harvested annually by hunters on public and private lands across the WYUB, where abundant populations of ungulates occur in diverse habitats. The average combined density of deer, elk, and pronghorn harvested annually in the WYUB is greater than all other ecoregions in the western U.S., with the exception of the Northern Rockies and Middle Rockies Ecoregions, which are dominated by forested mountains. The gutted carcasses and viscera left in the field by hunters, as well as animals wounded and not recovered, are likely the primary source of lead for golden eagles in the region. Fragments of bullets disperse widely throughout carcasses on impact and tissues with no noticeable fragments may still contain concentrations of lead dangerous to golden eagles (Hunt et al. 2006, Golden et al. 2016). The importance of big game carcasses as a vector of lead exposure is confirmed by numerous studies documenting a seasonal pattern of elevated blood lead levels in golden eagles and other avian scavengers during and after the big game hunting season in fall and early-winter (Kramer and Redig 1997, Stauber et al. 2010, Legagneux et al. 2014, Langner et al. 2015, Ecke et al. 2017). Given that a single ungulate carcass can contain enough lead to cause toxicosis, reducing exposure from big game hunting has been suggested as a potentially effective strategy to mitigate mortality of golden eagles (Cochrane et al. 2015). Efforts to reduce this source of mortality may be especially important in the WYUB, where regionally high levels of big game harvest provide greater exposure of golden eagles to lead-laden carcasses.

Shooting of prairie dogs and ground squirrels (i.e., “varmint shooting”) is also a likely source of lead for golden eagles and other raptors in the WYUB (Herring et al. 2016). Despite their smaller size, carcasses of prairie dogs shot with high-powered rifles can contain concentrations of lead lethal to eagles and other raptors (Pauli and Buskirk 2007). Varmint shooting is legal year-round, but occurs mainly during spring and summer in areas with access to public lands and large colonies of white-tailed prairie dogs, and on private ranches that offer permission or guided hunts. Although impacts from this practice are expected to be relatively localized, lead exposure for golden eagles in affected areas could be considerable given the number of animals shot is not restricted by bag limits (e.g., >100 prairie dogs per shooter per day), carcasses are typically not retrieved, and raptors may preferentially scavenge in shooting areas (Herring et al. 2016). While no studies in the WYUB explicitly linked lead toxicosis in adult or nestling golden eagles to varmint shooting, recent work in the neighboring Northern Great Basin Ecoregion suggests nestlings near shooting areas could ingest amounts of lead sufficient to reduce growth and survival (Herring et al. 2016). Shooting of coyotes for predator control and recreation may also be a source of lead exposure for golden eagles. Golden eagles in the WYUB occasionally prey and scavenge on coyotes and shooting is allowed year-round without a permit.

Upland game birds are generally not important in the diet of golden eagles; however, lead exposure is possible from wounded and unrecovered game birds, as well as birds taken as live prey that have ingested shotgun pellets in their gizzards. Hunting effort for upland game birds varies by species and habitat during fall and early-winter seasons in the WYUB. Sage-grouse hunting is permitted in a majority of the WYUB in Wyoming, while hunting of sharp-tailed grouse (*Tympanuchus phasianellus*) is more prevalent in the Great Plains; the forested habitats of ruffed grouse (*Bonasa umbellus*) and dusky grouse (*Dendragapus obscurus*) are rare in the region. Hunting opportunities for ring-necked pheasant (*Phasianus colchicus*) are also limited by habitat in the WYUB, but large numbers of chukar partridge (*Alectoris chukar*) are harvested annually, especially in the Bighorn and Wind River basins. Chukar are known to ingest and store lead pellets in their gizzards, leading to elevated lead concentrations in tissues (Walter and Reese 2003, Bingham et al. 2015). Further research is necessary to establish a link between upland game bird hunting and lead exposure for golden eagles in the WYUB.

Anticoagulant rodenticides

Anticoagulant rodenticides (ARs) have been used to control rodent pests since the 1940s. ARs inhibit blood clotting, causing the death of animals by internal hemorrhaging and external bleeding. As a facultative scavenger, golden eagles can be exposed to ARs by scavenging or preying on rodents that have consumed AR laced baits or other predators that have consumed AR-exposed rodents (Herring et al. 2017). Poisoned rodents are easier to capture and there is evidence that raptors (i.e., ferruginous hawks) preferentially foraged in black-tailed prairie dog colonies that had been poisoned with ARs (Vyas et al. 2017). ARs are divided into two classes: first generation ARs (FGARs; chlorophacione, diphacione, warfarin) are less acute in their effects, degrade over hours to days, and must be ingested multiple times to cause fatality in target species. Second generation ARs (SGARs; difethialone, bromadiolone, brodifacoum, difenacoum) typically kill target species with one dose, and persist up to a year in the environment and animal tissues (Herring et al. 2017). All ARs are considered a hazard to raptors, including golden eagles, although the scope of exposure, lethal dosage, and effects at sublethal levels are poorly understood (Herring et al. 2017). Similar to lead, the sublethal effects of ARs may be additive with other stressors, including contaminants, parasites, and diseases (Herring et al. 2017). Sublethal doses of ARs have been shown to cause behavioral effects such as lethargy in golden eagles (Savarie et al. 1979), which could increase risk of collisions with infrastructure (Herring et al. 2017).

The extent of AR use in the WYUB is unknown, but is likely restricted to local efforts to control sciurid populations on private lands (U.S. Fish and Wildlife Service 2017c). In the states in the WYUB, FGAR baits for prairie dogs are approved for use with a Restricted Use Pesticide (RUP) Applicator's or Dealer's License. AR use is prohibited on BLM lands, except where rodent colonies threaten human health, and use of chlorophacione (e.g., Rozol®) is prohibited by USFWS in black-footed ferret management areas (U.S. Fish and Wildlife Service 2017c). It is assumed that ARs are used more intensively to control black-tailed prairie dogs than white-tailed prairie dogs, due to the more concentrated colonies of the former species, and may thus be less of a threat in the WYUB than neighboring areas of the Great Plains (U.S. Fish and Wildlife Service 2017c). Further research is needed to understand the extent of AR use in the WYUB and potential negative impacts to golden eagle populations.

Other contaminants

Golden eagles are exposed to numerous other contaminants, including heavy metals (e.g., mercury), poisons intended for predators (e.g., strychnine), insecticides (e.g., phorate, carbofuran), and organochlorides (e.g., DDT, DDE; Kochert et al. 2002); however, information on the extent of exposure and effects are lacking for most contaminants. For example, records are not available on the number of golden eagles killed by poison baits intended for mammalian predators (e.g., coyotes) in the WYUB, but research from other regions suggests they are a considerable threat, with greater morality for females and during winter (Bortolotti 1984). Even relatively rare incidents of poisoning can have cumulative effects. For example, one incident of poisoning with the livestock euthanasia agent pentobarbital was the cause of death for 4 of 73 (5%) golden eagles processed by Wyoming State Veterinary Laboratory during 1997–2016 (Terry Creekmore, Wyoming Game and Fish Department, personal communication).

3.2.4. Disease and parasites

Starvation and disease are the leading causes of golden eagle mortality in North America, accounting for an estimated 22% or 1334 (95% CI: 681–2,626) deaths annually (U.S. Fish and Wildlife Service 2016). Diseases and parasites of golden eagles are not well documented in the WYUB; records are limited to eagles that were found opportunistically and submitted to wildlife laboratories or captured for research purposes. Results from golden eagles submitted to the Wyoming State Veterinary Laboratory confirm cases of West Nile virus, trichomonosis, and leucocytozoon in the region, but little information is available on their prevalence or distribution. While golden eagle populations in the region appear to be stable (see Status and Trend), changes in climate and land use may increase exposure to both native and introduced pathogens. Insect-borne pathogens (e.g., West Nile virus from mosquitoes, leucocytozoonosis from blackflies) and insect pests (e.g., blow flies, Mexican chicken bugs) will likely increase in response to rising temperatures and changing precipitation regimes (Walker and Naugle 2011), while diseases vectored by prey of golden eagles (e.g., trichomonosis from pigeons and avian cholera from waterfowl) could increase if native habitat of primary prey species is lost (Heath and Kochert 2015). Increased sampling effort is necessary to determine the current prevalence of diseases and parasites of the golden eagles in the WYUB and establish baselines to detect potential increases in response to changing conditions.

West Nile Virus

West Nile virus (*Flavivirus* sp.; WNv) is a mosquito-borne pathogen that infects humans, birds, and other animals, including golden eagles (Centers for Disease Control and Prevention 2016a). Introduced to North America in 1999, WNv spread rapidly across the continent, and was first detected in the states in the WYUB between 2001 and 2004 (Centers for Disease Control and Prevention 2016b). Although mosquitos are the primary vector for WNv, golden eagles could also contract the virus from feeding on tissue of infected animals (Straub et al. 2015). WNv was the proximate cause of death for 10 of 73 (16%) golden eagles processed by Wyoming State Veterinary Laboratory during 1997–2016 and suspected in 2 additional cases (Terry Creekmore, Wyoming Game and Fish Department, personal communication). A study in Colorado during 2002–2005 found 2 of 5 golden eagles tested positive for WNv (Nemeth et al. 2007). Annual prevalence of WNv in some bird species has been shown to correlate with incidence in humans (e.g., American white pelican, *Pelecanus erythrorhynchos*; Johnson et al. 2010). This may also be true for golden eagles, as the years in which golden eagle with WNv were documented by the Wyoming State Veterinary Laboratory (2003, 2007, 2013) corresponded to peaks in reported human cases of WNv neuroinvasive disease in the state (Centers for Disease Control and Prevention 2016b).

Risk of WNv transmission is influenced by numerous factors, including suitable temperature ranges for incubation (Schrag et al. 2011) and exposure of eagles to larval mosquito habitat. Seasonal abundance of the primary mosquito vector of WNv in sagebrush steppe habitats (*Culex tarsalis*; Turell et al. 2005) peaks in late-July and early August (Johnson et al. 2010) when recently fledged eagles have limited mobility and may be more vulnerable to infection. In the WYUB, human-made water bodies that provide habitat for larval mosquitoes include stock tanks, agricultural ponds, flood-irrigated agricultural fields, roadside ditches, and holding ponds for produced water from oil, gas, and coalbed methane extraction.

Research on effects of WNv on wildlife in sagebrush ecosystems has focused on impacts to greater sage-grouse in the neighboring Northwestern Great Plains Ecoregion (Walker and Naugle 2011). These efforts have included models to map infection risk based on mosquito breeding habitat (Zou et al. 2006) and to predict future risk under various climate scenarios (Schrag et al. 2011). Broad scale modeling suggests the relatively arid climate and variable terrain of the WYUB may reduce regional WNv risk, relative to the neighboring Great Plains region; however, overall prevalence is predicted to increase by 2050 in the intermountain West (Harrigan et al. 2014) and expand substantially in the WYUB under most climate change scenarios (Schrag et al. 2011).

Trichomonosis

Trichomonosis is a disease of the upper digestive tract caused by the protozoan parasite *Trichomonas gallinae*. Golden eagles contract trichomonosis or "frounce" by consuming rock pigeons (*Columba livia*) and other doves in the family Columbidae. Primarily known to affect nestling golden eagles, the disease causes the formation of lesions in the mouth and throat that can lead to death by starvation or suffocation (Kochert 1972, Dudek 2017). In the WYUB, golden eagles may occasionally prey on rock pigeons, and could also potentially contract the disease from mourning doves (*Zenaida macroura*) and Eurasian collared doves (*Streptopelia decaocto*). Trichomonosis was documented in only 1 of 73 golden eagles processed by Wyoming State Veterinary Laboratory during 1997–2016 (Terry Creekmore, Wyoming Game and Fish Department, personal communication). However, actual prevalence of trichomonosis may be greater because few nestlings were submitted to the lab and limited number of research projects in the region have involved intensive nest monitoring necessary to document diseases of nestlings. In two studies in the neighboring Snake River Plain Ecoregion, 4% of nestlings died from trichomonosis (Kochert 1972) and 41% of nestlings tested positive for *T. gallinae* infection (Dudek 2017). A study spanning 10 Western states conducted in 2015 found 13% (12/96) nestlings had *T. gallinae* infection, with 10 of 10 samples from Wyoming testing negative (Dudek et al. 2018). High incidence of trichomonosis resulted from increased consumption of rock doves due to declines in leporid populations following loss of native shrub-steppe habitat to wildfire (Heath and Kochert 2015; Dudek et al. 2018). Although similar habitat changes have yet to occur in the WYUB, climate change is predicted to cause the spread of annual invasive grasses and drought conditions that could result in a similar future scenario.

Leucocytozoonosis

Leucocytozoonosis is a disease caused by the hemosporidian blood parasite *Leucocytozoon toddi* that is transmitted to golden eagles by blackflies (*Simulian* sp.). While it rarely causes the death of raptors, leucocytozoonosis can weaken immune response to other diseases (Remple 2004). Leucocytozoonosis was documented in only 1 of 73 golden eagles processed by Wyoming State Veterinary Laboratory during 1997–2016, in which it contributed to a death by hepatitis (Terry Creekmore, Wyoming Game and Fish Department, personal communication). In a study of golden eagle nestlings in Idaho, Oregon, and California, infection rates ranged from 0–44% (MacColl et al. 2017). Although leucocytozoonosis is not likely a current hazard to golden eagle populations in the WYUB, human activities that increase surface water necessary for blackfly breeding (e.g., agricultural activities, road building, coal bed methane development) could potentially increase incidence of this parasite.

Other diseases and parasites

Other diseases and parasites known to occur in golden eagles have not been documented in the WYUB. These include avian cholera (*Pasteurella multocida*), tuberculosis (*Mycobacterium avium*), avian influenza, myiasis (blow fly infestation), avian pox (*Avipoxvirus*), and Mexican chicken bugs (*Haematosiphon inodorus*).

3.2.5. Persecution and poaching

Persecution of golden eagles by shooting, trapping, and poisoning was widespread in the 20th century (Beans 1997, Kochert et al. 2002) and has likely declined since the 1980s (Lutmerding et al. 2012). Persecution can result from a range of factors, including real and perceived conflicts with livestock (Beans 1997), opportunistic target shooting, and non-target capture by recreational and management trappers (Bortolotti 1984). Persecution of golden eagles is difficult to study because incidents often occur in rural areas and perpetrators may be intentionally secretive. Despite declines from historical levels, persecution remains a leading cause of golden eagle mortality in North America: shooting accounts for an estimated 15% or 926 (95% CI: 336–2,046) deaths per year and trapping for 4% or 231 (95% CI: 15–1,071; U.S. Fish and Wildlife Service 2016). Retrospective studies of golden eagles submitted to veterinary laboratories suggest similar rates: gunshot was the cause of death for 196 golden eagles (13.7%) and trapping for 30 (2.7%) submitted to the National Wildlife Health Center from 1982–2013 (Russell and Franson 2014). Gunshot was the cause of death for 6 golden eagles (6%) admitted to the Colorado State University Veterinary Teaching Hospital during 1995–1998 from an area including Wyoming, Colorado, and Nebraska (Wendell et al. 2002). Thorough necropsy methods that include X-rays for bullet fragments and lab tests for poisons are important to accurately document persecution because the cause of death may not be apparent in the field. For example, at least 10 of 108 (9%) golden eagles found below power poles in a study of electrocution rates in the WYUB in northwestern Colorado had actually been shot (Lehman et al. 2010). Current levels of persecution in the WYUB are unknown, but shootings of golden eagles continue to be documented by law enforcement and veterinary laboratories in the region (Terry Creekmore, Wyoming Game and Fish Department, personal communication).

Trafficking of feathers and other body parts of golden eagles is known to occur in the WYUB and associated poaching is likely. Similar to persecution, the extent of poaching is difficult to document, but recent legal cases suggest it could be extensive. For example, parts from 100–250 bald and golden eagles were recovered from a poaching ring with members based in the WYUB (*United States of America v. Alvin Brown, Jr., Michael Primeaux, and Juan Mesteth*, 2017, CR 17-50035).

3.2.6. Drowning

Golden eagles are at risk of drowning in various water bodies, including oil pits (see Oil and gas development) and stock tanks. Drowning accounts for an estimated 2% or 119 (95%: 6–747) golden eagle deaths annually (U.S. Fish and Wildlife Service 2016). No instances have been documented in the WYUB (Trail 2006).

3.3. Population limiting factors – Fecundity

Factors that limit fecundity of golden eagles can have negative impacts on populations. Fecundity of golden eagles is influenced by numerous factors, including prey abundance and availability, human disturbance, climate and weather, and predation (Kochert et al. 2002). We focus here on prey resource limitation and human disturbance because they are the most well studied and potentially responsive to management actions.

3.3.1. Prey resource limitation

Successful reproduction of golden eagles requires adequate abundance and availability of prey to support the full breeding cycle: from sustaining adults during courtship, egg laying, and incubation, to provisioning chicks, and enabling survival of fledglings. While the link between golden eagle fecundity and prey populations is intuitive, relatively few studies have monitored eagles and their prey over sufficiently long time periods to document a direct connection (e.g., Smith and Murphy 1973, Steenhof et al. 1997, Nyström et al. 2006, McIntyre and Schmidt 2012). Moreover, prey abundance alone may be a poor predictor of fecundity because numerous factors interact to influence the "decision" of golden eagles to breed, the number of eggs laid, and the number of young fledged in a given year (Steenhof et al. 1997). Nonetheless, long-term studies from the WYUB and other regions suggest maintaining prey populations is essential to sustaining fecundity of golden eagle populations (Kochert et al. 2002).

In the WYUB, recent work in the Bighorn Basin found that fewer young reached fledging age per occupied golden eagle territory in years when abundance of cottontails declined (Preston et al. 2017a). Breadth of golden eagle diets expanded in years of low cottontail abundance to include more jackrabbits, pronghorn fawns, and birds; however, this dietary shift was not sufficient to compensate for the lack of primary prey, and reproductive rates remained depressed (Preston et al. 2017a). Although changes in cottontail abundance during this study followed the 7–8 year population cycle previously documented in Wyoming (Fedy and Doherty 2011), the strong effect of prey abundance on productivity suggests that any factors with the potential to cause long-term declines in leporid populations in the WYUB would have negative consequences for golden eagles (Preston et al. 2017a). For example, declines in jackrabbit abundance following severe wildfires in the neighboring Snake River Plain Ecoregion led to long-term reductions in nest success and the number of territories occupied by golden eagles (Kochert et al. 1999). Results from the Great Basin may be instructive for the WYUB, where both annual grass invasion and wildfire risk are relatively lower, but increasing with human-caused climate change (Bradley 2009).

Several other studies in the WYUB have associated declines in territory occupancy of golden eagles with low-points in leporid population cycles: Young et al. (2010) suggested a decline in breeding success of golden eagles in the vicinity of the Foote Creek Rim wind energy facility was the result of low leporid abundance in the early 1990s. Similarly, Ayers et al. (2009) attributed changes in nest occupancy over 3 years to low prey abundance. Wallace (2014) monitored occupancy of golden eagle territories over two years in Wyoming and found nest height influenced occupancy rates, but density of leporids and sciurids did not. These results are not surprising, however, because the study was short and took place during the same low point of the leporid population cycle documented by Preston et al. (2017a). Oakleaf et al. (2014) conducted occupancy surveys in 2013 and compared them with results of Wallace (2014) and other historical data. They concluded territory occupancy of golden eagles in lowland areas of Wyoming had declined with leporid populations in the mid-1990s and had not returned to previous levels as of 2013, despite a predicted peak in the leporid cycle in 2014 (Fedy and Doherty 2011). Taken together, these results suggest territory occupancy and productivity of golden eagles in the WYUB are sensitive to fluctuations in primary prey populations and maintaining healthy leporid populations is an essential component of golden eagle conservation in the region. Although leporids are the most important prey group for golden eagles in the WYUB, other prey species like white-tailed prairie dogs may be locally important (MacLaren 1986) and should be considered in management. Management options to support prey populations include conservation and restoration of habitat, efforts to combat diseases, and incentives for cessation of hunting and poisoning (see Regional Conservation Measures–Prey Management).

3.3.2. Disturbance

Human disturbance to golden eagles qualifies as "take" under the Bald and Golden Eagle Protection Act (BGEPA) if the activity has the potential "...to agitate or bother a … golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available, (1) injury to an eagle, (2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior, or (3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior" (U.S. Fish and Wildlife Service 2007). In addition to direct sources of injury and mortality, many human activities in the WYUB have the potential to negatively affect golden eagle populations by reducing their fecundity. These include presence of humans (e.g., hikers, rock-climbers, researchers), vehicle traffic (e.g., cars, trucks, OHVs), and construction (e.g., drilling oil and gas wells, installing wind turbines, building roads; U.S. Fish and Wildlife Service 2017b). Golden eagles are most sensitive to disturbance during the early stages of nesting (Fyfe and Olendorff 1976, Richardson and Miller 1997, Spaul and Heath 2016), but may be affected throughout the nesting and fledging period (Fyfe and Olendorff 1976), as well as during the non-breeding season (Holmes et al. 1993). Management to protect golden eagles from human disturbance typically involves restricting human activities and surface occupancy within spatial buffers around nest sites on a seasonal or permanent basis. While application of nest buffers is integrated into stipulations for industrial activities, like oil and gas development, dispersed recreational activities, like OHV use and rock climbing, are more difficult to study and regulate.

Severity of a disturbance can be characterized by its duration and intensity, ranging from events that are short-term and low-intensity to those that are long-term and high-intensity. Ideally, studies of disturbance to wildlife should relate direct measures of the disturbance (e.g., amplitude and duration of noise, number vehicle passes) to multiple measures of response (e.g., physiological, behavioral, demographic; Tarlow and Blumstein 2007);

however, in practice most studies use surrogates for disturbance and response. Research on disturbance of golden eagles in the WYUB is limited to correlative studies that use landscape features (e.g., number of oil and gas well, length of roads) as surrogates for disturbance from energy development. Given the lack of research in the region, we discuss studies from other regions that provide valuable information on the response of golden eagles to human disturbances that occur in the WYUB.

Energy development

Conventional and renewable energy development involve a suite of human activities with the potential to disturb nesting golden eagles, including noise and visual disturbance during construction, increased road density and traffic, and ongoing human presence associated with maintenance of facilities (Wallace 2014). Wallace (2014) found no relationship between occupancy rates of golden eagle territories and length of roads or number of oil and gas wells in Wyoming; however, this study was retrospective and did not address potential displacement of golden eagles by construction of oil and gas fields. By contrast, use of nesting territories by golden eagles in Utah declined during a 3-year period of expansion of a natural gas field, but stabilized 2 years later, suggesting eagles either habituated to the disturbance or responded more strongly to the construction phase than the operation and maintenance phase of development (Smith et al. 2010). Relationships of golden eagles to roads in energy fields varied with scale and road-type: proportional use of nest sites in Utah and Wyoming decreased as density oil and gas development increased within an 800-m radius, but increased with density of non-oil and gas roads within 2.0 km (Smith et al. 2010). These results suggest roads in close proximity to nests cause disturbance, while at a broader scale roads may alter habitat to the benefit of raptors and their prey (Smith et al. 2010). The potential for increased prey abundance in energy developments remains speculative and further research is necessary to test this hypothesis, identify the mechanisms behind possible increases, and link prey abundance to habitat selection and fecundity of raptors.

Mining activities can reduce fecundity of golden eagles through direct loss of nest sites and disturbance (e.g., heavy vehicle traffic, blasting; Phillips 1984). Long-term monitoring data suggest some golden eagle pairs have habituated to disturbance at coal mines in Wyoming (Gwyn McKee, Great Plains Wildlife Consulting, personal communication) and studies document successful relocations of occupied nests from mine high walls (Postovit et al. 1982, Fala et al. 1985). Long-term monitoring of golden eagle territories around coal mines in northeastern Wyoming has informed successful relocations of multiple nests, using a strategy in which nesting platforms are moved incrementally away from the advancing mine edge (Gwyn McKee, personal communication).

OHVs and other recreational activities

Studies of recreational disturbance to golden eagles have not been conducted in the WYUB, but evidence from other regions suggests OHV use (Steenhof et al. 2014, Spaul and Heath 2016), hiking (Martin et al. 2009, Spaul and Heath 2016), and rock climbing (Richardson and Miller 1997) near nest sites can have negative effects on reproductive success (Spaul and Heath 2016, Pauli et al. 2017). The most comprehensive study to date of recreation effects on nesting golden eagles, conducted in sagebrush steppe habitat in the neighboring Snake River Plain Ecoregion, documented negative effects of motorized and non-motorized recreation on different stages of the nesting cycle (Spaul and Heath 2016). Motorized recreation was associated with reduced occupancy and increased nest failure: fewer territories were occupied by golden eagles in areas with higher average seasonal OHV use, while nest success was negatively impacted by spikes in OHV activity (Spaul and Heath 2016). Non-motorized recreation affected egg laying and nest attendance: fewer territorial pairs laid eggs in areas with more pedestrian activity and nest attendance was negatively associated with people exiting their vehicles (Spaul and Heath 2016). Disturbance by OHVs can have long-term impacts on local golden eagle populations: an earlier study in the same area found reduced rates of occupancy and reproduction over 40 years for golden eagles in areas with higher levels of OHV use (Steenhof et al. 2014). Moreover, spatial demographic models simulating long-term impacts on this population suggested moderate increases in recreational use could result in significant declines, even after accounting for the potential for habituation of golden eagles to disturbance (Pauli et al. 2017).

