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The Effects of Management Practices on Grassland Birds—Golden Eagle (*Aquila chrysaetos*)

Chapter O of

The Effects of Management Practices on Grassland Birds

Professional Paper 1842–O

U.S. Department of the Interior
U.S. Geological Survey

Cover. Golden Eagle. Photograph by Craig Koppie, used with permission.
Background photograph: Northern mixed-grass prairie in North Dakota, by Rick Bohn, used with permission.

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By Robert K. Murphy,[1] John P. DeLong,[2,3] Lawrence D. Igl,[2] and Jill A. Shaffer[2]

Chapter O of

The Effects of Management Practices on Grassland Birds

Edited by Douglas H. Johnson,[2] Lawrence D. Igl,[2] Jill A. Shaffer,[2] and John P. DeLong[2,3]

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Conversion Factors

International System of Units to U.S. customary units

Multiply	**By**	**To obtain**
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (ft^3)
	Mass	
gram	0.03527	ounce (oz)
kilogram	2.205	pound (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as

$$°F = (1.8 \times °C) + 32.$$

Abbreviations

APLIC	Avian Power Line Interaction Committee
APWRA	Altamont Pass Wind Resource Area
AR	anti-coagulant rodenticide
BACI	before-after-control-impact
BGEPA	Bald and Golden Eagle Protection Act
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
FWS	U.S. Fish and Wildlife Service
ppm	part per million
RND	relative nesting density
spp.	species (applies to two or more species within the genus)

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The Effects of Management Practices on Grassland Birds—Golden Eagle (*Aquila chrysaetos*)

By Robert K. Murphy,[1] John P. DeLong,[2,3] Lawrence D. Igl,[2] and Jill A. Shaffer[2]

Capsule Statement

Keys to Golden Eagle (*Aquila chrysaetos*) management in western North America's grasslands, particularly those of the Great Plains region, include maintaining open, mostly undeveloped landscapes that sustain at least modest population levels of suitable prey (most typically rabbits [Leporidae] and prairie dogs or ground squirrels [Sciuridae]); safeguarding nesting territories (that is, breeding areas), especially nest structures within territories, from human disturbances; mitigating major sources of anthropogenic mortality, particularly electrocution on powerlines, shooting, collisions with structures and vehicles, and poisoning by lead and rodenticides; and averting climate change.

Breeding Range

Golden Eagles have a Holarctic distribution, occurring throughout most of North America, Europe, Asia, and parts of northern Africa (Katzner and others, 2020b). One (*Aquila chrysaetos canadensis*) of six recognized subspecies inhabits North America. Figure O1 shows the breeding, year-round, migration, and nonbreeding distributions of the Golden Eagle in North America in general (not all geographic places mentioned in this report are shown on figure). A more detailed map of the species' distribution in western North America is found in Wheeler (2003). According to Wheeler (2003), the species' breeding range extends from far northern Alaska, Yukon Territory, and the Northwest Territory; south to central Mexico; west to much of the Pacific Coast; and east to southwestern North Dakota, central South Dakota, and far southwestern Kansas. An eastern North American population breeds in parts of Manitoba, Ontario, Quebec, and throughout Labrador (Katzner and others, 2020b). However, this account focuses mainly on Golden Eagles in the Great Plains and other grassland and shrubsteppe regions of western North America.

Golden Eagle. Illustration by Patsy D. Renz, used with permission.

The year-round distribution of nonbreeding Golden Eagles in western North America is as germane to conserving the species as is the species' breeding distribution. The Golden Eagle is a *K*-selected species, with sexual maturity (that is, adult age) typically delayed until the fifth year of life and breeding pairs exhibiting low reproductive output (Katzner and others, 2020b; Millsap and others, 2022). As such, preadult-aged individuals constitute a crucial population component, and their year-to-year survival is nearly as critical as that of adults. Many adult-aged Golden Eagles are floaters (that is, individuals that fail to secure a breeding area in a given year); these individuals are quickly able to fill vacancies in breeding areas as such opportunities arise, and thus serve to buffer populations from declines (Haller, 1996; Hunt, 1998; Hunt and others, 2017). Together with overwintering migrants, the geographic distribution of preadults and floaters extends beyond the species' breeding range and includes most of the Great Plains.