Comprehensive maps of OHV trails or high-use areas are not available for the WYUB. However, spatial models of golden eagle habitat-use in this report can be used in conjunction with known nest locations to inform planning to reduce conflicts of golden eagles with motorized and non-motorized recreation (see Regional Conservation Measures–Disturbance by recreation).

Research activities

No studies are available on impacts of scientific research activities on golden eagles in the WYUB. Research activities are likely to affect only a small percentage of golden eagles each year. Fecundity of golden eagles can be impacted by researchers entering nests for banding and observing nests from close distances (Steenhof and Kochert 1982), while individual behavior and fitness may be affected by stress from trapping and carrying telemetry instruments (Stahlecker et al. 2015). Strategies to minimize research impacts to golden eagles include coordination among agencies and consultants to reduce redundant nest visits, use of non-invasive sampling techniques whenever possible, and compliance of all entities involved in raptor research with appropriate standards for animal welfare.

Disturbance distances and recommended buffers

Agencies and entities in the WYUB recommend restrictions to development within buffers of various sizes and durations around golden eagle nests. The USFWS Wyoming Field Office recommends a seasonal 0.5-mi (805-m) nest buffer from January 15–July 31 (http://www.fws.gov/wyominges/Species/Raptors.php), while the USFWS Utah Field Office recommends no surface occupancy within 0.5-mi of nests year round (Romin and Muck 2002). Recommendations from BLM field offices also vary in size and duration, including 0.75 mi (1207 m) from February 1–July 15 in the Lander Field Office, 600 m from February 1–July 31 in the Rock Springs Field Office, and a year-round buffer of 0.25 mi (402 m) and seasonal buffer of 0.5 mi from December 15–July 15 in the Vernal Field Office. Colorado

Parks and Wildlife recommends the same size and duration of buffers as the Vernal Field Office.

Flushing distance, the distance from an approaching disturbance at which a bird initiates flight, is a common measure of sensitivity to disturbance. Only one empirical study is available on flushing distances of golden eagles (Spaul 2015), and other estimates of the distances at which golden eagles are impacted by various types of disturbance come from expert elicitations (Suter and Joness 1981, Whitfield et al. 2008, U.S. Fish and Wildlife Service 2017b). Accordingly, no data are available on flushing distances specific to the WYUB. Results from expert elicitations suggest buffer sizes of 0.5 mi (800 m) currently recommended by some agencies in the WYUB may be sufficient to protect many golden eagles from disturbance (U.S. Fish and Wildlife Service 2017b), while results from empirical studies suggest larger 1000-m (0.62 mi) buffers would be necessary to achieve a 95% reduction in flushing (Spaul 2015). Although flight initiation distance is the most common metric for response to disturbance, effects on behavior and reproduction may occur at greater distances. For example, experts estimated golden eagles could fail to breed in response to various forms of human disturbance within 914–1,408 m (U.S. Fish and Wildlife Service 2017b). Decreasing use of nest sites with greater density oil and gas development within an 800-m radius (Smith et al. 2010) suggests that stipulations for no surface occupancy, rather than timing limitations, could be necessary to maintain nest use. Another important consideration that is not addressed by current stipulations is that buffering only recently occupied nests may fail to protect the full territory of a breeding pair of golden eagles. For example, golden eagles in Idaho reused 34% of alternative nest sites at greater than 10-year intervals (Kochert and Steenhof 2012), and eagles perching and foraging away from nest sites can also be affected by disturbance (Spaul 2015). Experts consulted by USFWS agreed that buffers including all known nests or sized to the core areas of breeding territories would be the most effective way to protect golden eagles from human disturbance (U.S. Fish and Wildlife Service 2017b).

Seasonal buffers recommended by agencies in the WYUB begin as early as December 15 and last as late as July 31. Seasonal buffers are intended to cover the nesting period of golden eagles, when they are localized at nest sites and most sensitive to disturbance. Seasonal nest buffers do not protect territorial pairs outside the breeding season and little is known about effects of disturbance to golden eagles during the courtship phase, which begins before most seasonal buffers (U.S. Fish and Wildlife Service 2017b).

Spatial and seasonal buffers recommended in agency management plans are subject to exceptions that can be justified in the National Environmental Policy Act (NEPA) review process. Regional USFWS Ecological Services offices are the best resource for guidance on management practices least likely to qualify as "take" under law. Further research is necessary to assess the effectiveness of buffers and other management techniques to reduce disturbance. We are not aware of scientific evidence supporting some factors currently used to justify exceptions to recommended nest buffers in the NEPA process. For example, we are not aware of any research supporting reduced disturbance for nests with unobstructed lines of sight to potentially disturbing infrastructure or activities (e.g., well pads, drill rigs).

Further, it is important to note that all available research on impacts of disturbance and effectiveness of nest buffers has been conducted under nest protections similar to those currently stipulated. Exceptions to spatial and seasonal buffers should, therefore, only be made following rigorous scientific studies to quantify impacts.

4. Conservation and Risk Assessments

The Conservation and Risk Assessments section provides spatial planning tools based on information and modeling results compiled in the assessment. These include a regional habitat conservation prioritization and spatial risk assessments for major hazards. The areas of high conservation value and risk identified in the maps and discussion can be used to direct application of conservation measures recommended in the Conservation Strategy.

4.1. Conservation status

Golden eagles in the U.S. receive federal protection under the Bald and Golden Eagle Protection Act (BGEPA; 16 U.S.C. 668-668c) and the Migratory Bird Treaty Act (MBTA; 16 U.S.C. 703-712). BGEPA prohibits unauthorized "take" of golden eagles, which includes to "pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, destroy, molest or disturb" (16 U.S.C. 668c; 50 CFR 22.3). In addition to Federal protection, golden eagles receive various conservation designations from Federal and State management agencies in the WYUB (Table 4.1). Collaborative groups have been formed to advance conservation of golden eagles in the WYUB, including state golden eagle working groups in Utah, Montana, and Wyoming.

Table 4.1. Conservation status designations for the golden eagle by management agency in the Wyoming and Uinta Basins Conservation Strategy Area. Abbreviations are defined in the front matter.

State	Entity	Designation	Document
Federal	USFWS	BGPA, MBTA; BCC (Region 6)	Federal register; Birds of Conservation Concern 2008
Colorado	Colorado Parks and Wildlife	SGCN, Tier 1	2015 State Wildlife Action Plan
Idaho	Idaho Fish and Game	SGCN 3, Tier 2	2015 State Wildlife Action Plan
Montana	Montana Fish, Wildlife, and Parks	SGCN S3	2015 State Wildlife Action Plan
Utah	Utah Division of Wildlife	SGCN 4	2015 State Wildlife Action Plan
Wyoming	Wyoming Game and Fish Department	SGCN 4, Tier 2	2017 State Wildlife Action Plan

4.2. Conservation prioritization

The conservation prioritization identifies where concentrations of high-quality golden eagle habitat occur in the WYUB. To describe the distribution of habitat value within the WYUB, we calculated the *proportion of total habitat value* and *ratio of habitat value to area* within sub-regions (i.e., ecological sections). We then identified where opportunities exist for management and conservation by summarizing the amount and proportion of habitat within administrative areas (i.e., surface management entities, BLM Field Offices), and the current protected status of golden eagle habitat based on GAP protection categories (USGS-GAP 2014) and habitat protections for greater sage-grouse.

The *proportion of total habitat value* is a measure of the amount of habitat value in a given area as a percentage of the total amount of habitat value across the study area. It was calculated as the sum of the cell values from the habitat model within the focal area divided by the sum of all cells in the study area. The *ratio of habitat value to area* is a measure of the density or concentration of risk in a given area relative to what would be expected based on the size of that area. It was calculated as the percentage of habitat value within the focal area divided by the percentage of the study area composed by the focal area, with negative numbers indicating less habitat value than expected based on area and positive numbers indicating higher density of habitat value. Taken together, these metrics may be useful to prioritize areas within the WYUB for conservation or development based on the amount and concentration of golden eagle habitat value they contain.

This assessment identifies concentrations of high-quality habitat; however, we recognize that golden eagles inhabit most areas of the WYUB. Some management actions may be most effective when implemented in the concentrations of high-quality habitat identified here (e.g., establishment of protected areas), while others may provide disproportionate benefit in areas of marginal habitat (e.g., prey habitat restoration). Additionally, it is important to recognize that conservation measures can benefit eagle populations at a range of scales, from a single nest site, to an administrative unit, to the entire WYUB, and beyond. The conservation prioritization presented here is best applied at broader spatial scales of landscapes and ecoregions (thousands to millions of ha).

4.2.1. Breeding priority areas

The WYUB is one of the most important breeding areas for golden eagles in the western U.S. (Nielson et al. 2016b). Because golden eagles breeding in WYUB are non-migratory, high-quality nesting areas represent year-round habitat for the breeding segment of the population, as well as their sub-adult young. The prevalence of golden eagle habitat in the WYUB creates challenges for land managers seeking to designate areas for conservation and development. Unlike most other regions, there are few obvious, large areas of low-quality habitat. Nonetheless, smaller areas of concentrated high-quality habitat and relatively lower-quality habitat can be found in most areas of WYUB.

Golden eagles are highly selective of nesting habitat and the best-quality areas for nesting occupy only a small areal extent of the landscape. Based on the WGET RND model, only 0.1% of the land area of the WYUB consisted of the highest quality habitat (RND >0.9) and only 7.2% was of moderate-to-high quality (RND >0.6). Most of the ecoregion (64.3%) was composed of lower quality habitat (RND <0.3). Only 13.4% of the WYUB was of lowest habitat quality (RND <0.1), while most other ecoregions for which WGET created habitat models were predominately composed of lands with very low nesting densities (e.g., RND <0.1 in >65% of the Northern Basin and Range Conservation Strategy Area and >60% of the Central Great Basin Conservation Strategy Area; Dunk et al. in review). In the five other modeling regions, which were also selected because of their importance to golden eagle populations, the lowest RND bin accounted for the largest area. By contrast, the WYUB had only a small area with very low nesting densities. These results suggest that the WYUB is unique in lacking large areas of poor nesting habitat, and the relatively low-quality areas of the WYUB likely support higher nesting densities than the low-quality areas of other regions.

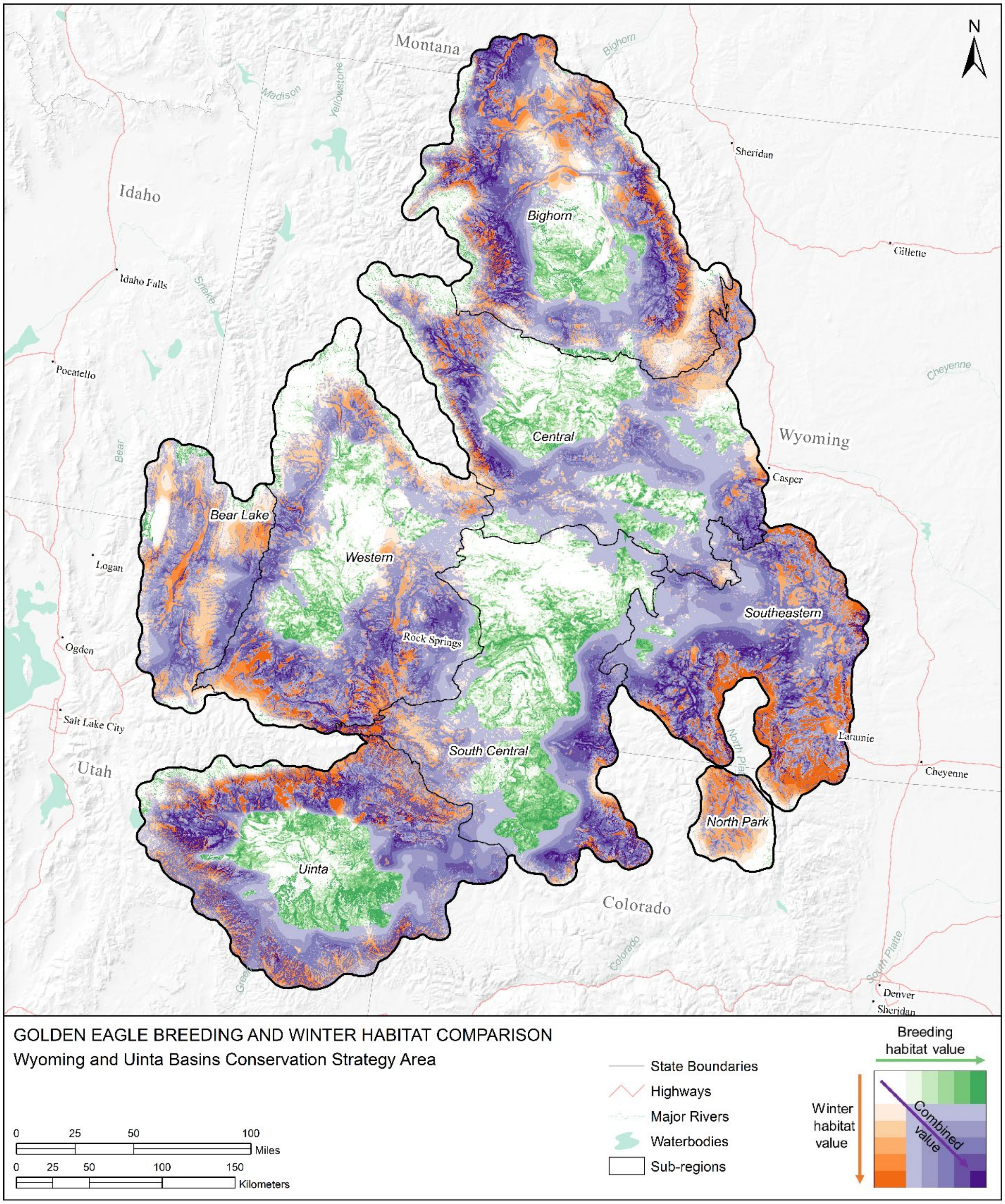

Figure 4.1. Comparison of breeding and winter habitats of golden eagles in the Wyoming and Uinta Basin Conservation Strategy Area. Breeding habitat value is shown in shades of green, winter habitat value in orange, and areas of overlapping habitat in purple.

The larger ecological sections of the WYUB had similar amounts of habitat value, ranging from 19% in the Uinta section to 11% in the Southeastern section, while the smaller sections had less habitat value, ranging from 6% in Bear Lake section to <1% in North Park (Figure 4.2). Only the Uinta Basin had a notably higher concentration of habitat than expected based on its size, while North Park had less habitat value than expected. Higher habitat values were concentrated in the Tavaputs Plateau, South Uinta Basin, and Axial Basin of Utah and Colorado; the portion of the Bighorn Basin in Montana; and Sage Creek Basin-Severson Flats, Hanna Basin-Rawlins Uplift, Bates Hole, Saratoga Basin, and Flaming Gorge Canyonlands in Wyoming. Other areas of higher habitat value included the western foothills of the Bighorn Basin, the western Wind River Basin, the Rattlesnake Hills and Granite Mountains, Shirley Basin, the Rock Springs uplift, Oyster Ridge, the Owl Creek Mountains, the western foothills of the Sierra Madre, and the southcentral Green River Basin. Lower concentrations of habitat values generally occurred in flat basins, including the upper Green River Basin, Great Divide Basin, North Park, the central Wind River Basin, and central Uinta Basin.

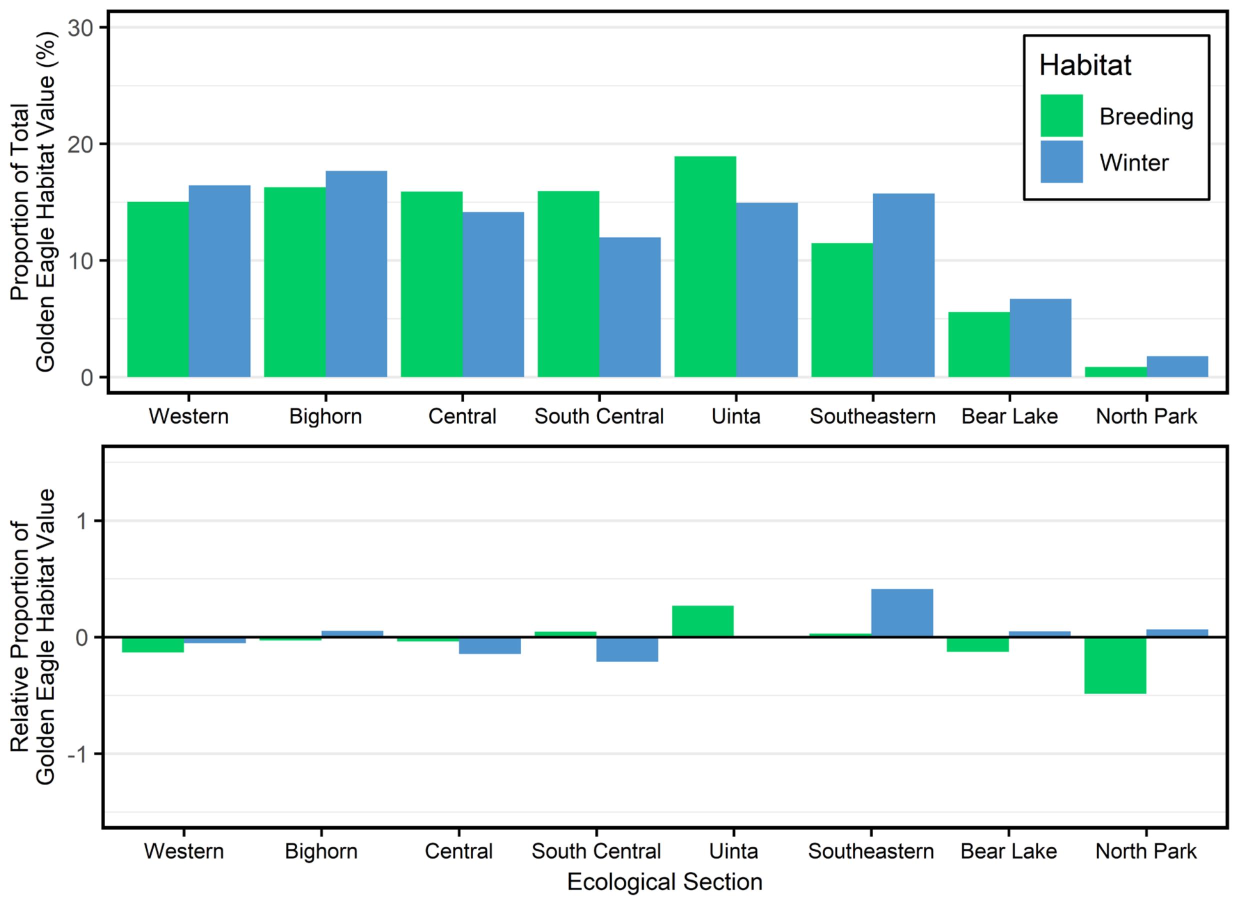

Figure 4.2. Golden eagle breeding and winter habitat value within eight ecological sections of the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total habitat value (top) shows the relative amount of habitat in each area, while the proportion of habitat value to area (bottom) shows the relative concentration of habitat. Ecological sub-regions are shown in descending size order from left to right.

Distribution of habitat among surface management agencies and entities (Figure 1.5) was generally proportional to their areas, with the greatest amount of habitat value managed by BLM (47%) and private landowners (32%), and lesser amounts by State (8%), Tribal (7%), USFS (4%), and others (<1% each; Figure 4.3). BLM field offices (FOs) with larger areas encompassed greater amount of habitat value, including Rawlins (19%), Vernal (12%), Lander (12%), Rock Springs (11%), Worland (8%), Little Snake (8%), Kemmerer (6%), and Cody (5%). Habitat value was generally proportional to FO area, except that FOs in the Uinta Basin had greater habitat value than expected based on their size. These included the White River, Price, Little Snake, Moab, and Vernal FOs. Similarly, the small extent of the Billings FO in the northern WYUB had a disproportionate concentration of habitat value.

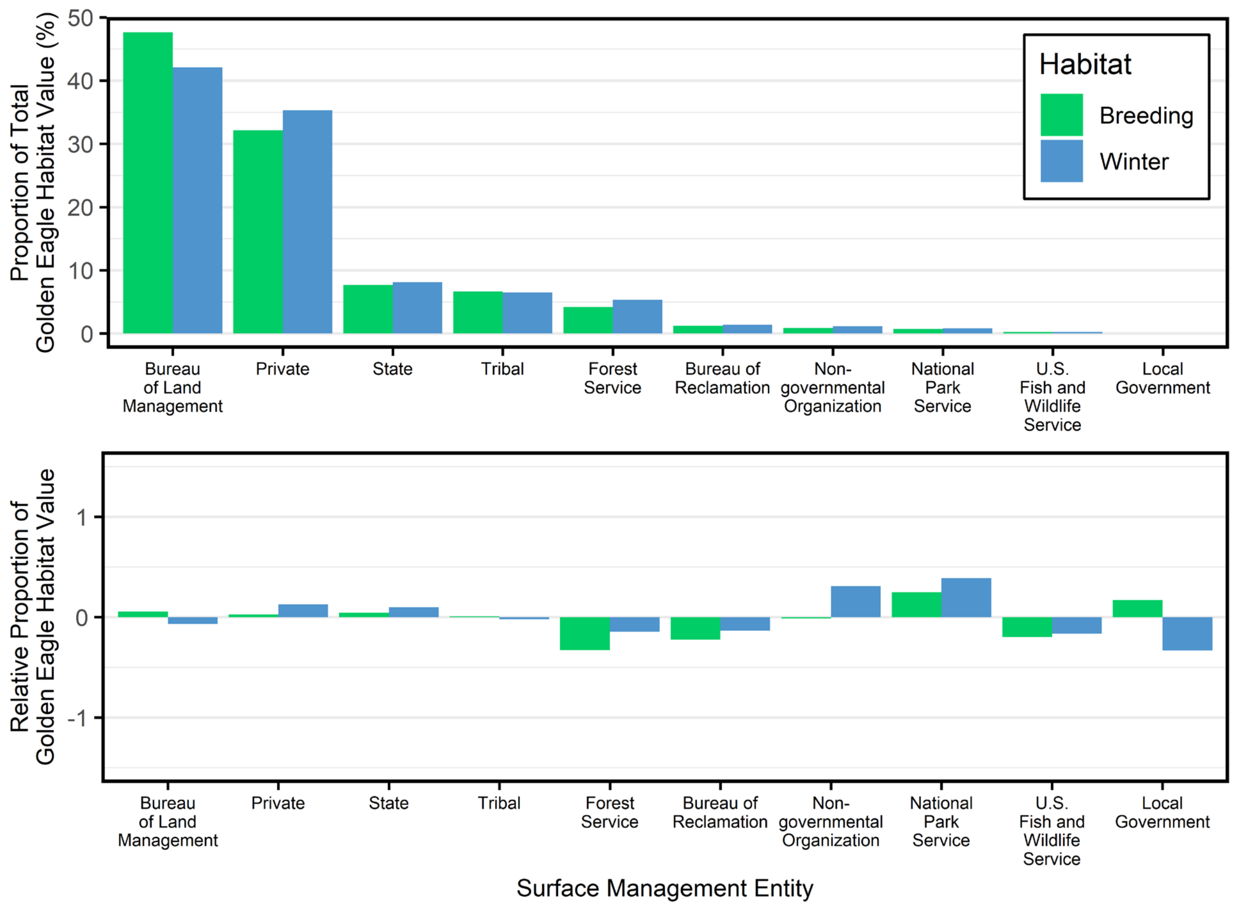

Figure 4.3. Golden eagle breeding and winter habitat value by surface management entity in the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total habitat value (top) shows the relative amount of habitat in each area, while the proportion of habitat value to area (bottom) shows the relative concentration of habitat. Management entities are shown in descending size order from left to right.

The majority of risk was in areas that had little (56%; GAP Status 3) or no known (38%; GAP Status 4) protection from development by extractive industries, while a smaller area (5%; GAP Status 1 and 2) had permanent or temporary protection from development.

Considering greater sage-grouse PACs (Figure 1.5), the amount of predicted habitat value in areas with protected status increased to 37%. The increase in protected habitat was driven by PAC coverage of lands in GAP categories 3 and 4 managed by BLM (+18%) and private owners (+12%). Although PACs substantially increased the area of protected land at a broad scale, the extent to which stipulations for sage-grouse co-benefit eagles is unclear. Fine-scale overlap of habitat may be limited because golden eagles nest in steep terrain that is typically be avoided by sage-grouse. Restrictions on densities of development in sage-grouse habitat are, thus, more likely to conserve golden eagle foraging areas than nesting habitat.

4.2.2. Winter priority areas

Selection of winter habitat by golden eagles was broader than breeding habitat. Similar to breeding habitat (WGET RND model), the highest quality winter habitat (winter use probability >0.9 from WGET RWD model) occupied a very small amount of the land area (0.01%). In contrast to breeding habitat, more than twice as much winter habitat area (15.5%) was of moderate-to-high quality (>0.6), less than half as much (27.6%) was composed of lower quality habitat (<0.3), and the majority (57.0%) was of moderate quality (0.3–0.6). These results suggest a larger area of the landscape provided moderate-to-high-quality habitat for golden eagles during winter, consistent with evidence that golden eagles are highly selective of nesting habitat (Dunk et al. in review), but expand their use areas during winter (Domenech et al. 2015). Additionally, the RWD model was developed at a broad spatial scale across the western U.S., resulting in more general distribution of predicted habitat values.

Breeding and winter habitat overlapped in some areas, while other areas were used more intensively during winter (Figure 4.1). Areas of increased winter use that were not captured by the breeding habitat model included the southern Laramie Basin, Saratoga Basin, upper Wind River Basin, southern slope of the Uinta Mountains, and southern Green River Basin. It is unclear which segments of the eagle population are using these areas, but they bear consideration for year-round habitat conservation, as well as planning of disturbing activities conducted during winter (e.g., oil and gas well drilling).

The amount of habitat value in ecological sections was broadly similar between winter and breeding habitat. Compared to breeding habitat, winter habitat values were slightly higher in the Western, Bighorn, Southeastern, Bear Lake, and North Park sections, and slightly lower in the Central, South Central, and Uinta Sections (Figure 4.1 and Figure 4.2). Concentration of habitat value was also broadly similar between breeding and winter, with the most marked increase during winter in the Southeastern section, due to greater use of the Laramie, Shirley, and Saratoga Basins. More concentrated use of the southeastern basins during winter also increased the proportion of habitat value on private lands, compared to the breeding season (Figure 4.3). The amount of habitat value in BLM FOs, GAP conservation status, and coverage by greater-sage grouse PACs were similar for winter and breeding habitats.

4.2.3. Migration priority areas

Migration corridors and concentration areas for golden eagles in WYUB remain largely unknown (see Movements and Migration above). Data from one study suggested most fall migrants passed through the western Bighorn Basin, along the eastern edge of the Greater Yellowstone Ecosystem, then down the eastern front of the Wind River Range, before dispersing into the Great Divide and Green River Basins (Bedrosian et al. 2018a). These results were broadly consistent with models developed by a different study (Pocewicz et al. 2013). Large numbers of migrating golden eagles were also counted in fall from Commissary Ridge on the western edge of the Green River Basin, near Kemmerer, Wyoming (Oleyar 2017). While broad-scale models of migratory concentration areas in the WYUB are still lacking, available studies have several important implications for conservation of golden eagle migration habitat in the region. First, they suggest fall migrants followed the eastern slopes of the interior ranges of the Rockies along the Absaroka, Wind River, and Wyoming Ranges, rather than the front-range of the Rockies along the Bighorns and Laramie Range. This pattern indicates that eagles migrating down the Rockies are expected to pass through the WYUB, rather than neighboring ecoregions. Second, migratory routes tended to follow the eastern foothills of major North-South trending mountain ranges. Priority areas for conservation of migratory habitat within the WYUB should include areas along the western edges of the Bighorn, Wind River, and Green River Basins. Third, migratory paths appear to disperse when they reach the low-lying terrain of the southern Wyoming basins. This pattern presents a challenge for conservation planning, as migrant eagles may follow any number of terrain features through southern Wyoming. Finally, little information is available on spring migration routes, which are expected to differ to some extent from fall. Models of spring and fall movement currently in development by WGET will enable data-driven prioritization of movement habitats and formal risk assessments.

4.3. Spatial risk assessments

Golden eagles have large home ranges and can move great distances during dispersal and migration (Brown et al. 2017, Murphy et al. 2017). As a result, eagles can be exposed to numerous hazards across wide geographic areas (USFWS 2016). Understanding the relative magnitude of a hazard and its distribution in relation to eagle use of the landscape is important to effective conservation and management. To address variation in golden eagle exposure to risk, WGET and collaborators developed regional-scale, predictive models of golden eagle distribution (Dunk et al. in review) and movements (Brown et al. 2018) throughout the year. To prioritize relative risk across the landscape, we evaluated the overlap between spatial models of golden eagle habitat suitability and spatial data on hazards to eagles (Bedrosian et al. 2018b). Specifically, we overlapped models of habitat use by breeding and wintering golden eagles with data on potential for electrocution, development of wind and oil and gas resources, and lead exposure from big game hunting. The resulting spatial risk assessments can be used to inform planning for conservation and development at regional scales, including targeted mitigation, land acquisition, and siting of conventional and renewable energy developments. However, because these assessments provide a relative ranking of risk, they are not appropriate for calculating absolute exposure rates or estimating golden eagle fatalities at finer spatial scales (e.g., within a project footprint).

Effective wildlife conservation strategies rely on clear definitions of the factors that influence animal populations, including terminology pertaining to threats, risk, and risk management. Risk assessments are often described as the process of determining the likelihood that a specified event (e.g., mortality) will occur. In practice, however, it is often impossible or impractical to quantify the absolute probability of such events. Thus, we assessed the relative spatial risks within a given region (i.e., risk is higher in some places and lower in others, but the exact probability of an event is unknown) using the following definitions adapted from Smith (2003):

Risk — the relative threat to individual golden eagles or populations of reduced survival or reproductive success caused by a specific hazard. Risk is estimated as the combination of *hazard*, *exposure*, and *vulnerability*. Risk assessments are formal evaluations that take into account two or more of these components.

Hazard — natural or anthropogenic object, condition or event that, over some period of time, could potentially result in the death or significant reduction in fitness of one or more golden eagles.

Exposure — the degree of opportunity to encounter hazards, sometimes approximated by the relative density of golden eagles occurring in a particular area.

Vulnerability — the likelihood and magnitude of effect to an individual, population, or species upon exposure. Vulnerability may vary according to numerous intrinsic factors such as life-history, age class, and behavior, and extrinsic factors such as habitat, weather, and season. For example, large numbers of eagles may migrate through an area with dense electrical infrastructure (high hazard and high exposure), but if they rarely stop to perch on power poles, their vulnerability may be low. Vulnerability may increase, however, if inclement weather causes the eagles to halt migration and roost. Due to the difficulty of quantifying and predicting vulnerability, our risk assessments are limited to measures of *exposure* and *hazard*.

We visualized risk using color-coded maps and tables. Both show areas with higher eagle use and lower hazard in green, areas with higher hazard and lower eagle use in orange, and areas where higher eagle use coincides with higher hazard (i.e., higher risk areas) in purple). These maps and tables were designed to identify areas of higher risk where mitigation could be targeted and development avoided, as well as areas of opportunity where development of resources (e.g., wind power) is expected to have lower risk to eagles.

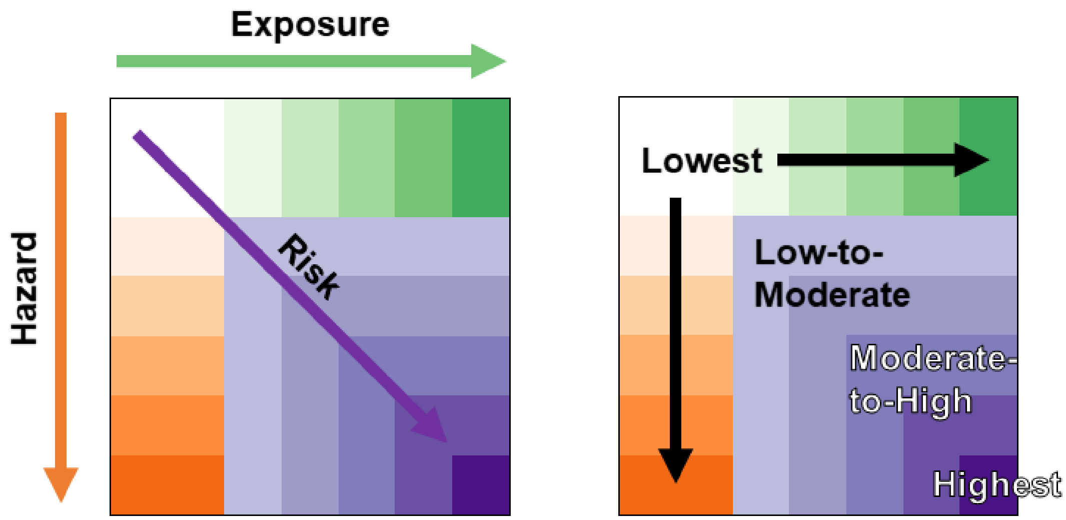

Figure 4.4. Color scheme for visualizing risk assessments. Left panel shows relative golden eagle habitat exposure (greens), hazard (oranges), and resulting risk (purples). Right panel shows terminology used for the level of risk in different areas of the matrix.

To further describe the pattern of risk within the WYUB, we calculated the *proportion of total risk* and *ratio of risk to area* within ecological sub-regions and administrative units. The *percentage of total risk* is a measure of the amount of risk in a given area as a percentage of the total amount of risk across the study area. It was calculated as the sum of the cell values from the risk model within the focal area divided by the sum of all cells in the study area. The *ratio of risk to area* is a measure of the density or concentration of risk in a given area relative to what would be expected based on the size of that area. It was calculated as the percentage of risk within the focal area divided by the percentage of the study area composed by the focal area, with negative numbers indicating less risk than expected based on area and positive numbers indicating higher density of risk. Taken together, these metrics may be useful to prioritize areas within the WYUB for conservation or development based on amount and concentration of risk.

4.3.1. Electrocution

To assess risk to golden eagles from electrocution (identified in the Conservation Assessment), we overlapped models of eagle breeding and wintering habitats with predicted density of power distribution poles (Dwyer et al. 2017a). The resulting maps identify areas of elevated electrocution risk to golden eagles, where higher-quality eagle habitat coincides with higher densities of power poles (Figure 4.8 and Table 4.3). These risk maps can also be used to identify high-priority areas where power pole retrofitting and other conservation measures (detailed in the Conservation Strategy) are expected to provide the greatest benefit to golden eagles. We used models of power pole density as a surrogate for electrocution risk because maps of actual power poles were not available. Results of this assessment should be compared with current, local data on power pole locations, configurations, and existing retrofits when assessing the feasibility of mitigation projects. The electrocution risk assessment is limited to the portions of Wyoming, Colorado, and

Montana in the WYUB (Figure 4.5) because power pole density models were not available for Idaho and Utah.

Risk from electrocution

A small portion of the WYUB was classified as having the highest (2.4%, bin 7 in Table 4.2) or moderate-to-high level of electrocution risk (16.7%, bins 5–6) to golden eagle breeding habitat. Most of the region had lowest (49.7%, bins 1–2) or low-to-moderate risk (31.5%, bins 3–4). Compared to breeding habitat, winter habitat had slightly more area with highest risk (3.2%), and similar amounts of moderate-to-high (16.9%), low-to-moderate (31.6%), and lowest risk (48.5%). Although the highest risk areas occupied only a small portion of the assessment area, they included a substantial number of distribution poles: of an estimated total of 136,460 distribution poles in the assessment area, the highest risk areas included 18,343 poles (13%) in breeding habitat and 25,169 poles (18%) in winter habitat.

A test of this risk assessment method in the neighboring Northern Great Plains CSA (NGP) found that 86% of golden eagle electrocutions in breeding habitat occurred in moderate-to-highest risk areas (bins 5–7) and 99% occurred in low-to-highest risk areas (all purple areas, bins 3–7; Bedrosian et al. 2018b). These results indicated that the modeling process was successful at discriminating higher-risk areas and suggested that improvements in conservation efficiency could be achieved by focusing retrofitting efforts in these areas. For example, the high-to-highest risk area (bins 6–7) of the NGP covered only 21% of the landscape, but accounted for 56% of electrocutions; focusing retrofitting effort in that area could more than double the effectiveness of mitigation efforts. The value of spatial risk assessment to prioritize retrofitting is also apparent when comparing variation in electrocution risk among areas of the WYUB. For example, a high density of power poles occurs in lower quality eagle habitat in the central Wind River Basin, whereas a similar density of power poles overlaps high-quality eagle habitat in northwestern Colorado (Figure 4.5). Even though the central Wind River Basin has a higher hazard density, our results suggest greater conservation benefit could be achieved by retrofitting power poles in northwestern Colorado because golden eagles are more likely to be exposed to the electrocution hazard in that area.

Table 4.2. Relative risk of electrocution for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within (A) breeding and (B) winter habitats. Colors match the maps in Figure 4.5. Cell values show the percentage of the total assessment area (184,505-km^2) in each risk class.

(A) Golden Eagle Breeding Habitat

Power Pole Density	1	2	3	4	5	6	7
1	1.7	1.8	1.9	1.9	2.0	2.2	2.7
2	1.8	2.1	2.4	2.4	2.2	1.8	1.6
3	2.0	2.1	2.3	2.3	2.1	1.9	1.6
4	2.2	2.2	2.2	2.1	2.0	1.9	1.7
5	2.2	2.2	2.1	2.0	2.0	2.0	1.9
6	2.0	2.0	1.9	1.9	2.0	2.3	2.3
7	2.4	1.9	1.7	1.8	1.9	2.3	2.4

(B) Golden Eagle Winter Habitat

Power Pole Density	1	2	3	4	5	6	7
1	2.0	2.3	2.4	2.3	2.0	1.9	1.5
2	2.1	2.4	2.4	2.2	1.9	1.7	1.5
3	2.1	2.3	2.3	2.2	2.0	1.8	1.6
4	2.0	2.3	2.2	2.1	2.0	2.0	1.7
5	1.9	2.2	2.1	2.1	2.0	2.0	2.1
6	1.6	2.1	2.0	2.0	2.0	2.1	2.6
7	1.5	1.9	1.7	1.8	1.9	2.2	3.2

Risk by region

Electrocution risk varied widely across the WYUB. Distribution pole density was greatest in areas with more roads, more oil and gas wells, and relatively flat terrain (Dwyer et al. 2016). Accordingly, risk was highest where these anthropogenic features overlapped higher-quality golden eagle habitat (Figure 4.5). Higher-risk areas included the major river valleys of the region, like the Bighorn and Saratoga Basins; areas of intensive energy development, like the gas fields of the southern Great Divide Basin, portions of northwestern Colorado, Bighorn Basin, and Green River Basin; and the vicinity of towns like Rock Springs and Casper. The lowest risk areas had low human population density, less energy development, and terrain that was steeper and more rugged. Differences in risk to breeding and winter habitats were driven by increased use of the southeastern Basins, northern Bighorn Basin, and southwestern Wyoming during winter.

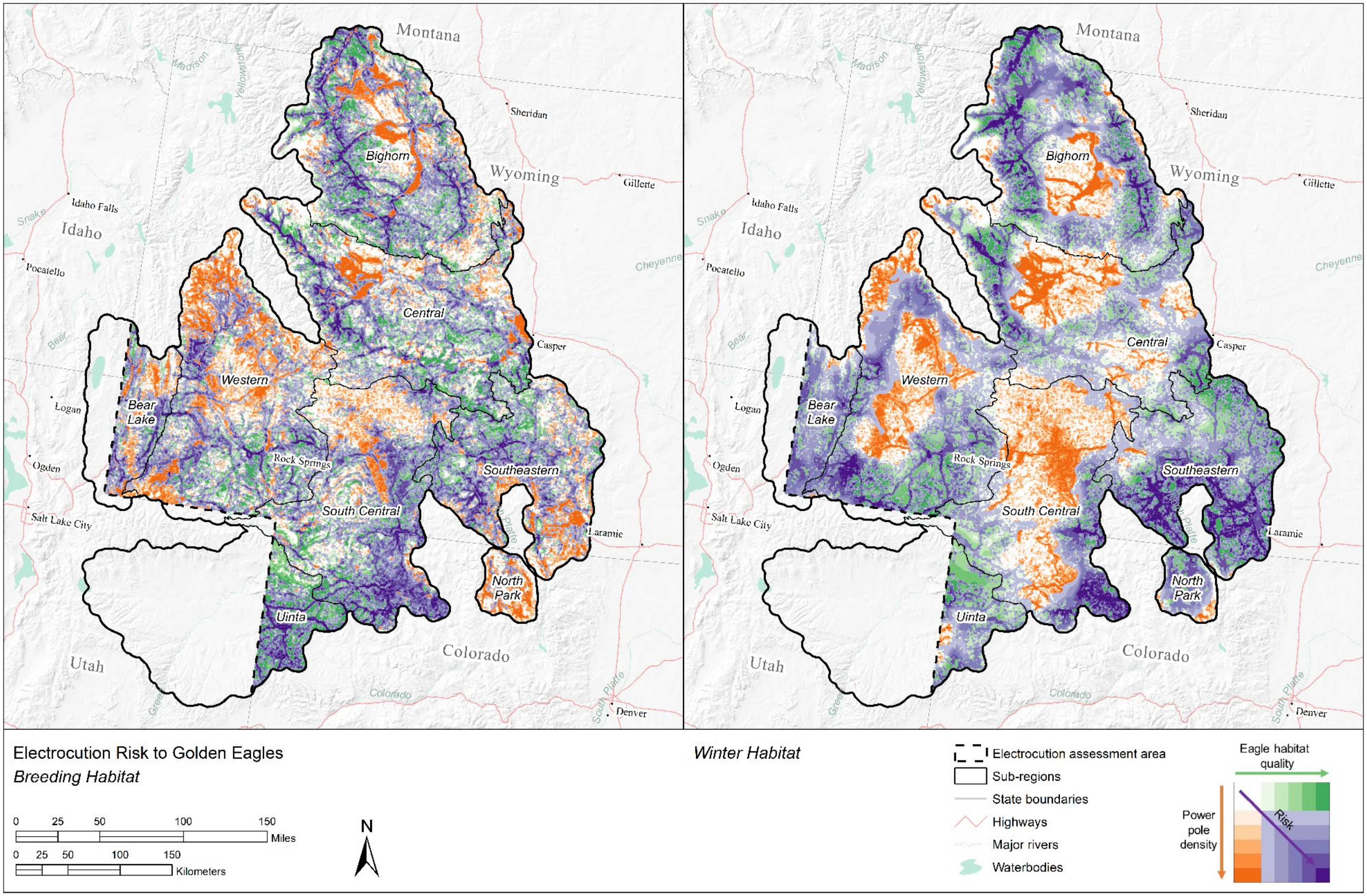

Figure 4.5. Relative risk of electrocution for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within (A) breeding and (B) winter habitats. Colors match the cells in Table 4.2.

Within ecological sections (Figure 4.5), the greatest amount of risk was in the Bighorn (Breeding: 20%, Winter: 22%), Western (Breeding: 18%, Winter: 19%), Central (Breeding: 18%, Winter: 16%), and South Central sections (Breeding: 17%, Winter: 12%; Figure 4.6). Risk was generally proportional to the area of ecological sections, except winter habitat in the Southeastern and North Park sections had more concentrated risk than expected, and winter habitat in the South Central and Uinta sections had less. Compared to breeding habitat, the amount of risk to wintering habitat was markedly greater in the Southeastern section, moderately greater in the Western and Bighorn sections, and similar in others.

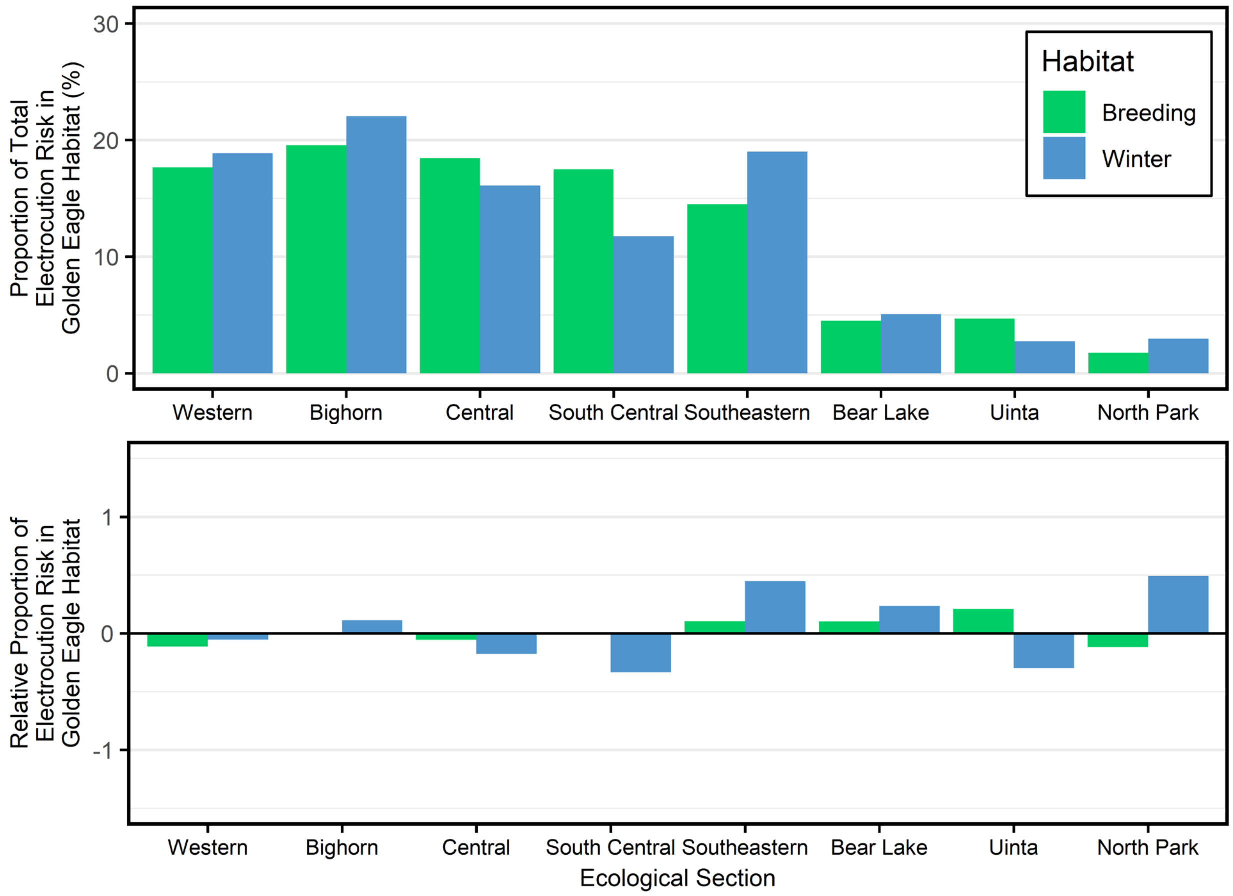

Figure 4.6. Electrocution risk in breeding and winter habitats of golden eagles within eight ecological sections of the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportions of risk to sub-region area (bottom). Ecological sub-regions are shown in descending size order from left to right.

Risk by management and protected status

Private lands had by far the greatest amount of electrocution risk (Breeding: 55%, Winter 62%), followed by BLM (Breeding: 27%, Winter 20%), Tribal (Breeding: 8%, Winter 7%), and State (Breeding: 6%, Winter 6%). Private lands also had a greater concentration of risk than expected for their area, while BLM, USFS, NPS, and other Federal lands had less risk than expected. Tribal and Bureau of Reclamation lands had moderately higher risk than expected. Elevated risk on private lands during winter was driven by increased golden eagle use of the southeastern basins, which have more private ownership than other areas of the WYUB.

BLM field offices (FOs) with relatively larger areas encompassed greater amount of risk: Rawlins (Breeding: 21%, Winter: 22%), Lander (Breeding: 14%, Winter: 11%), Cody (Breeding: 8%, Winter: 12%), Kemmerer (Breeding: 9%, Winter: 10%), Worland (Breeding: 9%, Winter: 8%), Little Snake (Breeding: 9%, Winter: 7%), Rock Springs (Breeding: 8%, Winter: 8%), and Pinedale (Breeding: 6%, Winter: 7%). In addition to having large amounts of risk, the Cody, Pinedale, and Kemmerer FOs had greater proportions of breeding and winter habitat risk than expected based on their size, and the Little Snake FO had greater than expected risk in breeding habitat. The small extents of the White River and Kremmling FOs in the WYUB also contained a disproportionate amount of risk for breeding and winter habitat, respectively, while the Rock Springs, Casper, and Lander FOs had moderately less risk than expected for their size.