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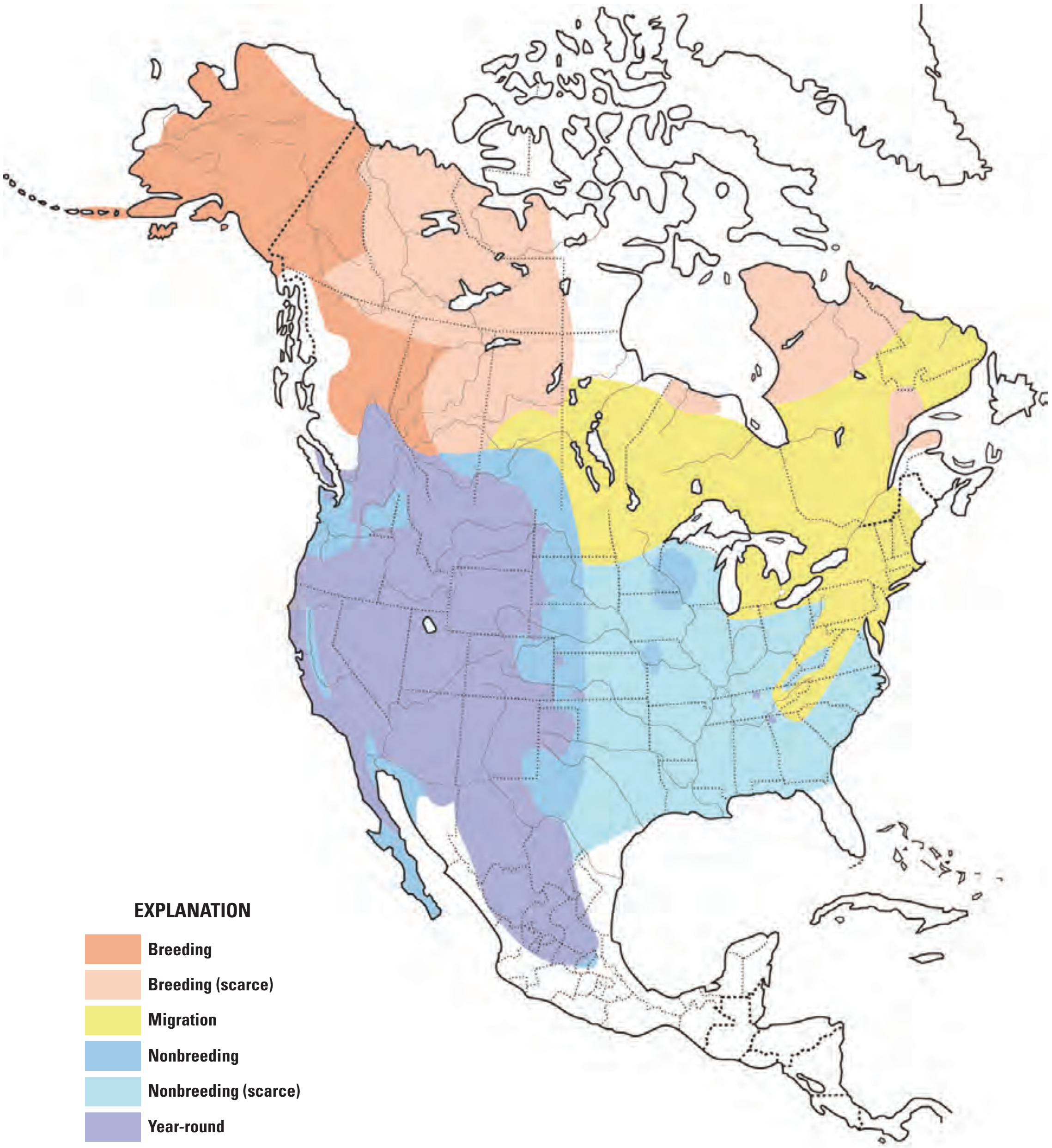

Figure 01. Breeding, year-round, migration, and nonbreeding distribution of the Golden Eagle (*Aquila chrysaetos*) in North America.