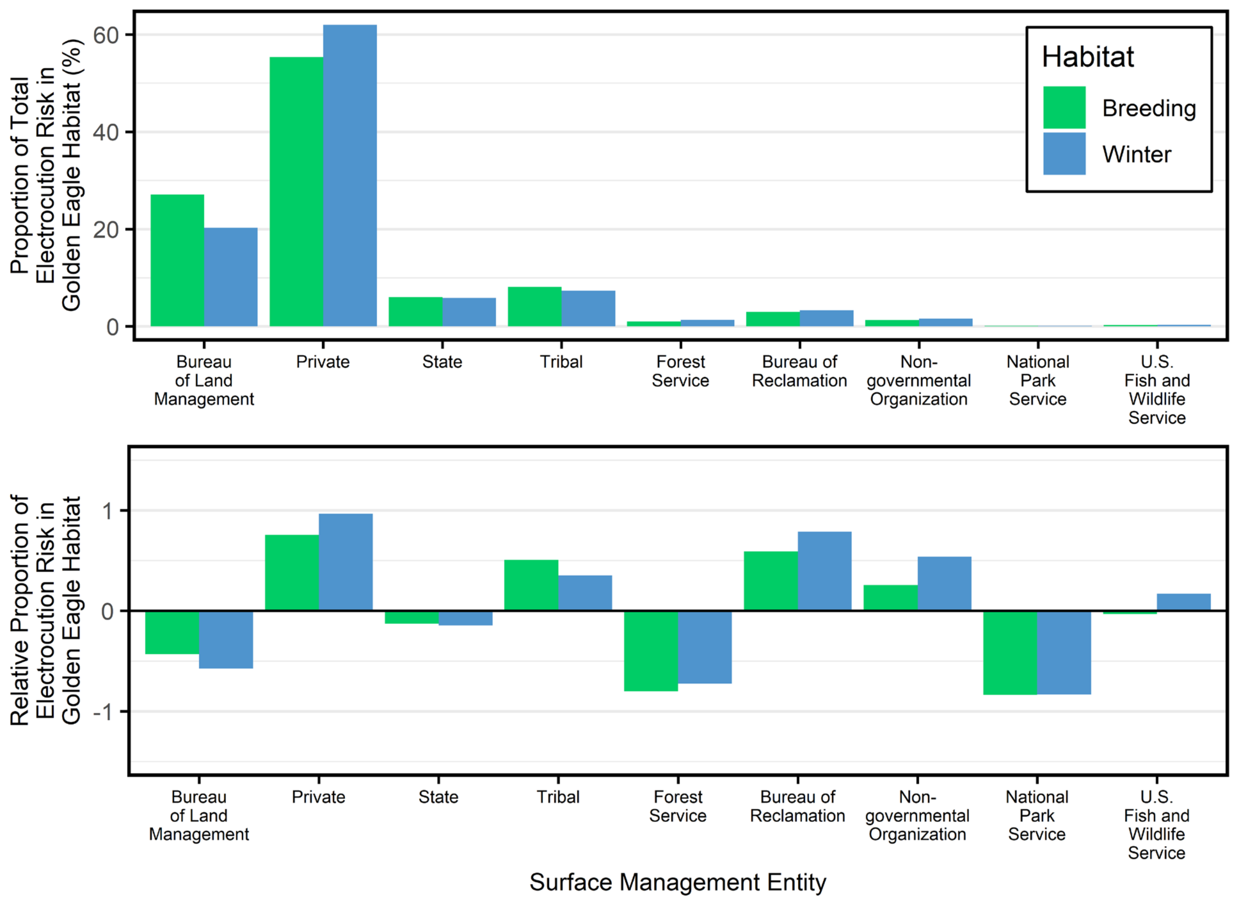

Figure 4.7. Electrocution risk in breeding and winter habitats of golden eagles by surface management entity within the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportions of risk to management area (bottom). Management areas are shown in descending size order from left to right.

The majority of electrocution risk was in areas with little or no protection from development by extractive industries. More than half of risk was in areas that had lower (GAP Status 3; Breeding: 36%, Winter: 30%) or no known (GAP Status 4; Breeding: 64%, Winter: 70%) protection from development, while a smaller amount of risk (GAP Status 1 and 2; Breeding: 2%, Winter: 3%) was predicted to occur in areas with permanent or temporary protection from development. This is not surprising because power distribution infrastructure is associated with developed areas; however, the low conservation status of higher-risk areas shows that future increases in power pole density and concomitant impacts to golden eagles are unrestricted in most areas of the WYUB.

4.3.2. Wind resource development

To assess spatial risk to golden eagles from hazards associated with wind energy development (identified in the Conservation Assessment), we overlapped models of eagle breeding and wintering habitats with data on wind speeds (National Renewable Energy Laboratory 2015). The resulting maps identify areas of elevated risk to golden eagles (where higher-quality eagle habitat coincides with higher wind speeds) and areas of opportunity for wind resource development (where high-wind speeds coincide with lower-quality eagle habitat; Figure 4.8 and Table 4.3). These maps can be used to avoid and minimize conflicts with golden eagles during preliminary site evaluation, equivalent to Stage 1 of the Eagle Conservation Plan Guidance (ECPG; U.S. Fish and Wildlife Service 2013). They can also be used to guide application of additional conservation measures (detailed in the Conservation Strategy). We acknowledge that wind energy siting decisions are influenced by factors in addition to wind speed (e.g., access to transmission, land ownership and management, permitting). However, due to the difficulty of predicting these factors, we have followed other studies (Tack and Fedy 2015, Mojica et al. 2016) that used wind power classes (WPC) as a surrogate for the likelihood of development. Results of this assessment should be compared with current, local data when assessing the feasibility of development or conservation of a given area.

Risk from wind resource development

Only a small portion of the WYUB was classified as having highest (0.1%, bin 7 in Table 4.3) or moderate-to-high risk (4.9%, bins 5–6) to golden eagle breeding habitat from wind resource development. Most of the region had lowest risk (68.4%, bins 1–2) or low-to-moderate risk (26.6%, bins 3–4). The pattern of risk was broadly similar between winter and breeding habitat, with slightly more area of winter habitat having moderate-to-high risk (5.1%), and slightly less area with lowest risk (66.7%). Like breeding habitat, most winter habitat had low risk of wind development and only a small area was classified in the highest risk category (0.3%, bin 7).

Wind power classes (WPC) ≥3 are considered sufficient for industrial-scale wind energy development with current technology and WPC ≥5 are excellent (Fargione et al. 2012). Risk to golden eagles from wind development occurred in a sizeable area where moderate-to-highest quality habitat (Breeding: 17.4%, Winter: 18.5%) overlapped areas with wind speeds sufficient for development. Although the majority of WYUB had relatively low risk, most of that area also had wind speeds too low for development. A quarter of the WYUB (Breeding: 25.5%, Winter: 24.3%) had moderate-to-highest quality habitat and wind speeds too low for development. Preservation of golden eagle habitat is unlikely to conflict with wind development in these areas (shown in green on maps and tables). Nonetheless, some opportunities for wind development existed where relatively high wind speeds coincided with relatively low-quality golden eagle habitat (shown in orange on maps and tables). Only a small portion of the WYUB (Breeding: 2.7%, Winter: 1.2%) had excellent wind resources and lowest-quality golden eagle habitat, but a larger area (Breeding: 13.6%, Winter: 12.0%) had wind speeds feasible for development in lowest-quality eagle habitat. Considering areas with lowest-to-moderate quality golden eagle habitat (bins 1–4), more than one quarter of the WYUB (Breeding: 27.8%, Winter: 26.7%) had wind speeds feasible for development in areas of relatively low potential conflict with eagles.

Table 4.3. Relative risk of wind resource development for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within (A) breeding and (B) winter habitats. Colors match the maps in Figure 4.3. Cell values show the percentage of the total assessment area (184,505-km²) in each risk class.

(A) Golden Eagle Breeding Habitat

Wind Potential Class	1	2	3	4	5	6	7
1	3.2	2.8	3.1	3.4	3.8	4.7	5.8
2	4.8	4.3	3.9	3.8	3.7	3.6	3.8
3	3.5	3.7	3.6	3.3	3.0	2.6	1.9
4	1.8	2.0	2.0	2.0	2.0	1.7	1.3
5	0.7	0.9	1.1	1.2	1.3	1.1	0.9
6	0.3	0.4	0.4	0.4	0.4	0.5	0.4
7	0.2	0.2	0.1	0.1	0.1	0.1	0.1

(B) Golden Eagle Winter Habitat

Wind Potential Class	1	2	3	4	5	6	7
1	4.5	3.7	2.8	3.3	4.2	3.9	4.3
2	4.5	4.0	3.8	3.9	4.0	4.2	3.7
3	3.4	3.7	3.1	2.8	2.8	2.9	2.9
4	1.6	2.2	2.4	2.0	1.5	1.5	1.6
5	0.2	0.6	1.6	1.6	1.4	1.0	1.0
6	0.1	0.2	0.5	0.6	0.4	0.5	0.6
7	0.2	0.1	0.1	0.1	0.1	0.2	0.3

Although areas with excellent quality wind resources and lower potential conflict with golden eagles covered only a small area of the WYUB (Breeding: 4,945 km²; Winter: 2,288 km²), that area had the capacity to generate 10–20 times the U.S. Department of Energy's (DOE) 2030 wind energy production goal for Wyoming (U.S. Department of Energy 2015). Based on the average MW/km² capacity in each WPC (Fargione et al. 2012), we calculated that lower conflict areas of the WYUB had the capacity to generate 26.6 GW in breeding habitat and 12.36 GW in winter habitat, far exceeding the DOE target of 1.28 GW. While the actual extent of development will likely be constrained by access to transmission and other factors, our results suggest wind capacity could be expanded substantially in the WYUB with minimal conflict for golden eagles.

Despite opportunities for low-risk development, existing wind energy facilities in the WYUB are concentrated in riskier areas: 46% (382) of turbines are in moderate-to-highest quality golden eagle breeding habitat, 32% (83) of turbines are in low-to-moderate quality habitat, and 21% (113) of turbines are in lowest-quality habitat. Compared to breeding habitat, existing turbines are in even riskier areas of golden eagle winter habitat: 60% (460) of turbines are in areas of moderate-to-highest quality habitat (60%), 40% (118) turbines are in low-to-moderate quality areas, and none are in the lowest quality habitat. The proposed turbine locations for Phase I of the Choke Cherry and Sierra Madre Wind Energy Development are also in areas with higher predicted risk to golden eagle breeding habitat: 86% (429) of turbines are in moderate-to-highest quality habitat, 14% (67) in low-to-moderate quality areas, and 1% (4) of turbines are in the lowest-quality habitat.

Risk by region

The largest contiguous area of moderate-to-highest risk from wind development was on low mountains and hills in the open basins of the southeastern WYUB (Figure 4.8), where continentally high wind speeds coincided with high-quality golden eagle habitat. Some predicted areas of highest-risk occurred in locations where development is unlikely due to steep or forested terrain, like the Laramie and Absaroka Mountains. Other moderate-to-highest risk areas were in open, lowland habitats where wind energy development is more plausible, including areas of the Granite Mountains, Rattlesnake Hills, Great Divide Basin, Bates Hole, Rock Springs Uplift, Upper Wind River Basin, and Saratoga Basin. Wind developments have already been approved or proposed in other moderate-to-highest risk areas, including Sage Creek Basin, Hanna Basin-Rawlins Uplift, and Shirley Basin in Wyoming, and the Bighorn Basin in Montana. Lower wind speeds resulted in lower risk for the Uinta Basin, North Park, upper Green River Basin, central Wind River Basin, and southern Big Horn Basin. Overall, the Wyoming Basin had substantially higher risk than the Uinta Basin and North Park, and inclusion of the latter two regions in the CSA reduced the total amount of risk in the WYUB.

Similar to breeding habitat, the largest contiguous area of moderate-to-highest risk to golden eagle winter habitat from wind development was in the southeastern WYUB. Some predicted areas of highest-risk were in locations where wind development is unlikely due to steep or forested terrain, like the Laramie, Sierra Madre, Wind River, Bighorn, and Absaroka Mountains. Other moderate-to-highest risk areas were in habitats where development is more likely, including the northern Bighorn Basin, upper Wind River Basin, Granite Mountains, Rattlesnake Hills, Shirley Basin, Bates Hole, Laramie Basin, Hanna Basin-Rawlins Uplift, and Sage Creek Basin-Severson Flats. Risk was lowest in the Uinta Basin, North Park, upper Green River Basin, central Wind River Basin, southern Big Horn Basin, and northwestern Colorado. Compared to the breeding season, the greatest predicted increases in risk during winter were in the foothills surrounding the Laramie and Shirley Basins, Bates Hole, western Saratoga Basin, upper Wind River Basin, western Bighorn Basin, and southeastern foothills of the Bighorn Mountains.

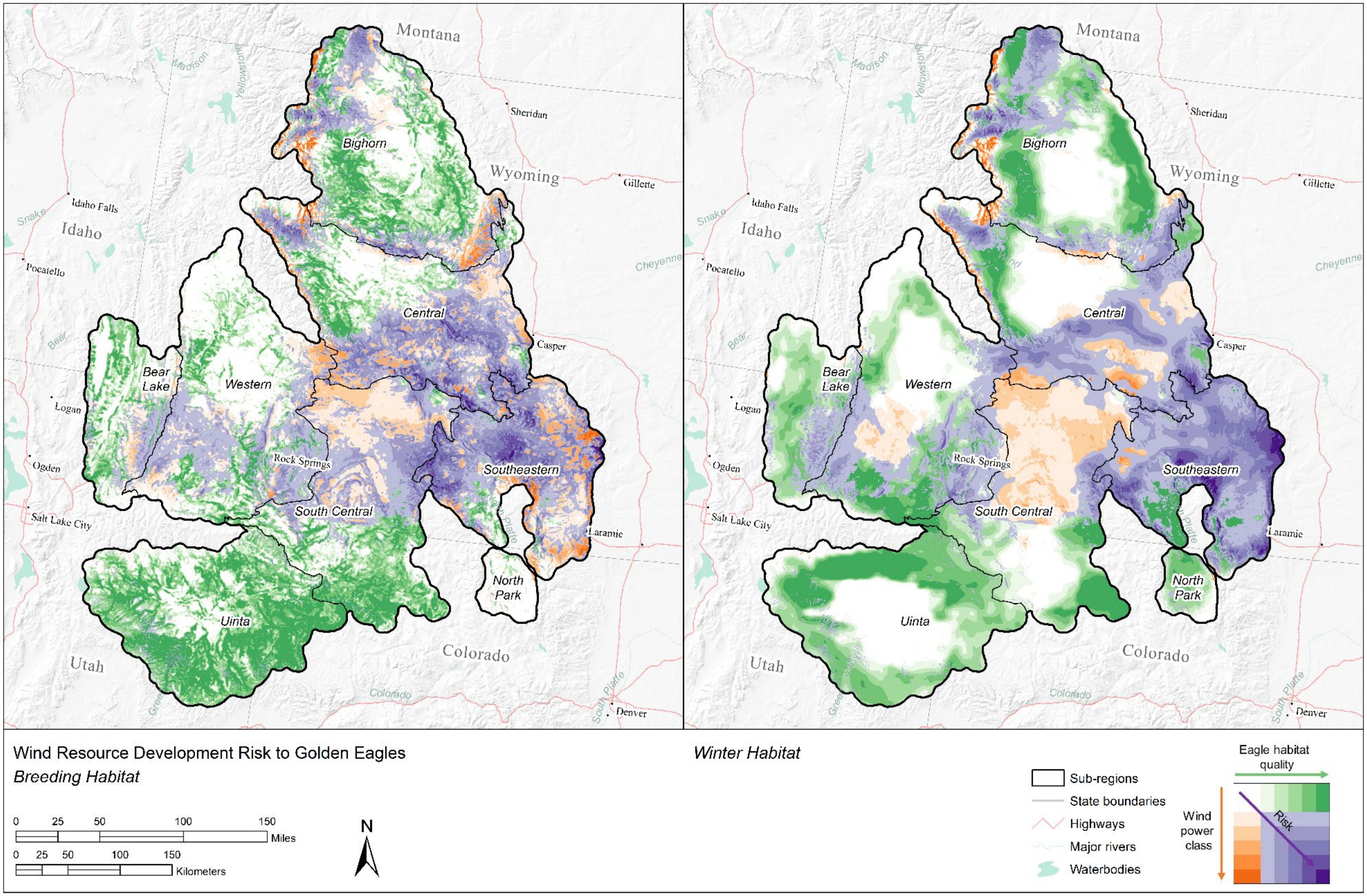

Figure 4.8. Relative risk of wind resource development for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area. Colors match the cells in Table 4.3.

Within ecological sections (Figure 4.8), the greatest amount of risk was in the Southeastern (Breeding: 25%, Winter: 31%) and Central regions (Breeding: 25%, Winter: 21%), both of which also had a greater proportion of risk than expected for their size (Figure 4.9). The South Central (Breeding: 15%, Winter: 10%), Western (Breeding: 14%, Winter: 14%), and Bighorn (Breeding: 14%, Winter: 15%) sections had moderate amounts of risk that were approximately proportional to their areas, while the Bear Lake (Breeding: 3%, Winter: 4%), Uinta (Breeding: 4%, Winter: 3%), and North Park (Breeding 0.4%, Winter: 1%) sections had lower amounts of risk and less risk than expected based on their size (Figure 4.9). Compared to breeding habitat, risk to wintering habitat was greater in the Southeastern section, moderately lower in the Central and South Central sections, and similar in others.

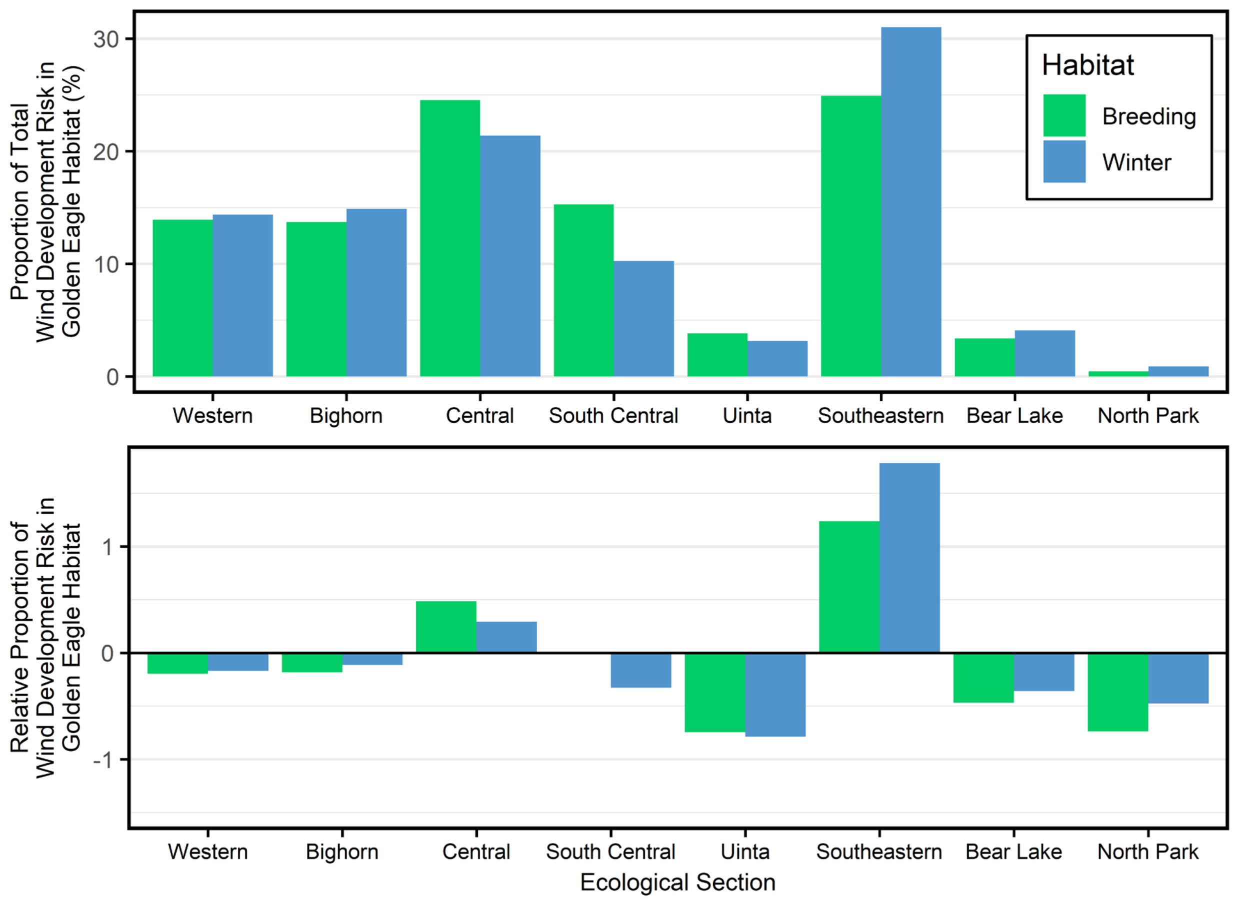

Figure 4.9. Risk from wind resource development to breeding and winter habitats of golden eagles within eight ecological sections of the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportions of risk to sub-region area (bottom). Ecological sub-regions are shown in descending size order from left to right.

Risk by management and protected status

Distribution of risk among surface management agencies and entities (Figure 1.5) was generally proportional to their areas, with the greatest amount of risk managed by BLM (Breeding: 48%, Winter 43%) and private landowners (Breeding: 36%, Winter: 38%), and lesser amounts by State (Breeding: 8%, Winter: 8%) and Tribal (Breeding: 4%, Winter: 4%) agencies (Figure 4.10). BLM field offices (FOs) with larger areas encompassed greater amount of risk: Rawlins (Breeding: 37%, Winter: 38%), Lander (Breeding: 16%, Winter: 14%), Rock Springs (Breeding: 12%, Winter: 12%), Casper (Breeding: 8%, Winter: 8%), Kemmerer (Breeding: 7%, Winter: 7%), and Cody (Breeding: 6%, Winter: 7%). In addition to having large amounts of risk, the Rawlins and Casper FOs had greater proportions of breeding and winter habitat risk than expected based on their size, and the Lander FO had greater than expected risk for breeding habitat. The small extent of the Billings FO in the WYUB also contained a disproportionate amount of risk for breeding and winter habitat. In Wyoming, the Pinedale and Worland FOs had less risk than expected for breeding and winter habitat, as did all FOs in the Colorado, Utah, and Idaho portions of the WYUB.

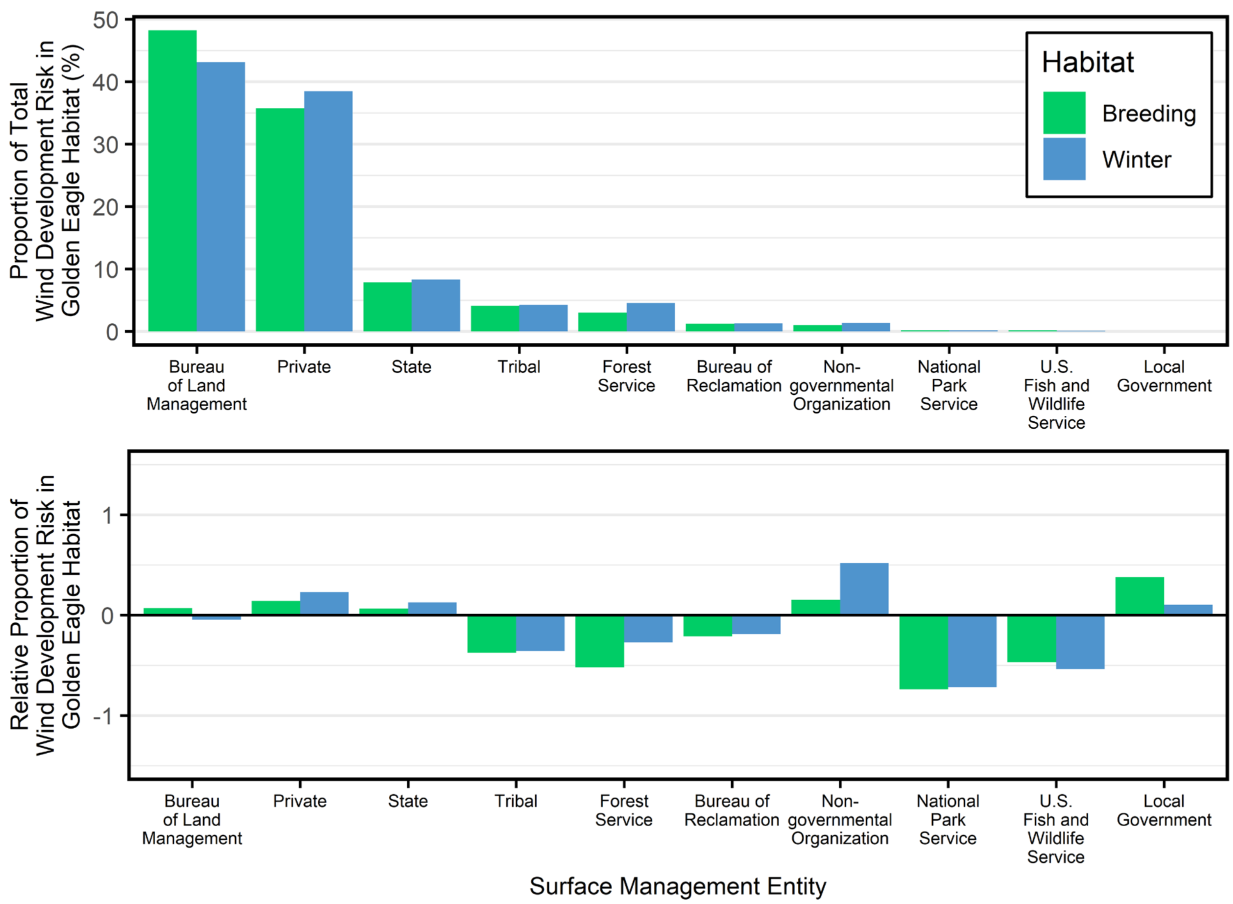

Figure 4.10. Risk from wind resource development to breeding and winter habitats of golden eagles by surface management entity in the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportions of risk to management area (bottom). Management areas are shown in descending size order from left to right.

The majority of wind development risk to golden eagles was in areas with little or no protection from development by extractive industries. More than half of risk was in areas that had lower (GAP Status 3; Breeding: 56%, Winter: 53%) or no known (GAP Status 4;

Breeding: 39%, Winter: 42%) protection from development, while a smaller area (GAP Status 1 and 2; Breeding: 5%, Winter: 5%) had permanent or temporary protection from development. Considering greater sage-grouse PACs, the amount of predicted risk falling in areas with protected status increased to 46% for breeding habitat and 47% for winter habitat. The amount of risk within each surface management and GAP status category was roughly proportional inside and outside of PACs, suggesting PACs provided equal conservation benefit across management entities and existing levels of protection.

4.3.3. Oil and gas development

To assess spatial risk to golden eagles from hazards associated with oil and gas development (identified in the Conservation Assessment), we overlapped models of eagle breeding and wintering habitats with predicted oil and gas development potential (Copeland et al. 2009). The resulting maps and tables (Figure 4.11 and Table 4.4) identify areas where golden eagles are more likely to be exposed to hazards from infrastructure and activities associated with oil and gas development, including electrocution, collision, disturbance, and drowning. These risk maps can also be used to identify high-priority areas where implementation of conservation measures (detailed in the Conservation Strategy) are expected to provide the greatest benefit to golden eagles. We used a predictive model of development potential as a surrogate for the suite of hazards associated with oil and gas developments. Results of this assessment should be compared with local data on current and planned locations of oil and gas developments when assessing the feasibility of management actions. Separate maps of breeding and winter habitat (Figure 4.11) may be useful for managing seasonal disturbances to golden eagles from oil and gas development. Breeding habitat models identify areas where seasonal nest buffers could be used to protect nesting eagles, while winter habitat models provide information on areas where wintering eagles are likely to be affected by seasonal activities, like well drilling.

Risk from oil and gas development

A small portion of the WYUB was classified as having highest risk (2.0%, bin 7 in Table 4.4) or moderate-to-high risk of oil and gas development (15.6%, bins 5–6) to golden eagle breeding habitat. Most of the region had lower risk (48.8%, bins 1–2) or low-to-moderate risk (33.7%, bins 3–4). Compared to breeding habitat, winter habitat had slightly less area with highest (1.2%) and moderate-to-high risk (11.2%), and slightly more low-to-moderate (34.4%) and lowest risk (53.2%). The highest risk areas for development already had some active oil and gas wells: of 32,748 active wells in the WYUB, the highest risk areas included 2247 wells (6.8%) in breeding habitat and 458 wells (1.4%) in winter habitat.

Table 4.4. Relative risk of exposure to oil and gas development for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within (A) breeding and (B) winter habitats. Colors match the maps in Figure 4.11. Cell values show the percentage of the total assessment area (184,505-km²) in each risk class.

(A) Golden Eagle Breeding Habitat

Oil & Gas Development Potential	1	2	3	4	5	6	7
1	2.0	2.5	2.4	2.2	2.0	1.8	1.5
2	1.9	1.8	1.9	2.0	2.1	2.3	2.2
3	1.5	1.6	1.8	2.0	2.3	2.4	2.7
4	2.1	2.1	2.0	2.0	2.1	2.1	1.9
5	2.3	2.1	2.2	2.0	1.8	1.8	2.0
6	2.0	2.0	2.1	2.0	2.0	2.0	2.1
7	2.4	2.1	2.0	2.0	1.9	2.0	2.0

(B) Golden Eagle Winter Habitat

Oil & Gas Development Potential	1	2	3	4	5	6	7
1	0.4	1.3	1.9	1.9	2.0	3.1	3.8
2	0.8	1.5	2.0	2.2	2.5	2.6	2.8
3	0.7	1.9	2.5	2.6	2.3	2.0	2.3
4	0.9	1.3	2.4	2.5	2.6	2.3	2.3
5	2.7	2.1	2.2	2.2	1.9	1.9	1.3
6	3.7	2.9	2.1	2.0	1.8	1.2	0.6
7	5.1	3.3	1.3	1.0	1.3	1.2	1.2

Risk by region

Oil and gas development risk varied widely across the WYUB. Risk was highest in the low basins of the region where geological features associated with oil and gas deposits overlapped areas of higher-quality golden eagle habitat. Within ecological sections (Figure 4.11), the greatest amount of risk was in the Uinta (Breeding: 26%, Winter: 21%), Western (Breeding: 21%, Winter: 25%), South Central (Breeding: 21%, Winter: 17%), Central (Breeding: 12%, Winter: 11%), and Bighorn sections (Breeding: 10%, Winter: 11%; Figure 4.12). Risk was generally proportional to the area of ecological sections, except risk was more concentrated than expected in breeding and winter habitats of the Uinta, Western, and South Central sections and less concentrated in the Southeastern, North Park, Bighorn, and Central sections (Figure 4.12).

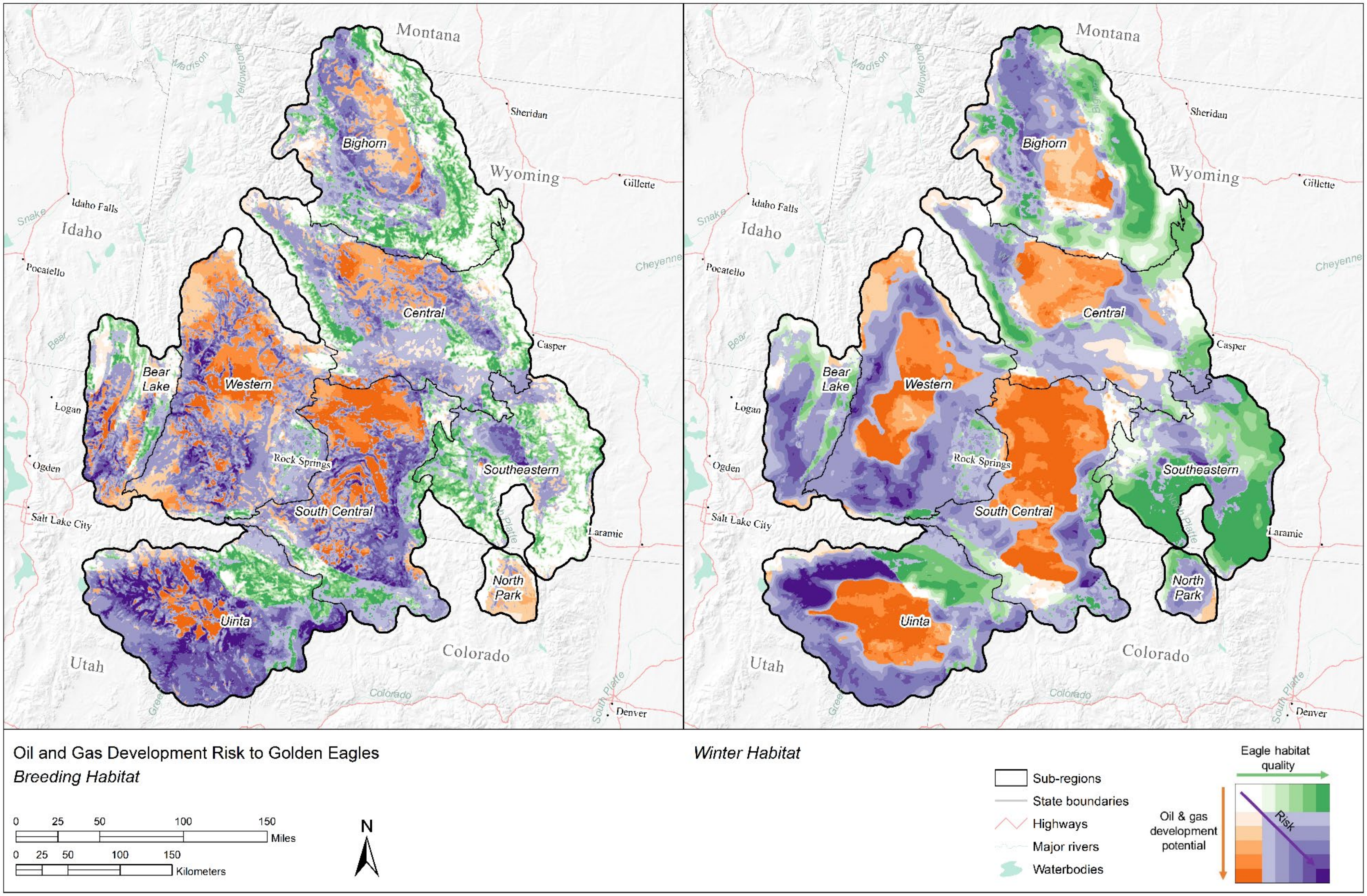

Figure 4.11. Relative risk of exposure to oil and gas development for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within (A) breeding and (B) winter habitats. Colors match the cells in Table 4.4.

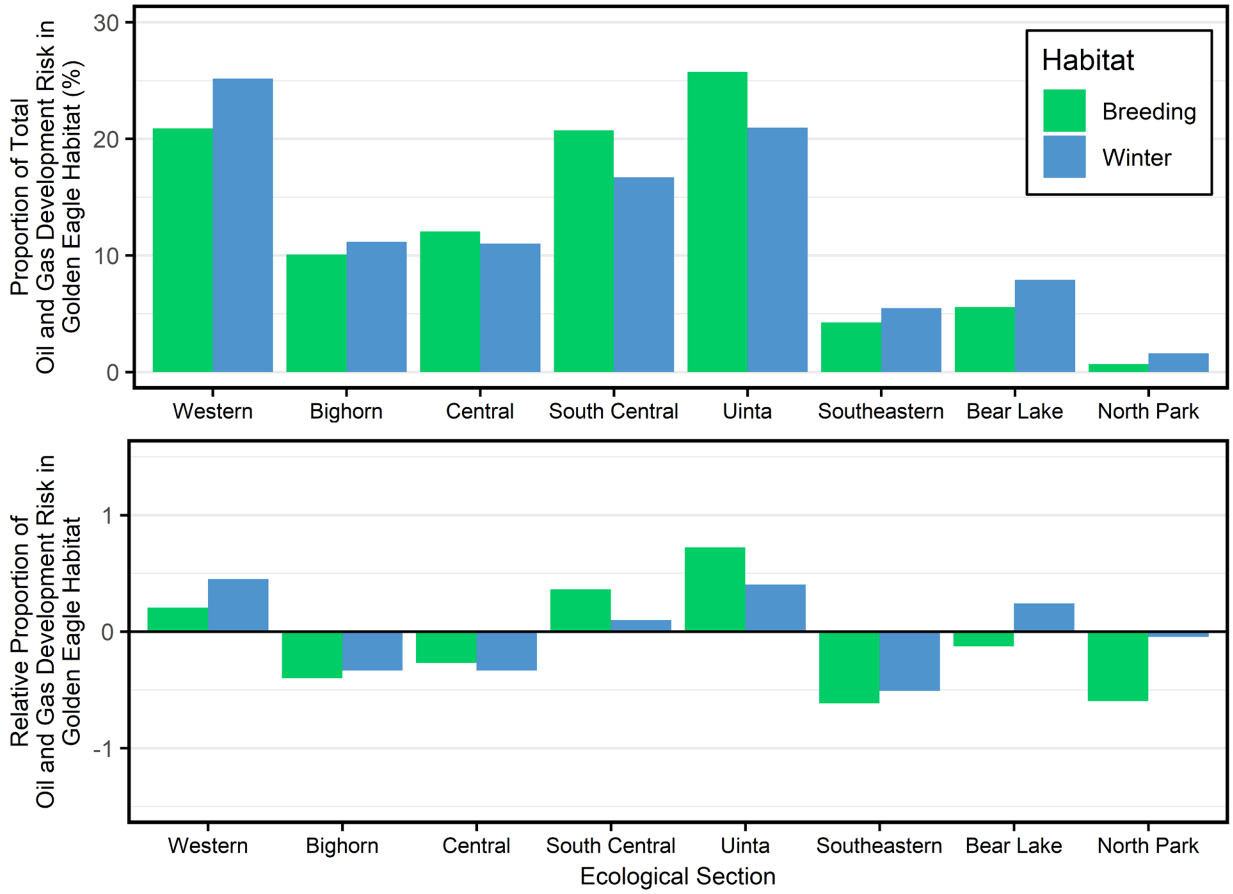

Figure 4.12. Risk from oil and gas development to breeding and winter habitats of golden eagles within eight ecological sections of the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportions of risk to sub-region area (bottom). Ecological sub-regions are shown in descending size order from left to right.

Risk by management and protected status

Land managed by the BLM had by far the greatest amount of oil and gas development risk (Breeding: 52%, Winter 47%), followed by private (Breeding: 30%, Winter 32%), Tribal (Breeding: 8%, Winter 8%), and State (Breeding: 7%, Winter 7%; Figure 4.13). Concentration of risk was generally proportional to area, with less risk than expected for USFS, NPS, and USFWS lands, and slightly greater risk for land managed by Tribal and local governments.

BLM field offices (FOs) with relatively larger areas encompassed greater amount of risk: Rawlins (Breeding: 14%, Winter: 12%), Lander (Breeding: 10%, Winter: 9%), Rock Springs (Breeding: 14%, Winter: 16%), Vernal (Breeding: 19%, Winter: 15%), Worland (Breeding: 5%, Winter: 4%), Kemmerer (Breeding: 8%, Winter: 10%), Little Snake (Breeding: 7%, Winter: 7%), and Cody (Breeding: 4%, Winter: 6%). In addition to having large amounts of risk, the Vernal, Rock Spring, and Kemmerer FOs had greater proportions of breeding and winter habitat risk than expected based on their size. Smaller FOs in the Uinta Basin also had greater risk that expected, including White River, Salt Lake, Price, Moab, and Grand Junction. Several FOs had moderately less risk than expected for the extent of their area in the WYUB, including Buffalo, Pocatello, Worland, Casper, Cody, and Lander.

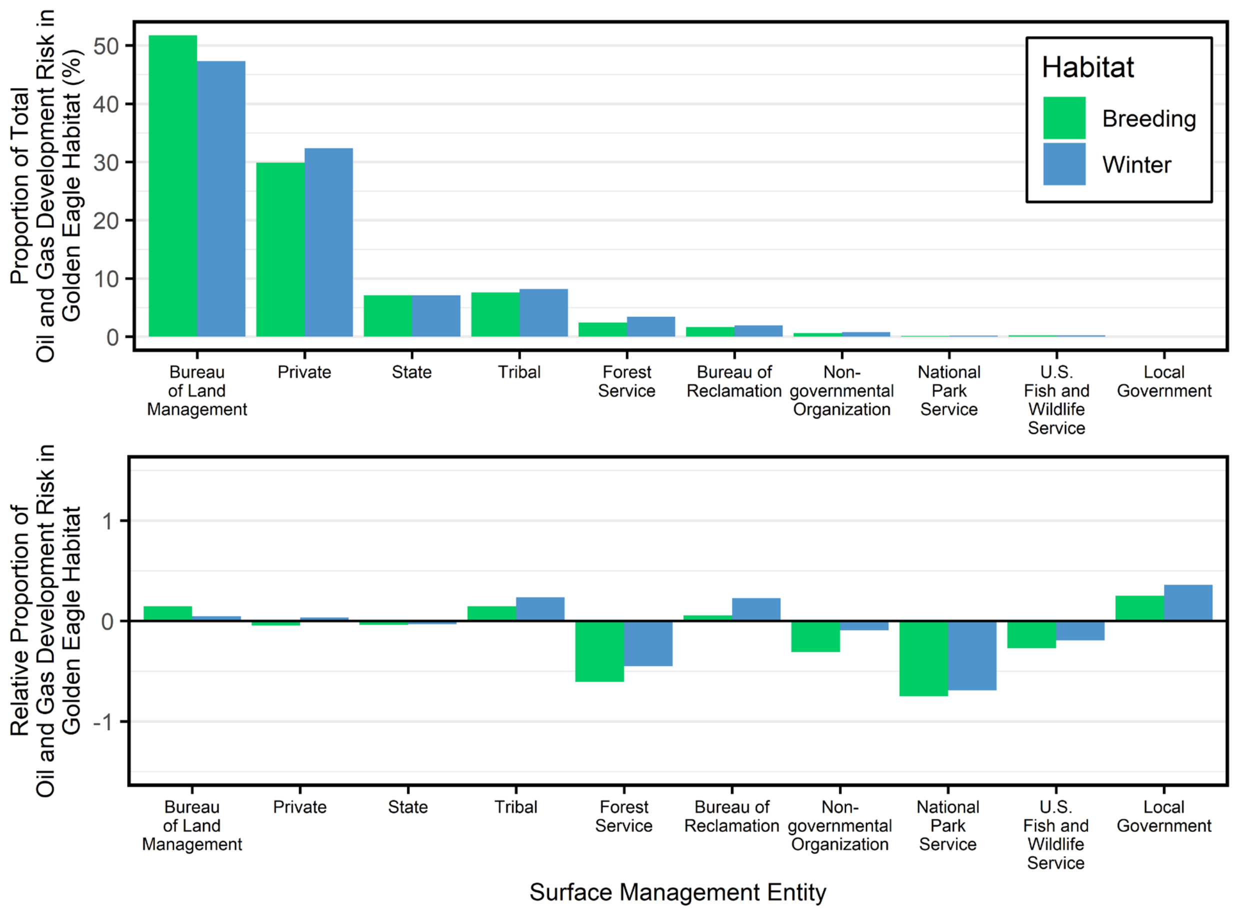

Figure 4.13. Oil and gas development risk in breeding and winter habitats of golden eagles by surface management entity within the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportions of risk to management area (bottom). Management areas are shown in descending size order from left to right.

The majority of oil and gas development risk was in areas with little or no protection from development by extractive industries. More than half of risk was in areas that had low (GAP Status 3; Breeding: 58%, Winter: 55%) or no known (GAP Status 4; Breeding: 37%, Winter: 40%) protection from development, while a smaller amount of risk (GAP Status 1 and 2; Breeding: 5%, Winter: 5%) was predicted in areas with permanent or temporary protection from development. This was not surprising because the scenarios considered in the oil and gas development model accounted for protected status; however, these results still underscore the rarity of protected lands in the WYUB. Considering greater sage-grouse

PACs, the amount of predicted risk falling in areas with protected status increased to 34% for breeding habitat and 38% for winter habitat. This increase was driven by PAC protection of BLM lands in GAP category 3 and Private lands in GAP category 4. Although PACs provide a substantial increase in the area of protected habitat, it is important to note that development is allowed within PACs up to stipulated density thresholds (State of Wyoming Executive Department, Executive Order 2019-3).

4.3.4. Lead exposure

To assess spatial risk to golden eagles from exposure to lead in big game carcasses and gut piles (identified in the Conservation Assessment), we overlapped models of eagle breeding and wintering habitats with data on harvest rates of big game animals (Lau et al. 2016). The resulting maps and tables (Figure 4.14 and Table 4.5) identify areas where golden eagles are more likely to be exposed to big game carcasses and gut piles that may contain fragments of lead bullets. These risk maps can also be used to identify high-priority areas where implementation of conservation measures for lead exposure (detailed in the Conservation Strategy) are expected to provide the greatest benefit to golden eagles. As a surrogate for lead exposure, we used the 5-year average of the most recent available data on the number of mule deer, white-tailed deer (*Odocoileus virginianus*), elk, and pronghorn harvested per hunt unit (Lau et al. 2016). Big game harvest data were only available at the relatively coarse scale of hunt units and no data were available for tribal lands. Results of this assessment should, therefore, be compared with local data on harvest rates, patterns of harvest within hunt units, and knowledge of areas where other routes of exposure (e.g., varmint shooting) may be more prominent. Regional knowledge of golden eagle fall migration routes and post-breeding habitat should also be considered in planning because they align with the timing of big game hunting seasons in fall and early-winter. This analysis did not account for additional known sources of lead exposure, including varmint shooting and hunting of other species of game animals.

Risk from lead exposure

A small portion of the WYUB was classified as having the highest level of risk (2.3%, bin 7 in Table 4.5) of lead exposure in golden eagle breeding habitat, while a larger area had moderate-to-high risk (15.6%, bins 5–6). Most of the region was in the lowest (50.7%, bins 1–2) or low-to-moderate risk category (31.4%). Compared to breeding habitat, winter habitat had slightly more area with highest (3.3%), moderate-to-high (17.8%), and low-to-moderate risk (34.0%), and less area in the lowest risk category (44.9%).

Harvest rates in the WYUB (mean: 0.39/km^2, range: 0–2.15, SD: 0.32) suggest an average golden eagle core area (8.09 km^2, Ross Crandall, Craighead Beringia South, personal communication) could contain 0–17 ungulate carcasses or gut piles each hunting season, while an average home range (20–33 km^2, Kochert et al. 2002) could include as many as 71. Given that a single ungulate carcass can contain enough lead to cause toxicosis, reducing exposure from big game hunting has been suggested as a potentially effective strategy to mitigate mortality of golden eagles (Cochrane et al. 2015).

Table 4.5. Relative risk of exposure to lead from big game carcasses for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within (A) breeding and (B) winter habitats. Colors match the maps in Figure 4.14. Cell values show the percentage of the total assessment area (172,091-km2) in each risk class.

(A) Golden Eagle Breeding Habitat

Big Game Harvest Density	1	2	3	4	5	6	7
1	1.3	1.7	2.0	2.1	2.3	2.3	2.8
2	2.5	2.2	2.1	2.1	2.0	2.1	2.2
3	2.3	2.0	1.9	1.7	1.7	1.9	2.2
4	2.0	2.1	2.0	2.1	2.0	1.7	1.8
5	2.3	2.3	2.2	2.2	2.1	1.8	1.5
6	2.3	2.5	2.3	2.1	1.9	1.7	1.4
7	1.6	1.5	1.6	2.0	2.5	2.8	2.3

(B) Golden Eagle Winter Habitat

Big Game Harvest Density	1	2	3	4	5	6	7
1	4.0	3.2	2.0	1.3	1.8	1.9	0.5
2	3.9	2.0	1.8	1.6	1.8	2.1	2.0
3	2.2	1.4	1.7	2.9	2.6	2.0	0.9
4	0.8	2.4	2.4	2.2	2.2	1.8	2.1
5	2.1	1.7	2.2	2.5	2.1	1.8	1.9
6	0.5	1.5	2.1	2.2	2.1	2.6	3.3
7	0.4	2.0	2.4	2.1	1.9	2.1	3.3

Risk by region

Lead exposure risk varied widely across the WYUB and was greatest in areas with higher big game harvest rates. Harvest rates were highest (>1 animals/km^2) where habitats of multiple ungulate species overlapped near larger cities (e.g., Casper and Sheridan, Wyoming and Craig, Colorado) and lowest (<0.10 animals/km^2) in arid basins (e.g., Great Divide Basin, Uinta Basin). Data were not available for tribal lands (Lau et al. 2016).

Within ecological sections (Figure 4.14), the greatest amount of risk was in the Southeastern (Breeding: 26%, Winter: 29%), Central (Breeding: 26%, Winter: 28%), Bighorn (Breeding: 14%, Winter: 18%), South Central (Breeding: 16%, Winter: 5%), and Western sections (Breeding: 15%, Winter: 13%; Figure 4.15). Risk was generally proportional to the area of ecological sections, except risk was more concentrated than expected in the Southeastern section and less concentrated in the Uinta, South Central, and North Park sections (Figure 4.12).

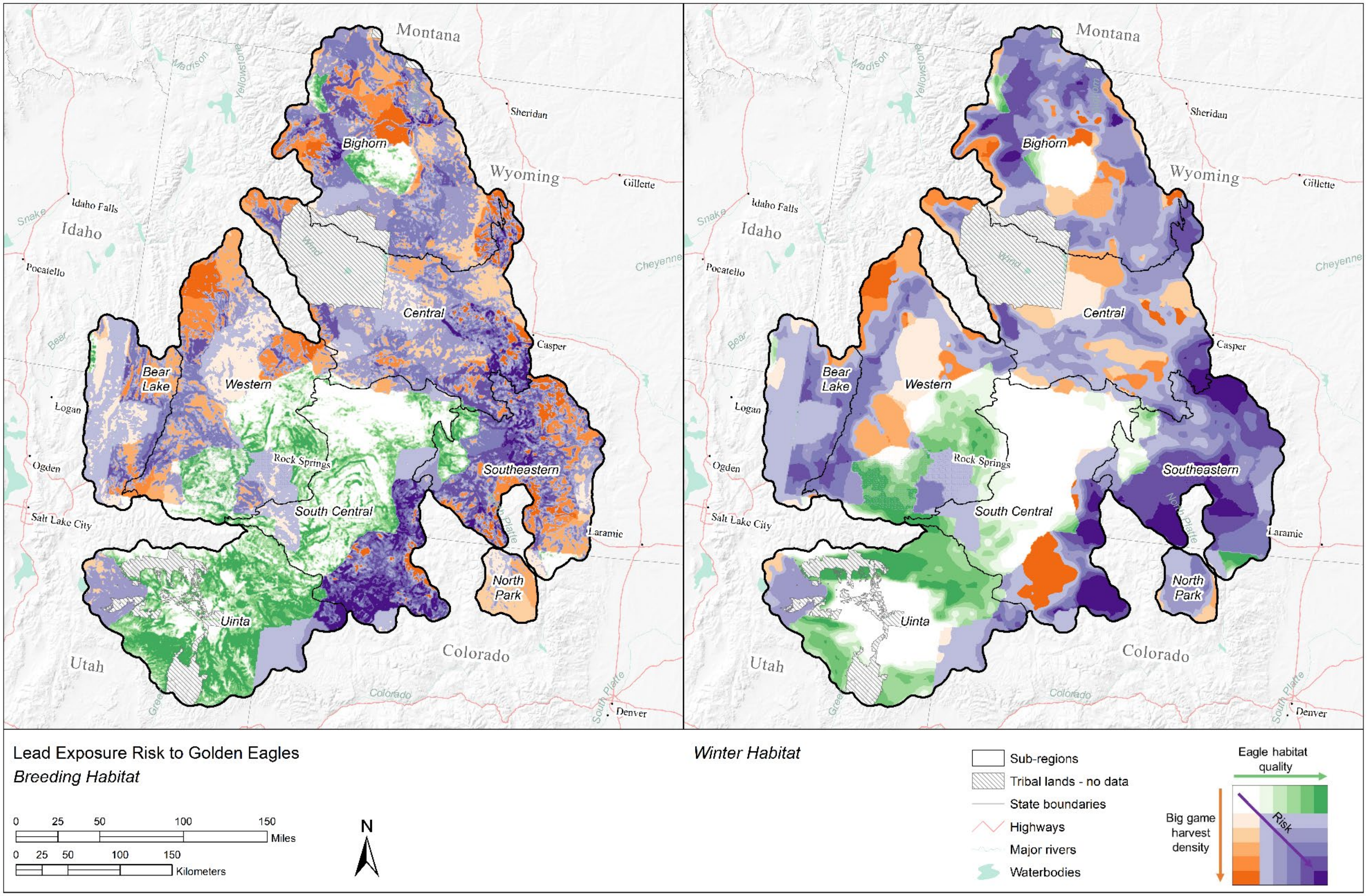

Figure 4.14. Relative risk of exposure of golden eagles to lead from big game carcasses in the Wyoming and Uinta Basins Conservation Strategy Area within (A) breeding and (B) winter habitats. Colors match the cells in Table 4.5.