Golden Eagles from northern Canada and most of Alaska are strongly migratory (Kochert and others, 2002; Katzner and others, 2020b). The species occupies its northern summer range from about mid-March through mid-October, except some individuals remain year-round in parts of southern Alaska, southern Yukon Territory, and northwestern British Columbia (Wheeler, 2003) and in parts of Saskatchewan (Houston, 1985). Individuals migrating from northern latitudes of western North America overwinter in much of southwestern Canada; throughout the conterminous western United States, eastern portions of the Great Plains, occasionally western parts of the upper Great Lakes States, and the upper Mississippi River Valley; and most of northern and central Mexico (Kochert and others, 2002; Wheeler, 2003; Katzner and others, 2020b). Golden Eagles from regions south of the boreal forest are mostly nonmigratory, although some individuals from mid-latitudes could be considered short-distance migrants; breeding individuals tend to remain on territory year-round but their home ranges may increase in size during winter (Katzner and others, 2020b). Based on a compilation of telemetry-based movements from 571 Golden Eagles across North America, annual ranges of individuals from western North America seldom overlapped with those of conspecifics from eastern North America (Brown and others, 2017).

Suitable Habitat

Golden Eagles use a broad range of habitat types but generally occupy open landscapes ranging from arid deserts, grasslands, and shrubsteppe to arctic and alpine tundra (Katzner and others, 2020b). In North America, Golden Eagles breed at elevations from nearly sea level (Poole and Bromley, 1988) to 3,630 meters (m) (G.R. Craig, personal commun. *in* Katzner and others, 2020b). In the southern Rocky Mountains, breeding occurs up to 3,048 m (E. Wellein and T. Ray, unpublished report *in* McGahan, 1968), and nonbreeding individuals use areas up to 4,000 m (R. Murphy, personal obs., July 10, 2020). Habitat use varies with season, an individual's age and breeding status, and specific activity or behavior (for example, night-roosting, migration, or territorial display) (Katzner and others, 2020b). Golden Eagles sometimes use woodland, riparian, and cropland habitats but generally shun extensive closed-canopy forest, areas of intensive agriculture, and dense populations of humans, with some exceptions. Domenech and others (2015) studied winter ranges and habitat use of 14 adult, migrant Golden Eagles overwintering mainly in the Rocky Mountains from Idaho to New Mexico; the primary habitat used by the eagles was coniferous forest, although habitat use varied considerably among individuals. Migrant eagles probably used forests to avoid intraspecific competition with resident breeding eagles, although gut piles from hunter-killed big-game animals may have attracted eagles to forests in many cases (Domenech and others, 2015). Golden Eagles overwintering in eastern North America (from the coastal plains to the bottomlands of the Mississippi River) often perched and roosted in forests and may have foraged there if edges and small openings were available for access to prey (Miller and others, 2017).

High topographical relief (that is, large hills or ridges to mountains) likely is the species' "most consistent habitat association" (Katzner and others, 2020b, unpaginated). However, dense breeding populations of Golden Eagles occur across the Powder River Basin of northeastern Wyoming and locally in other parts of the northern Great Plains (Bedrosian and others, 2019; Dunk and others, 2019); these landscapes on average are much less rugged than other places where the species breeds at relatively high densities. Moreover, Katzner and others (2020b, unpaginated) acknowledged that a relationship between Golden Eagles and rugged landscapes is less clear during the nonbreeding season, especially among overwintering migrants, which can occur nearly "wherever perches and prey are available." This use of less-rugged landscapes could be said also of nonmigratory, preadult-aged Golden Eagles year-round; many juveniles (that is, first year of age) from the southern Rocky Mountains and Colorado Plateau disperse east to the southern Great Plains and south to arid grasslands of the Chihuahuan Desert (Murphy and others, 2017). Generally, as Katzner and others (2020b, unpaginated) stated, "Shrublands or grasslands are the dominant cover types of [Golden Eagle] home ranges at intermediate latitudes."