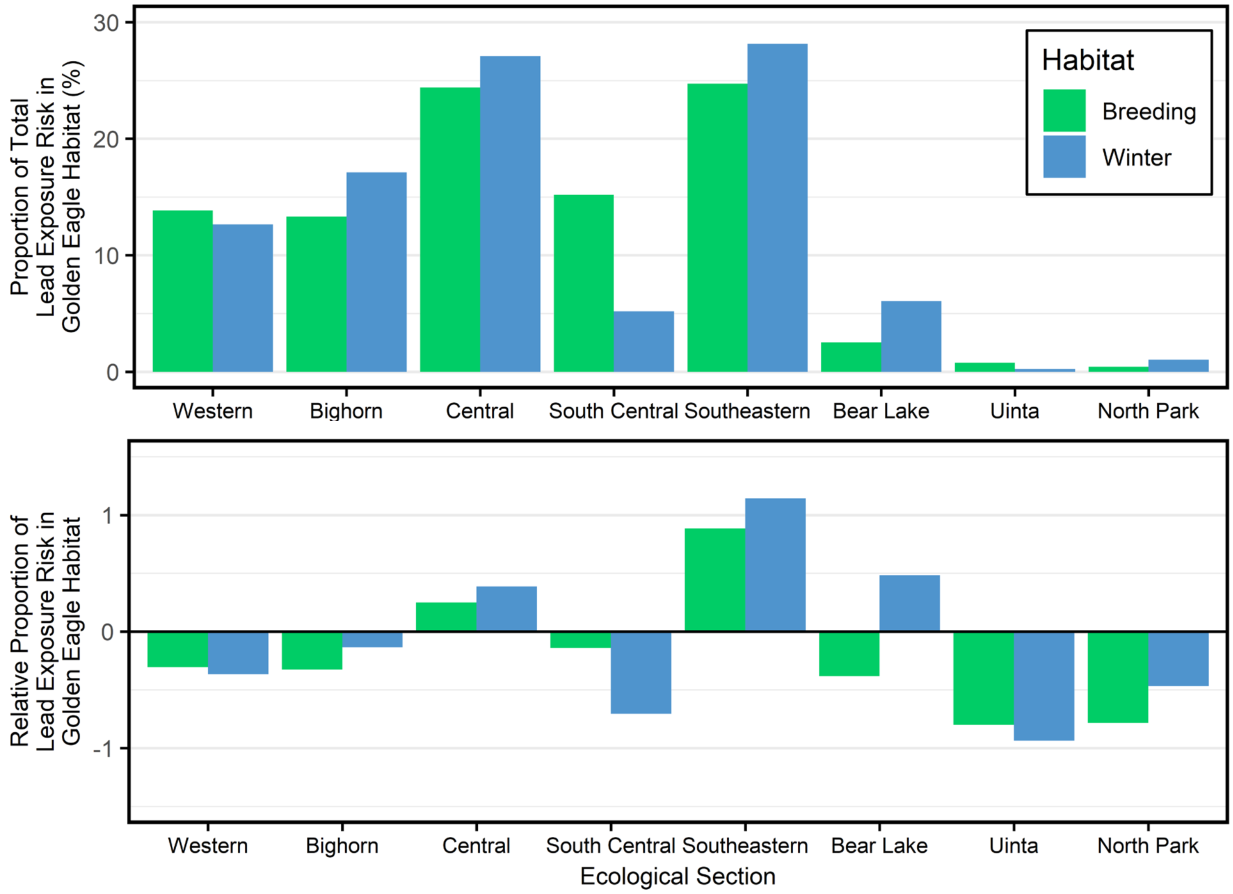

Figure 4.15. Risk of exposure to lead from big game carcasses in breeding and winter habitats of golden eagles within eight ecological sections of the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportions of risk to sub-region area (bottom). Ecological sub-regions are shown in descending size order from left to right.

Risk by management

The majority of lead exposure risk was split evenly between land managed by the BLM (Breeding: 44%, Winter 40%) and private owners (Breeding: 40%, Winter 43%). Lesser amounts of risk occurred in State (Breeding: 9%, Winter 9%), Forest Service (Breeding: 4%, Winter 5%), and other lands (Breeding: 3%, Winter 4%; Figure 4.13). Concentration of risk was generally proportional to area, with slightly more risk than expected in the small extent of NGO lands.

BLM field offices (FOs) with relatively larger areas encompassed greater amount of risk: Rawlins (Breeding: 23%, Winter: 27%), Little Snake (Breeding: 14%, Winter: 11%), Casper (Breeding: 10%, Winter: 10%), Cody (Breeding: 8%, Winter: 9%), Kemmerer (Breeding: 7%, Winter: 8%), Worland (Breeding: 8%, Winter: 7%), Lander (Breeding: 8%, Winter: 6%), and Rock Springs (Breeding: 6%, Winter: 6%). In addition to having large amounts of risk, the Rawlins, Little Snake, and Casper FOs had greater proportions of breeding and winter habitat risk than expected based on their size. Other FOs with moderately greater risk than expected included Buffalo and Rawlins, while Vernal, Rock Springs, and Salt Lake had less risk than expected for the extent of their area in the WYUB.

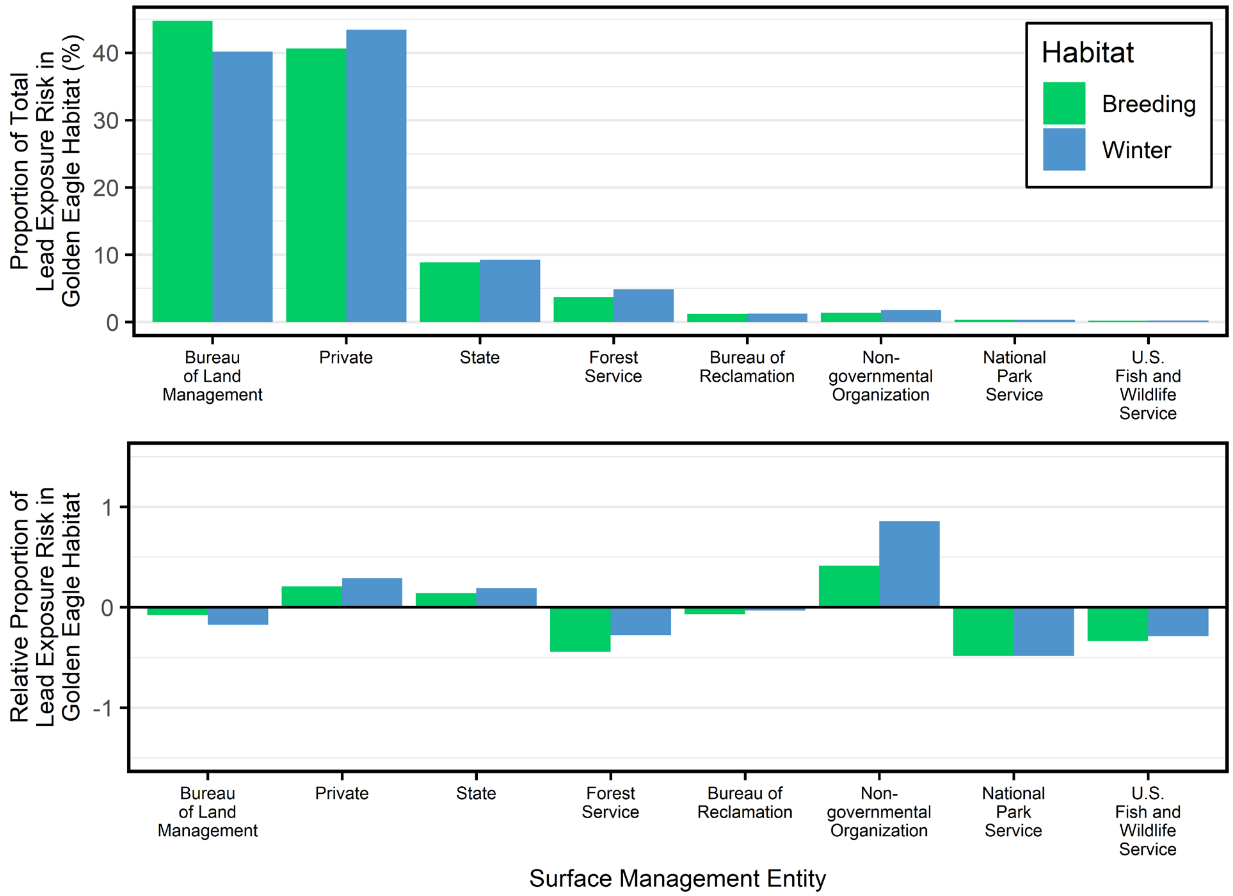

Figure 4.16. Risk of exposure to lead from big game carcasses in breeding and winter habitats of golden eagles by surface management entity within the Wyoming and Uinta Basins Conservation Strategy Area. Proportion of total risk (top) and ratio of the proportion of risk to management area (bottom). Management areas are shown in descending size order from left to right.

II. Conservation Strategy

The abundance of golden eagles and their habitat in the WYUB presents both challenges and opportunities for conservation. Unlike most regions of the U.S., high-quality golden eagle breeding and wintering habitat occur in nearly all areas of the WYUB, and large areas of low-quality habitat are exceedingly rare. The ubiquity of eagle habitat in the region makes a traditional protected areas strategy for conservation impractical. Effective conservation and management of golden eagles in the WYUB will, thus, require a combination of coordinated, landscape-scale planning to avoid development of the highest-priority habitat, with implementation of conservation measures to mitigate impacts elsewhere. Proactive, collaborative efforts will be essential to golden eagle conservation, as the majority of habitat in the region is managed by the BLM or private land owners and has little or no permanent protection from development. Partnerships with extractive industries will also be essential, as significant hazards to golden eagles result from conventional and renewable energy development, which are also the primary economic drivers in the region.

The Conservation Strategy is a collection of conservation measures known to benefit golden eagles and their populations based on the best available science. Each section uses the mitigation hierarchy to describe actions with the potential to avoid, minimize, or mitigate regional hazards identified in the Conservation Assessment. Conservation measures include management actions that can be implemented over a range of scales from landscapes, to project areas, to individual nest sites. The maps of priority eagle habitat and spatial risk assessments can be used to target implementation of conservation measures in areas where they will have the greatest benefit. Spatial risk assessments address four key hazards: electrocution, wind resource development, oil and gas development, and lead exposure from big game carcasses. Risk assessment maps are useful to inform broad-scale planning and prioritization, especially when less is known about the pattern of a given hazard relative to eagle habitat. For other hazards, maps of priority eagle habitat can be used in combination with regional knowledge of hazards to guide spatial planning. This approach may be more useful when region-wide spatial data on a hazard are lacking, the location of a hazard is already well known, or the area of management interest is constrained (e.g., by a project area).

The conservation measures described here are not officially endorsed by USFWS and do not represent a complete list of possible management actions to benefit golden eagles. Rather, they are intended as a "toolbox" of techniques and guidelines based on best available science that can be considered in management planning (e.g., Resource Management Plans, Forest Plans, Avian Protection Plans), and implemented proactively by government, tribal, NGO, and industry partners. Because these measures do not constitute a coordinated plan, each agency or entity will be independently responsible for measuring success and adapting management.

1. Electrocution prevention

Electrocution on power infrastructure is a leading causes of mortality for golden eagles in North America (U.S. Fish and Wildlife Service 2016). Best management practices (BMPs) for avoidance and minimization of raptor electrocutions have been the subject of extensive research (see Electrocution above). The most complete source of information on preventing avian electrocution is the Avian Power Line Interaction Committee (APLIC; http://www.aplic.org/).

To assess the risk of electrocution in the WYUB, we overlapped spatial models of golden eagle habitat and distribution pole density. The resulting risk assessment maps (Figure 1.1) and information can be used for conservation planning and to prioritize retrofitting of power poles in higher-risk areas. At a project scale, power lines can be installed away from known nesting and foraging areas of golden eagles; however, further research is necessary to understand how eagle habitat use overlaps and is influenced by the locations of power poles within home ranges.

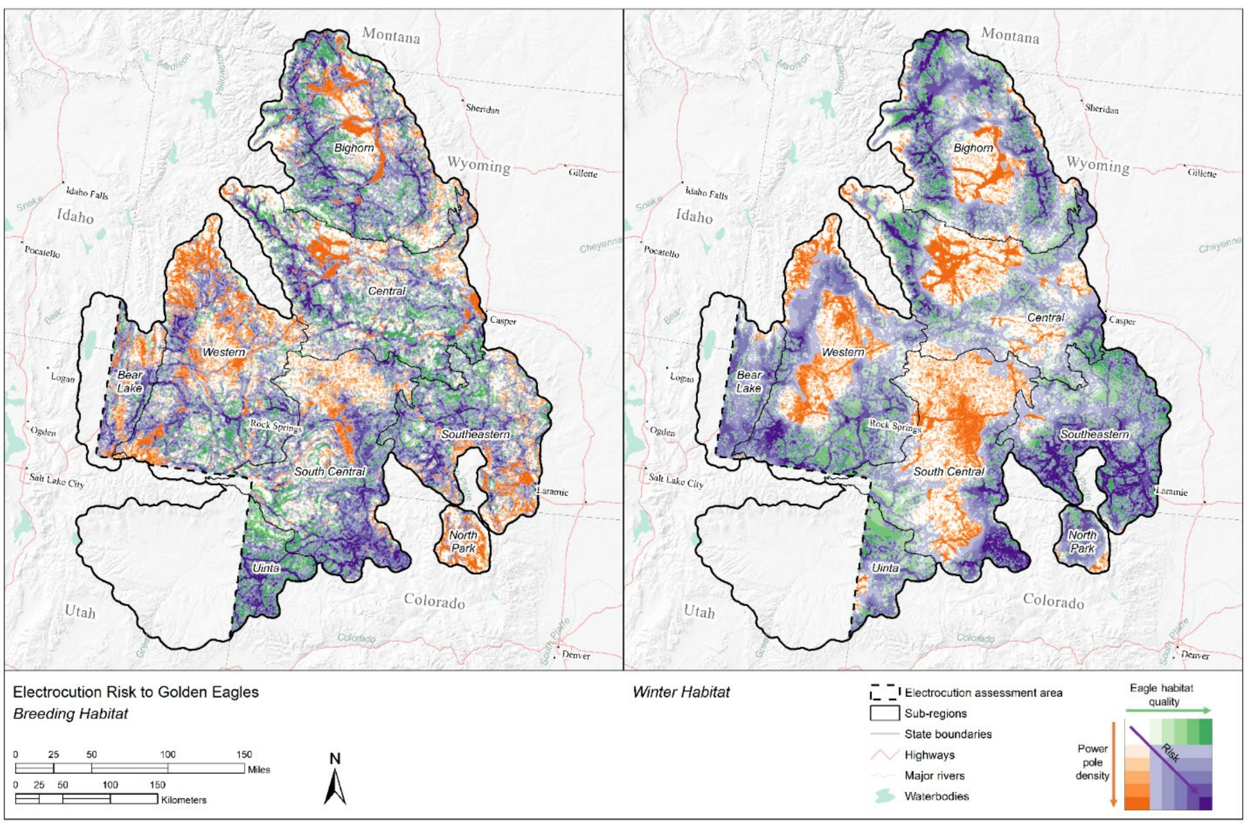

Figure 5.1. Relative risk of electrocution for golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within breeding (left panel) and winter habitat (right panel) from Electrocution Risk Assessment.

Avoidance: lower-risk construction

For new construction projects, the best approach is to build structures with configurations likely to avoid or greatly reduce the potential for electrocution. Critical dimensions and configurations of electrical equipment necessary to prevent electrocution of golden eagles are detailed in Dwyer et al. (2015). In the WYUB, construction of new distribution lines in golden eagle habitat is often associated with energy development, rural and suburban housing, and agriculture (Dwyer et al. 2016). Agencies and entities with permitting authority for power distribution projects should use APLIC BMPs to build infrastructure that is safe for golden eagles. Spacing of equipment sufficient to avoid electrocution of golden eagles will have the added benefit of preventing electrocution of other raptors because eagles are the largest raptor regularly found in the WYUB.

Minimization and mitigation: power pole retrofits

When potentially hazardous equipment has been installed, poles should be retrofitted to minimize risk. The spatial risk assessment in this report can be used to prioritize retrofitting efforts in areas with higher concentrations of power poles and eagle use. WGET risk maps (Figure 1.1) can be complemented by local knowledge on patterns of eagle use and electrocution, industry data on dangerous pole configurations, and information on where retrofits have already been implemented. Once priority areas are selected, the riskiest poles can be identified on the ground using a relative risk index (Dwyer et al. 2014). Retrofitting should follow BMPs for installation of covers and perch discouragers to maximize their effectiveness and avoid common errors that can make retrofits ineffective or even increase risk (Dwyer et al. 2017b).

In the event that golden eagles build a nest on existing power distribution or transmission structures, the nest should be moved to reduce electrocution risk to both breeding adults and young. Proper training of linepersons should be conducted prior to moving a nest and the new nesting platforms should conform to known standards for golden eagle nests. A USFWS permit is required for moving nests, but can be acquired expediently with consultation with regional USFWS personnel. Nests relocated should be on a separate pole taller than nearby power poles, have proper shading and drainage, an attached perch, and be located further from existing roads than the power poles. All power poles within the territory should also be retrofitted to reduce electrocution risk during perching and to dissuade future nest building.

Research and monitoring

Data on raptor electrocution collected in the WYUB vary among utility providers and agencies. Currently there is no standard method for collecting electrocution data or a central repository for storage. Coordinated monitoring and data compilation could improve efforts to prevent electrocutions by providing data necessary to refine risk models and improve understanding of environmental, seasonal, and behavioral risk factors. Monitoring should include areas where poles have already been retrofitted to verify that retrofits are functioning properly (Dwyer et al. 2017b) and repair if needed. Reporting of avian electrocutions also varies among utility providers in the WYUB. Education and outreach to encourage utility personnel to document and report electrocutions could improve knowledge of this problem in the region. Similarly, education of industry and agencies on best practices for retrofitting could reduce errors that make retrofits ineffective or even increase risk. Educational materials developed by WGET for utility providers and linemen are available online: https://ecos.fws.gov/ServCat/Reference/Profile/83430, https://ecos.fws.gov/ServCat/Reference/Profile/97630.

2. Wind resource development

The potential for conflict between wind resource development and golden eagles is high in the WYUB, due to the region's high wind speeds and high-quality eagle habitat (see Wind Resource Development above). Wind energy development is the only hazard to golden eagles with a Federal permitting and mitigation framework (U.S. Fish and Wildlife Service 2013). Retro-fitting of electrical poles is the only currently approved form of mitigation for permitted take of golden eagles at wind energy facilities. However, many other techniques are available to proactively reduce impacts to eagles. These include siting wind energy facilities away from high-quality golden eagle habitat, installing turbines in portions of project areas with lower eagle use, curtailing turbines when eagles are nearby, supporting research on interactions between eagles and windfarms, and improving regional population monitoring.

To assess the risk of wind resource development in the WYUB, we overlapped spatial models of golden eagle habitat and wind speeds. The resulting risk assessment maps (Figure 2.1) and information can be used to inform implementation of conservation measures and siting of wind energy developments.

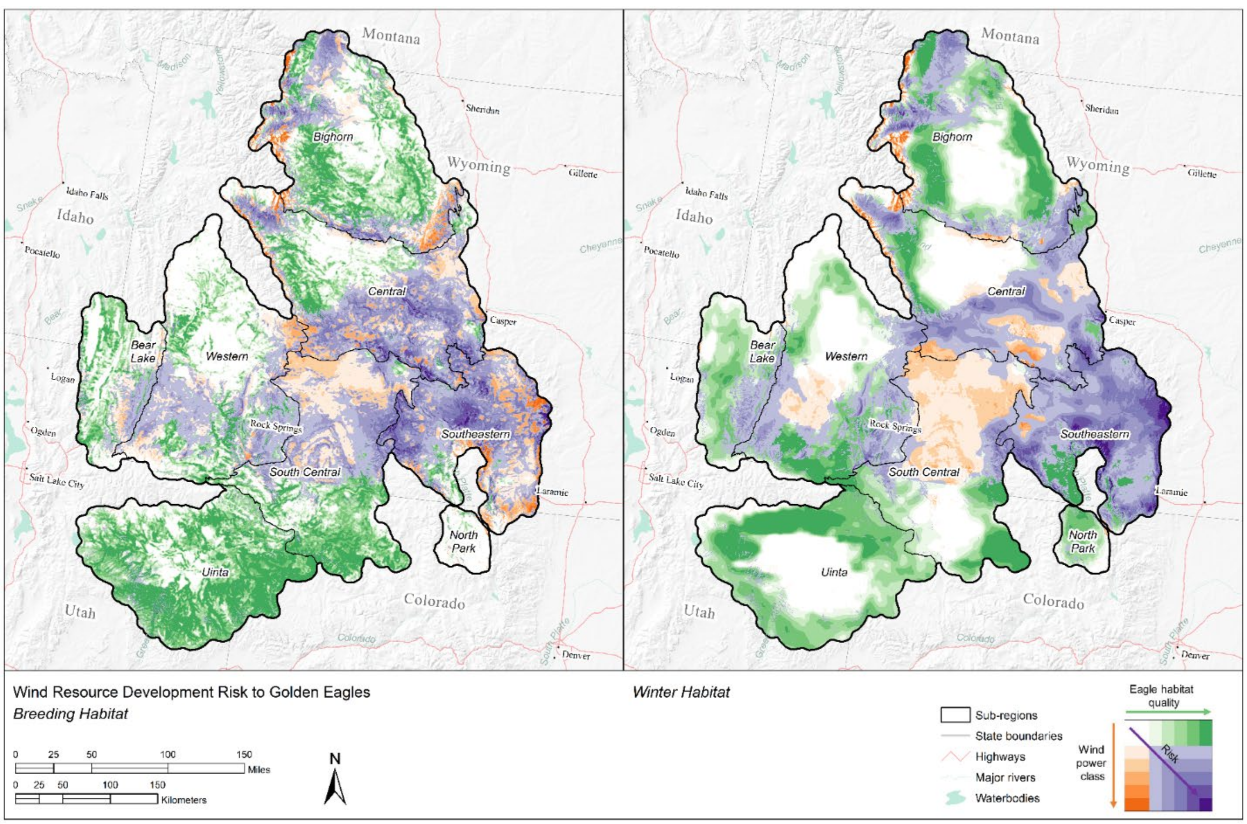

Figure 5.2. Relative risk of wind resource development to golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within breeding (left panel) and winter habitat (right panel) from Wind Resource Development Risk Assessment.

Avoidance: siting and design

Landscape-scale siting of wind energy facilities away from concentrations of nesting, wintering, and migrating eagles is the best way to avoid turbine strikes. The spatial risk assessment in this report can be used to identify areas of opportunity for development with high wind speeds in relatively low-quality golden eagle habitat. WGET risk maps (Figure 4.10) can be complemented by regional knowledge on other considerations for development, like access to transmission, land ownership and management, and permitting. Resources are available from The Nature Conservancy to support siting of wind energy developments in areas where wildlife habitat has already been disturbed by other activities, like conventional energy development, agriculture, and human settlement (Kiesecker et al. 2011). Technological progress towards more efficient turbines is an important consideration for long-term planning of development, as turbines with taller towers and longer blades are expected to allow commercially viable development of areas with lower wind speeds. These technologies could reduce development pressure in the WYUB and increase flexibility to site facilities in areas of the WYUB with lower risk to eagles. In the longer term, new technologies, like blade-less vertical-axis and vibration turbines, could substantially reduce collision risk.

Once a project has been installed in golden eagle habitat, collisions can be avoided or minimized by placing turbines in areas used less frequently by golden eagles. Patterns of eagle use should be documented using methods recommended by USFWS (2013). Reductions in risk can be considerable: for example, changes to the turbine layout for the Choke Cherry and Sierra Madre Wind Energy Development reduced predicted take by approximately half from 40–64 golden eagles/yr for the full project (1000 turbines) to 10–14 golden eagles/yr for Phase I (500 turbines; Power Company of Wyoming 2015, U.S. Fish and Wildlife Service 2016).

Minimization: turbine curtailment

For windfarms operating in golden eagle habitat, risk of strikes can be minimized by curtailing turbine operation when eagles are present. This method has been implemented with trained observers spotting eagles (Watson et al. 2018). Tests of automated camera systems suggest they can identify eagles more accurately than human observers (McClure et al. 2018).

Mitigation: power pole retrofits

Power pole retrofitting is the only currently approved method to mitigate programmatic take of golden eagles at wind energy facilities (U.S. Fish and Wildlife Service 2013). Maps from the spatial risk assessment in this report can be used to prioritize retrofitting efforts in areas with higher concentrations of both eagle use and power poles. Further information on implementation of retrofits is included in the conservation strategy for electrocution prevention.

Research and monitoring

Ongoing research and monitoring are necessary to improve strategies to reduce golden eagle mortality from wind turbine strikes. At the project scale, surveys of nest sites and habitat use are recommended by USFWS (2013) to characterize the level of risk and estimate annual take for permitting. Project-scale monitoring should be complimented with regional-scale surveys to estimate population trends and cumulative impacts. Golden eagle population trend estimates are currently available at the scale of BCRs (Nielson et al. 2014), but data on trends specific to the WYUB or states within the region are lacking. Standardization of monitoring protocols and increased data sharing among industry, agencies, and researchers could increase the value project-level data by allowing them to be compared more directly. Similarly, collaboration among state agencies and other regional groups could support regional-scale population monitoring, or enable broad-scale monitoring programs, like the WGES survey (Nielson et al. 2014), to be scaled down to areas smaller than BCRs. In addition to monitoring of trend and distribution, further research is necessary to understand behavior of golden eagles around wind turbines. Studies from other regions on interactions of golden eagles with wind energy developments should be replicated in the WYUB to test their applicability in the region. Finally, potential impacts of factors other than turbine strike at wind energy developments have received little study. These sources of disturbance and mortality common to all forms of energy development include habitat loss and fragmentation, increased traffic, and human presence associated with maintenance.

3. Oil and gas development, mining, and power generation

The extraction of oil, gas, and mineral resources is not a direct threat to golden eagles; however, energy development requires infrastructure and activities that increase other hazards with known negative effects (see Oil and gas development above). These include electrocution on distribution lines, collisions with vehicles, collisions with transmission structures, increased road access for persecution of eagles and their prey, drowning in oil waste pits, and disturbance by vehicle traffic, human presence, and other activities associated with construction and maintenance of facilities. Disturbance can be at both nest sites and foraging habitat, which may lead to decreased use by eagles. Habitat fragmentation and loss from roads, train tracks, well pads, mining pits, and other infrastructure increases risk of noxious weeds and changes in prey populations. Mining and other power generation activities in the WYUB affect a relatively small amount are land and there is a low probability of new large-scale activities. Conservation measures for mining activities generally include minimizing, mitigation, and reclamation. Conversely, the area affected oil and gas development is likely to increase. Conservation measures for oil and gas development consist of strategies to avoid and minimize associated hazards.

To assess the risk of oil and gas development in the WYUB, we overlapped spatial models of golden eagle habitat and oil and gas development potential. The resulting risk assessment maps (Figure 3.1) and information can be used to inform implementation of conservation measures and siting of oil and gas developments.

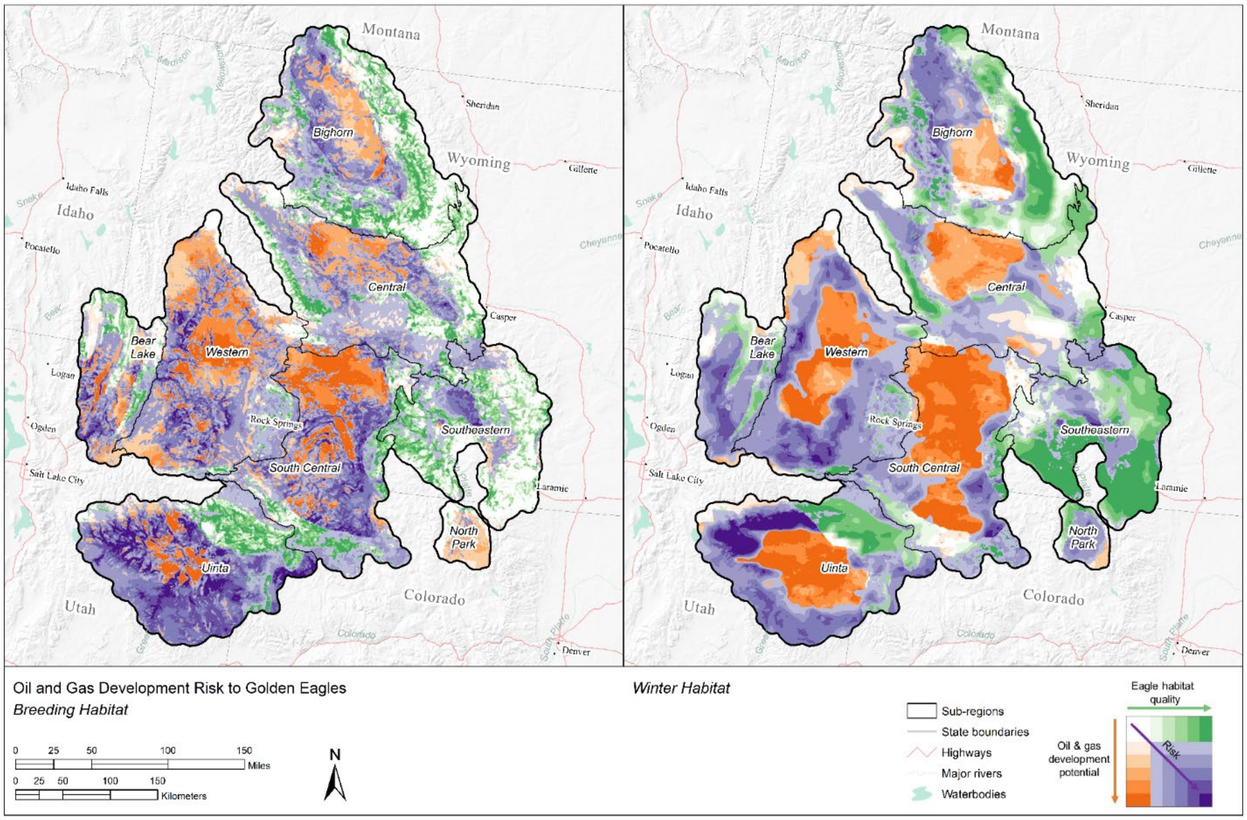

Figure 5.3. Relative risk of oil and gas development to golden eagles in the Wyoming and Uinta Basins Conservation Strategy Area within breeding (left panel) and winter habitat (right panel) from Oil and Gas Development Risk Assessment.

Avoidance: siting and design

Landscape-scale siting of oil and gas fields, mines, and other energy facilities away from concentrations of nesting, wintering, and migrating eagles is the best way to avoid impacts. The spatial risk assessment and maps (Figure 3.1) in this report can be used to identify areas of opportunity for development in relatively low-quality golden eagle habitat. In practice, however, consideration of golden eagle habitat is unlikely to influence broad-scale siting of fossil fuel developments. Instead, avoidance and minimization of impacts to golden eagles are more likely to happen in the design and configuration of energy developments. These include siting infrastructure, like wells, power lines, access roads, and oil pits away from high-quality eagle habitat. Such no-surface-occupancy (NSO) buffers are required in agency management plans for some areas. Similarly, collisions can be avoided if roads are sited away from nest sites and important foraging areas, like prairie dog colonies (U.S. Bureau of Land Management 2007). Construction of new infrastructure in energy fields is an opportunity for agencies to require BMPs, like configuration of distribution poles to prevent electrocution, covering oil pits with netting, and reducing habitat loss by minimizing the extent of pads and roads.

Minimization: reduce threats from known hazards

In existing developments where avoidance measures were not implemented, conservation measures can be used to mitigate risks. These include retrofitting distribution poles to prevent electrocution, reducing speed limits and removing road-killed animals to minimize risk of eagle-vehicle collisions, and covering oil pits with netting (flagging only is not sufficient to prevent drowning; U.S. Fish and Wildlife Service 2017a). Where NSO buffers have not been implemented, disturbance of nesting eagles can be minimized with seasonal buffers for construction and other disturbing activities. Persecution can be minimized through education of oil and gas field personnel and the general public about the value and legal protections of raptors.

Mitigation: reclamation

Reclamation is required on federal lands for any energy extraction activity that required a federal action, such as Environmental Impact Statement or Environmental Analysis. A reclamation plan and strategy should be designed with an initial phase to stabilize the area and control runoff or erosion, an interim phase to restore vegetation and landcover in any areas not essential for operational function during the project, and final reclamation and restoration to return the land to the approximate condition and function prior to disturbance. To benefit golden eagles, reclamation plans should replace any lost nesting habitat (e.g., trees and rock outcrops) and restore prey habitat.

Research and monitoring

Standardization of methods and metrics for eagle monitoring in the WYUB are needed to facilitate the integration of project-level datasets to inform management. Large amounts of nest monitoring data are collected in oil and gas fields and other energy developments across the WYUB every year. Unfortunately, the lack of standardized survey protocols, datasheets, and data repositories limit the ability to combine these data in regional-scale analyses. Additionally, project-level monitoring is rarely implemented as part of broader, design-based studies. This limits the power to make inference on urgent management questions, including impacts of disturbance to golden eagles nesting near resource extraction, effectiveness of current measures used to minimize disturbance (i.e., nest buffers), and effects of development on prey. Further research is necessary to understand effects of reclamation on prey communities and effectiveness of artificial nesting structures to mitigate disturbance.

4. Collisions with vehicles

Golden eagles are known to collide with vehicles, including motor vehicles, and occasionally aircraft and trains (see Collisions with Vehicles above).

Avoidance: siting

To avoid collisions, roads can be routed away from nest sites, known foraging areas, and other high-use habitats. Maps of golden eagle habitat priority areas in this report can be used to route roads away from important habitats.

Minimization: signage, speed limits, carcass removal

Risk of collision can be minimized by signage, reduced speed limits, and removal of road-killed animals that attract golden eagles to roads. Maps of golden eagle habitat priority areas in this report can be used to target conservation measures like carcass removal in areas where they will provide the greatest benefit to eagles. In high volume ungulate movement corridors, wildlife-safe crossings can be constructed to significantly reduce ungulate collisions (McCollister and Van Manen 2010). Removing road-killed animals during the fall and winter will have the greatest impact to eagle populations in the WYUB. Ungulates should be removed from the right-of-way but not removed from the area because they are a valuable food resource to eagles in the WYUB. Smaller animals, such as leporids, should also be removed because they may become frozen to the pavement in winter, increasing exposure of eagles in the roadway. Eagles frequenting airports can be hazed away from runways using trained birds of prey or other techniques; hazing and harassment of golden eagles requires a permit from USFWS. Train-wildlife collisions are generally not reported in the United States due to a low frequency of passenger trains, but train-wildlife collisions can exceed vehicle-wildlife collisions in Europe, where is has been extensively studied (Seiler and Olsson 2017). To date, the only effective strategy to reduce train-wildlife collisions has been acoustic warnings using natural predator and conspecific alarm ungulate calls (Barbinska-Werka et al. 2015).

Research and monitoring

Further research is necessary to identify hot spots of vehicle collision where conservation measures can be applied, as well as to quantify the effectiveness of techniques, like carcass removal and speed limit reductions.

5. Collisions with transmission structures

Golden eagles are known to collide with transmission towers, lines, and guy-lines, but relatively little is known about the magnitude of this hazard (see Collisions with transmission structures above).

Avoidance: siting

To avoid collisions, transmission lines should be sited away from migration corridors and foraging areas (Barrientos et al. 2011). Maps of priority areas for conservation of golden eagle habitat in this report could be used to route transmission corridors away from important breeding and winter habitats.

Minimization: line markers

Risk of collision with transmission structures could be mitigated with markers that make lines more visible. Studies have shown reductions in mortality for some bird species from marking of power lines (Barrientos et al. 2011), but no studies have addressed golden eagles specifically. Structure designs that require fewer guy-lines could also reduce risk of collisions.

Research and monitoring

Standardized survey methods and better reporting of collisions could improve knowledge of patterns of risk in the WYUB.

6. Contaminants

Exposure to environmental contaminants is a significant threat to golden eagle populations (see Contaminants above). While the extent of exposure and population-level effects to golden eagles from most contaminants remain poorly understood, conservation measures are available to proactively avoid and minimize their impacts.

6.1. Lead poisoning

Lead poisoning is a widespread and persistent hazard to golden eagles in North America (see Lead above).

Avoidance and minimization: non-lead ammunition and gut pile removal

Use of non-lead ammunition and removal of big game gut piles have been proposed as mitigation measures to offset permitted take of golden eagles. Results of simulations by Cochrane et al. (2015) suggested median golden eagle mortality in the area around Casper, Wyoming could be reduced by 50% if half of hunters switched to non-lead ammunition, while removal of 50% of big game gut piles reduced mortality rates by only 30%. Although gut pile removal may be a more feasible option for states in the WYUB because it does not require participation of hunters, voluntary programs to incentivize use of non-lead ammunition for big hunting have been successful in areas of Wyoming and Utah outside the WYUB. Hunters participating in the elk management program within the boundaries of Grand Teton National Park are required to use non-lead ammunition, but a voluntary incentive program to encourage the use of non-lead ammunition on the National Elk Refuge has also been a success (Bedrosian et al. 2012). Similarly, in 2016 over 1,500 hunters participated in a voluntary non-lead ammunition program in southern Utah, which aimed to reduce lead exposure for the California condor (*Gymnogyps californianus*; Utah Division of Wildlife Resources 2017). Maps from this report (Figure 6.1) overlapping hunt-unit level data on big game harvest in the WYUB with seasonal models of golden eagle habitat could be used to identify priority areas for mitigation efforts. Unlike big game harvest, spatial data on locations of varmint shooting and upland game hunting are not available; instead, regional knowledge of shooting hot spots (e.g., Shirley Basin, Wyoming) could be used in concert with maps of golden eagle habitat (Figure 4.1) to prioritize areas to incentivize use of non-lead ammunition, removal of carcasses, or cessation of varmint shooting.

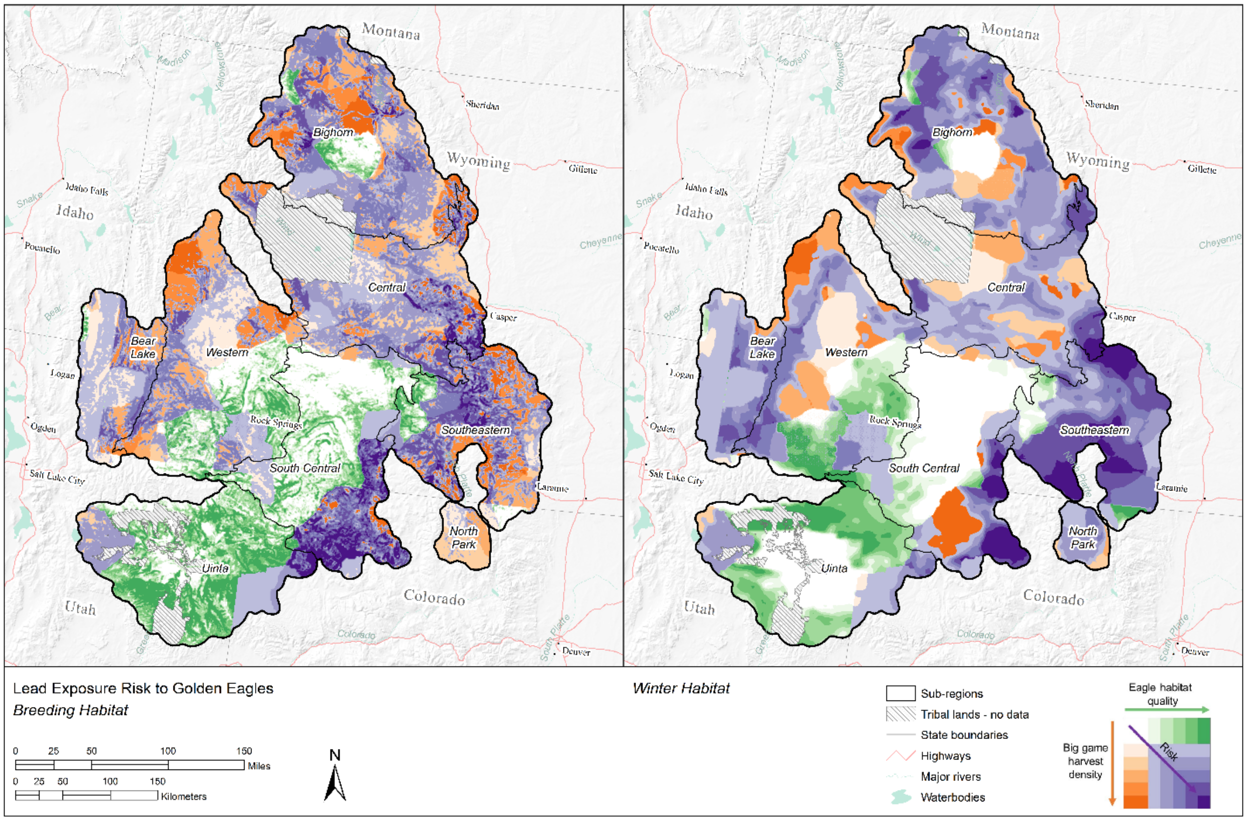

Figure 5.4. Relative risk of exposure of golden eagles to lead from big game carcasses in the Wyoming and Uinta Basins Conservation Strategy Area within breeding (left panel) and winter habitat (right panel) from Lead Exposure Risk Assessment.

Research and monitoring

Further research is necessary to understand sub-lethal effects of lead exposure on golden eagle and nestlings. Additionally, most research has been conducted on migrating eagles and less is known about impacts and pathways for exposure to lead for breeding adult eagles and nestlings. Ongoing efforts to test lead concentrations in live eagles and carcasses will contribute to understanding the problem in the WYUB.

6.2. ARs and other poisons

Poisoning by anti-coagulant rodenticides (ARs) is increasingly recognized as a hazard to golden eagles and other raptors (see Anticoagulant rodenticides above). The extent of AR use in the WYUB is unknown, but is likely restricted to local efforts to control sciurid populations on private lands (U.S. Fish and Wildlife Service 2017c). AR use is prohibited on BLM lands, except where rodent colonies threaten human health, and use of chlorophacione (e.g., Rozol®) is prohibited by USFWS in black-footed ferret management areas (U.S. Fish and Wildlife Service 2017c).

Avoidance and minimization:

Poisoning can be avoided through incentives for private landowners and lessees not to use ARs in areas frequented by golden eagles. Efforts for black-footed ferret conservation in the WYUB provide a model of successful, collaborative management of prairie-dog habitat that could benefit golden eagles. Additionally, ARs should not be used in wind farms as a method to deter eagle use by controlling rodent populations. Maps of golden eagle habitat priority areas in this report can be used to target conservation measures like cessation of AR use in areas where they will provide the greatest benefit to eagles. Other poisons responsible for killing eagles in the WYUB include the agricultural euthanasia agent pentobarbital. To minimize poisoning of golden eagles, carcasses of animals euthanized with pentobarbital or other chemicals should be buried, covered, or burned.

Research and monitoring

Better data on the magnitude and locations of AR use in the WYUB is necessary to understand effects on golden eagles. Data on amounts and locations of AR application could be required with the Restricted Use Pesticide (RUP) Applicator's License necessary to use of ARs, and by BLM when use of ARs is permitted on public lands. Further research is also needed on the pathways of AR exposure, and effects of ARs on reproduction and behavior of eagles. Linking data on AR exposure to characteristics of eagle habitat, like human settlement and agriculture, could support spatial risk assessments to inform planning.

7. Diseases and parasites

While limited data suggest diseases and parasites of golden eagles may be less prevalent in the WYUB than other areas, changes in climate and land use could increase exposure of eagles to both native and introduced pathogens (see Diseases and parasites above). Insect-borne pathogens (e.g., West Nile virus from mosquitoes and leucocytozoonosis from blackflies) and insect pests (e.g., blow flies, Mexican chicken bugs) could increase in response to rising temperatures and changing precipitation regimes (Walker and Naugle 2011). Diseases vectored by prey of golden eagles (e.g., trichomonosis from pigeons and avian cholera from waterfowl) could increase if habitats of primary prey species are lost to wildfire or other disturbances (Heath and Kochert 2015).

Avoidance and minimization: habitat management and nest treatment

Conservation measures to minimize diseases and parasites involve habitat management or treatment of eagles and nests. None of these techniques have been applied and broad scales and should currently be considered experimental. Research on management strategies to prevent WNv in wildlife, which has focused on greater sage-grouse, suggests risk of WNv could be reduced through mosquito control and limiting the extent of human-made surface water (Walker and Naugle 2011). Limiting surface water may also reduce exposure to leucocytozoon, which is spread by blackflies. Preservation and restoration of native prey habitat could prevent dietary shifts to rock pigeons that vector trichomonosis and waterfowl that vector avian cholera (Heath and Kochert 2015). If nests with parasites are identified, medical treatments are available for trichomonosis. Similarly, application of insecticides to control Mexican chicken bugs and other ectoparasites have proven effective. Such intensive nest management is unlikely to be practical at a broad scale, but may be applicable for local study areas, conservation properties, and other areas where nests can be closely monitored. Maps of golden eagle habitat priority areas in this report can be combined with regional knowledge on patterns of risk to target conservation measures in areas where they will provide the greatest benefit to eagles.

Research and monitoring

Data on diseases and parasites are limited to eagles that are found opportunistically and submitted to wildlife laboratories or captured for research purposes. Increased sampling effort is necessary to determine the current prevalence of diseases and parasites of the golden eagles in the WYUB and establish baselines to detect potential increases in response to changing conditions.

8. Prey resource limitation

Healthy prey populations are vital to the reproduction and survival of golden eagles in the WYUB (see Prey resource limitation above). Despite the necessity of small mammalian prey to eagles and other raptors, relatively little research is available on the habitat requirements of prey species or management strategies to sustain prey populations in perpetuity. Studies in the WYUB (Preston et al. 2017a) and elsewhere (Kochert et al. 2002) have established a strong link between prey abundance and golden eagle productivity, but none have quantified the baseline densities of prey required for successful reproduction or the extent and condition of habitat required to support sufficient prey.

Avoidance and minimization: prey habitat conservation and management

Management techniques that conserve or restore native vegetation in golden eagle habitat are expected to support the long-term persistence of eagle populations. Compared to other regions of the sagebrush biome, the WYUB is fortunate to have relatively intact native vegetation communities. The focus of management is, thus, on maintaining existing habitats by limiting disturbances that transform large areas of native shrubland and grassland (e.g., wildfire, invasion of exotic plant species, sustained intensive livestock grazing, and agricultural tillage), while addressing hazards where they exist (e.g., cheatgrass invasion in the Bighorn Basin). Some measures to protect sagebrush steppe habitats of the greater sage-grouse, like establishment of fire breaks and cheatgrass treatment, could benefit the habitats of golden eagle prey. On the contrary, some treatments designed to improve greater sage-grouse habitat, like conifer removal, may have adverse effects on eagle habitat.

In addition to habitat loss, prey species may be negatively affected by habitat fragmentation from anthropogenic development (e.g., energy development, exurban expansion) and associated infrastructure (e.g., roads, well pads, pipe lines, power lines). Current research on habitat fragmentation is equivocal, with indications that anthropogenic infrastructure could increase densities of some small mammals, while negatively impacting others (APPENDIX A. Prey Group Summaries). Management strategies that preserve native vegetation communities are expected to provide the greatest benefits, until the thresholds at which surface disturbance constitutes habitat loss for golden eagles and their prey are firmly established.

Diets of Golden eagles in the WYUB are dominated by leporids (i.e., jackrabbits and cottontails), but prairie dogs and ground squirrels are locally important in areas where they are abundant (e.g., Shirley Basin, Wyoming; see Prey community above). Cessation of varmint shooting and poisoning in areas where golden eagles rely on prairie dogs is a possible management strategy to support reproductive success of eagles, especially during periods of low leporid abundance. Limiting varmint shooting and poisoning in eagle habitat may also have the added benefit of reducing exposure to poisons and lead from carcasses.

Research and monitoring

More research is necessary to understand distribution and habitat associations of golden eagle prey species in the WYUB. Restoration of prey habitat to increase golden eagle productivity has been proposed as a possible mitigation strategy for take of eagles; however, current knowledge of golden eagle ecology is insufficient to support this approach. Implementation of prey-based mitigation would require regional studies to quantify both the relationship of habitat conditions to prey density and prey density to golden eagle reproduction. Ongoing studies of vegetation treatments for greater sage-grouse offer an opportunity for collaborative research to understand effects of habitat manipulations on key prey species of golden eagles in sagebrush steppe habitats; however, research funding is rarely dedicated to jackrabbits and cottontails because they are not considered species of concern. Potential impacts of climate change on prey abundance are unknown, including direct (i.e., physiological) and indirect (i.e., habitat-mediated) effects. Finally, fluctuations of leporid populations remain poorly understood in the WYUB. Rigorous, long-term monitoring of golden eagles and their prey are needed to clarify the role of prey abundance in eagle reproduction, and to separate cyclic, prey-driven variation in breeding success from potential long-term declines.

9. Disturbance by recreation

Recreational activities, like OHV riding, hiking, and rock climbing can have negative effects on reproductive success of golden eagles (see OHVs and other recreational activities above).

Avoidance: siting and design of road and trail systems

Disturbance to golden eagles from recreation can be avoided by routing roads and trails away from nest sites, foraging areas, and other high-use habitats. Comprehensive maps of roads and OHV trails are not available for the WYUB. Instead, maps of golden eagle habitat priority areas in this report can be used in conjunction with regional knowledge on hot spots of recreational use to inform road and trail design.

Minimization: seasonal closures

Conflicts of motorized and non-motorized recreation with golden eagles can be minimized with seasonal restrictions on heavily used roads and trails in priority eagle habitats. These include seasonal restriction of rock climbing, hiking, OHV riding, and other activities taking place near nest sites. Research in the neighboring Snake River Plain ecoregion showed that motorized and non-motorized recreation had negative effects at different stages of the nesting cycle (Spaul and Heath 2016). Results from this study could be used to inform timing of seasonal restrictions for different types of recreation. For example, areas with higher average seasonal OHV use had lower occupancy rates, while non-motorized recreation affected egg laying and nest attendance.

Research and monitoring

Further research is necessary to understand impacts of recreation on golden eagles in the WYUB. Studies from other regions have documented negative effects of motorized and non-motorized recreation on nesting eagles. The severity of the hazard could be clarified by replicating these studies in the WYUB, where human population density and recreational pressure may be relatively lower.

10. Agriculture

A variety of agricultural activities have the potential to impact golden eagles. Hazards posed to eagles by agriculture include habitat loss and degradation, electrocution on distribution power poles, exposure to agricultural poisons, drowning in stock tanks, and trapping and harassment resulting from livestock depredation.

Loss of golden eagle habitat from conversion to cropland is not a widespread hazard in the WYUB because the current climate limits the extent of tilled agriculture in the region. However, golden eagle habitat could be impacted in the future, if climate change enables the expansion of agricultural development. Potential impacts of livestock grazing on the habitats of golden eagle prey are unknown. However, sustained, intensive livestock grazing and other agricultural practices with the potential to degrade the shrubland and grassland habitats of key prey species could have negative impacts to eagles.

Avoidance and minimization

Agricultural areas with center pivots and other infrastructure introduce relatively high densities of power poles into golden eagle habitat. Recommendations to avoid, minimize, and mitigate risk of electrocution in agricultural developments are the same as for other areas. These include using lower-risk configurations for new poles and retrofitting existing poles (see Electrocution prevention above).

Poisons used to control agricultural pests are a known hazard to eagles, including common poisons for prairie dogs and ground squirrels (see Anticoagulant rodenticides above). Impacts from rodenticide poisoning can be avoided by discontinuing use in important habitats of golden eagles. Additionally, chemicals used to euthanize livestock are known to kill eagles (see Other contaminants above). Poisoning by euthanasia agents can be avoided by burying, covering, or otherwise disposing of carcasses.

Livestock depredation can be avoided or minimized with interventions, like installation of netting over lambing pens, removing dead livestock and other potential eagle attractants, and the use of guard dogs (Center for Wildlife Damage Management 2015). Seasonal shifts in agricultural activities, like lambing, away from known golden eagle nests and habitat can also reduce impacts. Minimizing opportunities for livestock depredation by golden eagles could help reduce persecution in the long term by helping to shift negative cultural perceptions of eagles as predators. Harassment or trapping of golden eagles requires an Eagle Depredation Permit from USFWS (https://www.fws.gov/pacific/eagle/permit_types/depredation.html).

Simple, metal mesh ladders installed in stock tanks can prevent drowning of eagles and other wildlife (Rocky Mountain Bird Observatory 2006).

Research and monitoring

More research is necessary to understand effects of grazing practices on habitat and abundance of golden eagle prey. Similarly, the threshold at which cropland conversion constitutes habitat loss for golden eagles is unknown in the WYUB. Management of risks from other hazards associated with agriculture, including electrocution, poisoning, and harassment from livestock depredation could benefit from improved data collection and educational outreach.

11. Poaching and persecution

Despite declines from historical levels, poaching and persecution persist as causes of golden eagle mortality in the WYUB.

Avoidance and minimization

Strategies to reduce poaching and persecuting of golden eagles include law enforcement, prosecution of offenders, and education on legal protections of golden eagles and negative effects of trafficking on wildlife populations. Incidents can be reported to USFWS Office of Law Enforcement (https://www.fws.gov/le/regional-law-enforcement-offices.html) for Region 6 (Wyoming, Colorado, Utah, and Montana) or Region 1 (Idaho). Dead eagles should be reported as soon as possible to USFWS or state wildlife management agencies, so they can be collected before they are taken by poachers.

12. Research activities

Research activities affect only a small number of golden eagles each year in the WYUB. Nonetheless, impacts of research on eagles should be minimized by selecting non-invasive methods when possible and following best-practices when using invasive techniques. Invasive research methods provide essential data on golden eagle ecology. For example, models in this report could not have been developed without the use of GPS telemetry data from eagles that were trapped and instrumented with transmitters. Likewise, essential information on parasites, diseases, and contaminants could not have been obtained without entering nests and trapping eagles.

Avoidance and minimization

Many research questions important to the conservation of eagles, however, can be answered using non-invasive methods like structured visual surveys. Researchers should consider choosing the lowest impact method that will address their objectives and have their methods approved by appropriate ethics bodies (e.g., Institutional Animal Care and Use Committees). Common recommendations include measures to minimize handling stress and reducing the number and duration of nest visits. To improve understanding of sources of mortality, including potential impacts of transmitters, all instruments attached to golden eagles should include technology that allows them to be located and recovered in the event of mortality.

Research and monitoring

Data from ad hoc research designs, like opportunistic deployment of transmitters and nest checks, can contribute to meta-analyses. However, inferences are stronger when research is conducted as part of coordinated studies with clear objectives and hypotheses, design-based sampling, and target sample sizes based on power-analysis. Following basic principles for the design of scientific studies increases the value of data that are necessarily collected at the expense of golden eagles. Similarly, monitoring efforts conducted for industrial compliance on public lands should be required to use standardized methods and metrics to facilitate data integration. Where study areas overlap, improved coordination among entities that monitor nests is essential to avoid disturbance of eagles by excessive, repeated surveys.

13. Nest management and enhancement

Interventions to conserve or enhance individual nests are an option for smaller management areas. Possible measures include restoration or improvement of nest sites, insecticide treatment of nests, and medical treatment of nestlings.

Avoidance and minimization

Installation of shade structures at nest sites is being tested experimentally as a method to increase nestling survival by reducing heat stress (Kochert et al. 2019). This technique could be useful for eagle territories where nestlings experience heat stress and alternative nest sites that offer more shade are not available. In eagle territories with few suitable nesting substrates, loss of a nest site can constitute the loss of the territory. For example, nests in some territories in WYUB are on isolated, senescent cottonwood trees that decay and fall over. Likewise, nests on lone rock outcrops or cliffs are sometimes lost when substrates fracture, erode, or are removed by development. In these situations, a breeding territory could be conserved with a relatively simple intervention, like reinforcing a rock ledge or replacing a fallen tree with an artificial nesting platform. For sites where ectoparasites affect nestling survival, nestlings can be treated with medications and nests treated with insecticides (see Diseases and parasites above).

Research and monitoring

Further research is necessary to understand the effectiveness of nest management techniques. Artificial nest platforms have been used extensively to relocate and replace nest sites; however, it is difficult to determine the factors that influence their effectiveness because they are typically deployed on a case-by-case basis and may not receive long-term monitoring. Experimental studies could provide valuable information on the effectiveness of nest platforms, including the feasibility of creating new territories by installing platforms in areas that lack suitable substrates. Nest enhancements, like shade structures, treatment of nests with insecticides, and medication of nestlings should also be tested experimentally in the WYUB.

14. Land conservation

Avoidance and mitigation:

Less than 5% of golden eagle breeding and winter habitat in the WYUB has permanent protection from development (see Conservation Prioritization above). Land protection tools, like conservation purchases, easements, and mitigation banks are unlikely to play a large role in golden eagle conservation in the region, given the broad extent of eagle habitat on public lands in the WYUB. Nonetheless, private land protection tools have the potential to benefit eagles, especially if they are applied where concentrated areas of high-quality eagle habitat are at risk of development, or in conservation banks to offset development in other areas. Maps of golden eagle habitat priority areas and risk assessments in this report can be used to identify areas where land protection could provide the greatest benefit. For example, private land protection could play an important role in the southeastern WYUB where extensive wind resource development is proposed in high-quality golden eagle habitat on private lands.

Minimization

Conservation measures to minimize risk from various hazards to golden eagles (see Conservation Strategy) could be voluntarily applied on private lands or required in easement agreements. Some measures that are not likely to be mandated by regulations on public lands (e.g., use of non-lead ammunition, cessation of varmint shooting or poisoning) could be implemented voluntarily on private lands. Intensive nest management (see Nest management and enhancement) may also be most practical for small, private conservation areas that contain relatively few golden eagle territories.

15. Climate change

Golden eagles are likely to be affected by climate change; however, little is currently known about the timing and severity of potential impacts to eagles, their habitats, or prey. Potential direct effects include heat-stress of nestlings, increases in insect pests and diseases, and loss of nesting attempts to severe storms. Indirect effects could include reduced prey abundance from direct and indirect impacts on key prey species. Loss of prey habitat from wildfire has impacted fecundity of golden eagles in the neighboring Snake River Plain ecosystem, and risk of wildfire could increase in the WYUB under climate change. Asynchrony of eagle and prey phenology could also become an issue, if burrowing-rodent prey, like Wyoming ground squirrels, begin to estivate earlier in summer when eagle fledglings are learning to forage.

Avoidance and minimization

In the short term, conserving prey by protecting and restoring native vegetation communities in golden eagle habitat is the best strategy to increase resiliency of eagle populations to climate change (see Prey resource limitation above). In the long term, reductions in carbon emissions is necessary to minimize negative effects of climate change (IPCC 2018).

Research and monitoring

Intensive studies of golden eagle diet, reproduction, and prey habitat are urgently needed to predict potential changes in prey abundance and golden eagle reproduction under climate change scenarios. Further research is also necessary to understand effects of heat-stress on eagles and identify potential refugia, like higher-elevation nesting and foraging habitats, and shaded micro-habitats in existing territories. Finally, states and management agencies in the WYUB should collaborate to implement monitoring programs sufficient to establish current densities and reproductive rates of golden eagles in the region. Robust baseline data are essential to detect impacts and inform management of golden eagle populations in response to climate change and other stressors.

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III. APPENDIX: Prey Group Summaries

1. Cottontails

The combined ranges of three species of cottontail rabbits cover the majority of the WYUB: the desert cottontail (*Sylvilagus audubonii*) and mountain cottontail (*S. nuttallii*) are widely distributed across the region, while the eastern cottontail (*S. floridanus*) inhabits only a small portion of the Laramie Basin. Cottontails occur in the diet of golden eagles across their range (Bedrosian et al. 2017) and were the principal prey species identified in three studies in the WYUB (Arnold 1954, Millsap 1978, Preston et al. 2017a). Cottontails are intermediate in mass between ground squirrels and jackrabbits, with adult desert cottontails ranging from 755–1250 g (Chapman and Willmer 1978). Cottontails are active year-round, and thus potentially available as prey for golden eagles in all seasons (Hansen and Bedrosian 2017).

Cottontails occur in a wide range of habitats across their distribution and in the WYUB, including urban, suburban, and rural areas with shrubland, grassland, and forest vegetation (Hansen and Bedrosian 2017). Descriptions of cottontail habitat emphasized importance of hiding cover, like shrubs and downed woody debris (Chapman and Willmer 1978), shrubs, and gullies (Flinders and Hansen 1973). Distribution models for cottontails included a wide range of predictors indicative of the broad and variable habitat associations of these species. A model developed by the U.S. Geological Survey (USGS) suggested occurrence of cottontails in the Wyoming Basin was positively related to habitat amount (large areas of grassland, mixed shrubland, and coniferous forest), landscape heterogeneity (sagebrush edge density rugged terrain), hydrology (riparian land cover and distance to intermittent water), and anthropogenic factors (power lines), and negatively associated with increasing elevation and vegetative productivity (Hanser et al. 2011). While cottontails occurred over the full range sagebrush cover, they were most strongly associated with moderately high (60–75%) sagebrush cover within 5 km (Hanser et al. 2011). Although Hanser et al. (2011) defined the Wyoming Basin as a larger area that contained more mountainous habitat than our study, the broad range of factors included in their model is consistent with descriptions of cottontails as habitat generalists (Hansen and Bedrosian 2017).

There is evidence that fluctuations in abundance of cottontail populations in Wyoming have followed an approximately 8-year cycle, although the mechanisms underlying this cycle are unknown (Fedy and Doherty 2011). Cottontail rabbits are hunted recreationally in all states in the WYUB and hunters in Wyoming harvested an average of 94,086 cottontails (± 99,945 SD) annually during 1982–2007 (Fedy and Doherty 2011). Effects of hunter harvest and other factors (e.g., habitat modification, predators, disease) on population trends and local abundance of cottontails in the WYUB are unknown.

2. Jackrabbits

Two species of jackrabbits occur in the WYUB: the white-tailed jackrabbit (*Lepus townsendii*) is widely distributed across the region, while the black-tailed jackrabbit (*L. californicus*) has a limited distribution along the southern and western edges of the region, where it is largely sympatric with the white-tailed jackrabbit. Jackrabbits figure prominently in the diet of golden eagles across their range (Bedrosian et al. 2017). All studies of golden eagle diet in the WYUB documented use of jackrabbits; they were the primary prey group in one study (Schmalzried 1976) and secondary to cottontails in two studies (Arnold 1954, Millsap 1978). Jackrabbits are among the largest prey taken regularly by golden eagles: white-tailed jackrabbits weigh 2800–4400 g (Lim 1987) and black-tailed jackrabbits average 1510–3550 g (Best 1996). Jackrabbits are active and potentially available as prey for golden eagles year-round (Lim 1987).

Like cottontails, habitat of jackrabbits is associated with shrubs used for hiding cover and food (Simes et al. 2015). Unlike cottontails, jackrabbits occurred in less rugged terrain (Hanser et al. 2011) described as flat or gently sloping (Lim 1987). The black-tailed jackrabbit is considered a habitat generalist, whereas the white-tailed jackrabbit is more strongly associated with native grasslands, agricultural fields, and sagebrush steppe (Simes et al. 2015). In the WYUB, white-tailed jackrabbits used areas with >82% big sagebrush cover within 0.27 km as daytime roosting habitat (Hanser et al. 2011). The USGS distribution model for white-tailed jackrabbits in the Wyoming Basin performed poorly in internal validation tests and should thus be interpreted with caution (Hanser et al. 2011). The model suggested relationships with vegetation varied by scale: occurrence of white-tailed jackrabbits was positively associated with percent cover of sagebrush and grassland at a fine spatial extent, but broadly associated with salt desert shrubland (Hanser et al. 2011). Model results also suggested complex relationships with anthropogenic factors: occurrence of white-tailed jackrabbits was positively associated with distance to pipelines, but negatively associated with distance to highways and density of other roads (Hanser et al. 2011). White-tailed jackrabbits preferentially forage in grasslands (Flinders and Hansen 1973) and may thus have benefitted from the interspersion of pipeline routes re-vegetated with exotic grasses into shrubland habitats. Although roads can also increase habitat heterogeneity, potential benefits to jackrabbits may have been negated by risks associated with roads, including vehicle collision and predation by raptors using anthropogenic perches (Hanser et al. 2011). Overall, these results suggest habitat for white-tailed jackrabbits in the WYUB was characterized by salt-desert shrublands in smooth terrain, intermixed with a mosaic of other shrub communities, and native and exotic grasslands.

Cycling of black-tailed jackrabbit populations has been documented in the Great Basin (Steenhof et al. 1997, Bartel et al. 2008), but has not been confirmed in the WYUB. Jackrabbit populations in the WYUB have fluctuated historically and several studies reported sustained low abundance of jackrabbits in recent years (Oakleaf et al. 2014, Preston et al. 2017a). Average density of white-tailed jackrabbits in sagebrush habitats of southwestern Wyoming (0.07/ha, 95% CI: 0.04–0.09; Rogowitz and Wolfe 1991) was similar to the average from other regions (0.08/ha; Simes et al. 2015). Despite periodic increases to "plague" levels, white-tailed jackrabbit populations have likely experienced range-wide declines due to modification of habitat for agriculture (Simes et al. 2015). Little agricultural land conversion has occurred in the WYUB and potential influences of this and other factors on abundance of white-tailed jackrabbits in the region are unknown.

3. Ground squirrels

Wyoming ground squirrels (*Urocitellus elegans*) occur throughout the WYUB, except the Bighorn Basin, while Uinta ground squirrels (*U. armatus*) occur only along the western edge of the region. Although Uinta ground squirrels appeared rarely in the diet of golden eagles (Preston et al. 2017a) and their importance as prey in this region is unknown because only a small portion of one study area overlapped their range. Ground squirrels were the secondary prey group to jackrabbits in one study (Schmalzried 1976), tertiary to leporids and white-tailed prairie dogs (*Cynomys leucurus*) in one study (MacLaren et al. 1988), tertiary to cottontails and jackrabbits in another study (Millsap 1978), and occurred in small numbers in two studies (Arnold 1954, Preston et al. 2017a). These results are consistent with evidence of sciurids as secondary or tertiary prey of golden eagles across the majority of their range, especially where leporids are abundant (Bedrosian et al. 2017). Wyoming ground squirrels are small (305 g average; Clark 1970), semi-fossorial rodents. They are obligate hibernators, emerging from subterranean burrows in mid-March in response to warming temperatures and estivating in mid-July in response to hot weather (Clark 1970). Accordingly, ground squirrels in Wyoming are only available as prey during an approximately 4-month period corresponding to nesting and early post-fledging periods of golden eagles.

Ground squirrels occur in shrubland and grassland habitats ranging from alpine meadows to sagebrush steppe (Zegers 1984). Distribution models for Wyoming and Uinta ground squirrels developed by the Wyoming Natural Diversity Database had overall low performance, possibly due to confusion among species in the field (Keinath et al. 2010a). The model for Wyoming ground squirrels suggested they were associated with middle elevations, moderate sagebrush cover, and predictors describing a warm and stable climate envelope (Keinath et al. 2010a). Johnson et al. (1996) found that Wyoming ground squirrels occurred in areas with low sagebrush density (2%), but were most abundant in areas with moderately low sagebrush cover (12–15%). Uinta ground squirrels have habitat associations similar to Wyoming ground squirrels, although they may select more open habitats (Eshelman and Sonnemann 2000).

Population trends of ground squirrels are unknown in the WYUB, but conversion of deep-soil habitats to agriculture may have reduced historical distribution and abundance of these species (Johnson et al. 1996). Density of Wyoming ground squirrels varied seasonally, with lowest densities in early spring (0.2/ha in March) due to overwinter mortality and peak densities in mid-summer (1.2/ha in June) when young emerged aboveground (Clark 1970). Wyoming ground squirrel populations are controlled by poisoning, shooting, and trapping in areas where they are considered an agricultural pest. Recreational shooting of ground squirrels is allowed year-round in Wyoming without a permit, and the population-level effects of this and other hazards are unknown.

4. Prairie dogs

White-tailed prairie dogs (*Cynomys leucurus*) occur throughout the WYUB, while black-tailed prairie dogs (*C. ludovicianus*) occur in a limited area where the east-central Wyoming Basin borders the Northwestern Great Plains Ecoregion. The highest known frequency of any prairie dog species in the diet of golden eagles was documented for white-tailed prairie dogs in the WYUB (MacLaren et al. 1988, Bedrosian et al. 2017). Nonetheless, white-tailed prairie dogs were secondary to leporids as prey for golden eagles in that study (MacLaren et al. 1988) and occurred in smaller numbers in three other studies in the WYUB (Schmalzried 1976, Millsap 1978, Preston et al. 2017a). White-tailed prairie dogs are medium-sized (800–1500 g; Clark et al. 1971), semi-fossorial rodents that form colonies of subterranean burrows in grasslands and shrublands. White-tailed prairie dogs are obligate hibernators (Harlow and Menkens Jr 1986) and their abundance as prey for golden eagles varies over the approximately 9-month period in which they are active above-ground. In Wyoming, adult males emerged from burrows in early February, with all adults active above ground by mid-March (Clark 1973). Colony activity peaked with the emergence of juveniles in mid-May, then declined as adult males immerged below ground by late July, followed by adult females in August (Clark 1973). Juveniles were the last to immerge, with some remaining above-ground until early November (Clark 1973).

White-tailed prairie dog habitat in the WYUB consisted of moderately sloping (<20%) grasslands and shrublands at middle elevations (1,150–3,050 m; Seglund et al. 2004). Vegetation included common mixed-grass prairie grasses, and shrubs like big sagebrush, greasewood, and rabbitbrush (Orabona-Cerovski 1991). White-tailed prairie dog colonies have more shrubs and other vegetation than the characteristically barren colonies of black-tailed prairie dogs (Keinath 2004), although cover of bare ground averaged 62% in the extensive colony complex at Shirley Basin, Wyoming (Orabona-Cerovski 1991). Bare ground was also an important predictor of white-tailed prairie dog occurrence in Wyoming, in addition to low herbaceous ground cover index, lack of conifers, and climate variables suggesting moderate winter temperatures and warm, dry summers (Keinath et al. 2010b).

Large colony complexes in Shirley Basin, Wyoming and northwestern Colorado contain 50–75% of all white-tailed prairie dogs (Keinath 2004). Known colonies covered 186,000 ha in Wyoming (Seglund et al. 2004), with many smaller colonies yet to be documented (Keinath 2004). Although the historical range of this species has not changed significantly, occupied area and abundance may have declined by as much as 99% during the 20th century from a combination of plague (*Yersinia pestis*), pest control, and anthropogenic habitat modification (Keinath 2004). Plague, an exotic bacterial disease introduced to North America in the late 19th century, is currently the primary factor limiting white-tailed prairie dog populations (Keinath 2004). Rapid and extensive mortality from plague events can cause occupancy and abundance of white-tailed prairie dogs to vary dramatically between years (Keinath 2004). Furthermore, individual colonies may have divergent trends due to site-specific variation in patterns of disease, resource extraction, fire suppression, intensity of livestock grazing, and sport shooting (Seglund et al. 2004).

5. Additional prey species

Among the wide range of alternate prey used by golden eagles in the WYUB, relatively larger species appeared more frequently. Two studies documented larger birds, like sage-grouse (Arnold 1954) and waterfowl (Schmalzried 1976) as tertiary prey, and one study suggested importance of pronghorn fawns and birds other than sage-grouse (Preston et al. 2017a).

Sage-grouse occur throughout the WYUB in suitable sagebrush steppe habitats (Schroeder et al. 2004). While one study in the WYUB reported sage-grouse as the tertiary prey species of golden eagles, this study was based on a limited sample of four nest sites (Arnold 1954), and four other studies documented only infrequent use of sage-grouse (Schmalzried 1976, Millsap 1978, MacLaren et al. 1988, Preston et al. 2017a). Population declines have led to conservation concern for sage-grouse, which has inspired interest in the potential role of avian predation. In Wyoming, sage-grouse selected habitat to avoid golden eagles (Dinkins et al. 2012), but predation by golden eagles did not affect survival of breeding-age hens, which is the most important demographic rate to population growth for this species (Dinkins et al. 2014). Instead, the primary threats implicated in declines of sage-grouse were loss and fragmentation of sagebrush steppe habitat by conversion to agriculture, energy development, and invasive annual grasses (Connelly et al. 2004). Sage-grouse are potentially available as prey to golden eagles year-round and occur seasonally in a range of sagebrush vegetation communities associated with different life-history stages (Connelly et al. 2000, Fedy et al. 2014). Sage-grouse populations declined precipitously during the 20th century (e.g., 90% decline in southwestern Wyoming during 1952–2003; Connelly et al. 2004) and, thus, may have been of greater historical importance as prey for golden eagles.

Ducks and other waterfowl occur throughout the WYUB in suitable wetland, marshland, riverine, and lacustrine habitats. Waterfowl appeared infrequently in the diets of golden eagles in three studies (Arnold 1954, Millsap 1978, MacLaren 1986), but were the tertiary prey species in a study conducted in the Laramie Basin (Schmalzried 1976). The Laramie Basin has relatively more surface water than other parts of the WYUB, which may have increased availability of waterfowl to golden eagles nesting there. Although waterfowl are not currently important as prey for most golden eagles breeding in the WYUB, research from the Northern Great Basin Ecoregion found some golden eagle pairs switched to waterfowl as primary prey following a decline in leporids (Heath and Kochert 2015).

Pronghorn antelope occur in open habitats throughout the WYUB, including sagebrush steppe, prairie, and salt-desert shrublands (Rowland et al. 2011). Although golden eagles are capable of taking adult pronghorn (see Winter diet and prey communities), neonates occurred more frequently in golden eagle diet. Pronghorn fawns, which made up 9.6% of diet in one study (Preston et al. 2017a), are available to golden eagles beginning in mid-to-late May, corresponding to the brooding period of golden eagles.