There are various qualitative, brief descriptions of Golden Eagle habitat in the Great Plains and adjoining areas. In the northern Great Plains, landscapes used by Golden Eagles include shortgrass prairie, mixed-grass prairie, and xeric scrub/grassland in southwestern North Dakota (Stewart, 1975; Allen, 1987); prairies and riparian areas in western South Dakota (Johnsgard, 1980; Tallman and others, 2002); Sandhills mixed-grass prairie and shortgrass prairie interspersed with buttes and cliffs in western Nebraska (Mathisen and Mathisen, 1968; Faanes and Lingle, 1995); and shrubsteppe and grassland interspersed with scattered hayfields and woodland in eastern Wyoming (Phillips and Beske, 1990; Phillips and others, 1990). In Montana, Golden Eagles use grazed and ungrazed shortgrass prairie, montane grasslands, shrubsteppe, and mixed-conifer woodlands (Baglien, 1975; Crandall and others, 2015). In the southern Great Plains, landscapes used by Golden Eagles include shortgrass prairie and shrubsteppe in northeastern Colorado (Ryder, 1972; Olendorff, 1973), and shortgrass prairie, shrublands, and open pinyon pine (*Pinus edulis*)/oneseed juniper (*Juniperus monosperma*) habitats in western Oklahoma, southeastern Colorado, northeastern New Mexico, and northwestern Texas (Lish, 1975; Andersen and others, 1990; Andrews and Righter, 1992; Boal and others, 2008; Stahlecker and others, 2022). Croplands were avoided in northeastern Colorado (Olendorff, 1973) and eastern Wyoming (Phillips and others, 1984). In the Great Basin in southwestern Idaho, Golden Eagle home ranges included shrubsteppe, native and nonnative grasslands, cropland, and riparian habitats (Collopy and Edwards, 1989; Marzluff and others, 1997).

Breeding Habitat

Before the early 2000s, attributes of Golden Eagle breeding habitat in the conterminous western United States (hereafter, western United States) were quantified mainly in areas known or thought to have high numbers of breeding pairs and in areas dominated by publicly owned lands potentially subject to resource development (for example, fossil-fuel extraction). In the cold desert shrubsteppe ecoregion (or the northern Great Basin region), Marzluff and others (1997) found that habitat composition and use by Golden Eagles within breeding territories associated with the Snake River Canyon in southwestern Idaho varied considerably among individual eagles and between breeding and nonbreeding seasons, based on radio-telemetry data collected from 15 Golden Eagles at 8–9 breeding areas annually during 1992–94. Home ranges of most individuals included less cover dominated by agriculture (not defined) and grassland (*Poa secunda*, *Bromus tectorum*, *Elymus elymoides*), and more cover dominated by big sagebrush (*Artemisia tridentata*) and rubber rabbitbrush (*Ericameria nauseosa*), than expected based on availability within 4.5 and 9.5 kilometers (km) of the canyon rim (where the eagle's nests were sited), in breeding and nonbreeding seasons, respectively (Marzluff and others, 1997). Cliffs and rock outcrops also were important, largely because they constituted a small yet crucial home-range component by providing nest sites, perch sites, and updrafts for flight. Preference for big sagebrush-rabbitbrush habitat was most obvious when this habitat occurred infrequently within eagle home ranges dominated by agriculture and grassland cover. Sagebrush-rabbitbrush habitat probably was favored strongly because black-tailed jackrabbits (*Lepus californicus*), a main prey of the species, were closely associated with this habitat type. Salt-desert shrubs (*Sarcobatus vermiculatus* and *Atriplex* species [spp.]) also were selected but to a lesser degree; sagebrush-rabbitbrush habitat constituted a much greater proportion of used habitats, and its use tended to be correlated with its availability within eagle home ranges (Marzluff and others, 1997). Use of sagebrush-rabbitbrush habitat increased during the breeding season. Grassland was the most common habitat type within eagle home ranges; it was used less than expected based on availability, but this selection tendency likely reflected the predominance of grassland habitat (Marzluff and others, 1997). However, wildfires burned parts of the northern Great Basin landscape 10–15 years before the study (Knick and Rotenberry, 1997), exacerbating invasion by cheatgrass (also known as downy brome; *Bromus tectorum*), an aggressive, nonnative grass species that has vastly diminished the quality of sagebrush shrubsteppe as habitat for native species of birds and other wildlife (Knick and others, 2003; Bradley and others, 2018), including black-tailed jackrabbits (Kochert and others, 1999). Agriculture (not defined) and disturbed areas (not defined) were combined in the habitat-selection analyses; these habitat types were avoided consistently by individual eagles during both seasons (Marzluff and others, 1997).

In other early, but more local, research in cold desert shrubsteppe of the northern Great Basin, several species of raptors, including up to eight pairs of Golden Eagles, nested on transmission line towers in areas of southeastern Oregon and southwestern Idaho with more rangeland, fewer roads, and shorter total lengths of powerline compared to areas around unused towers (Steenhof and others, 1993). Collectively, however, towers used for nesting by all raptors did not differ from unused towers in amounts of cover in the surrounding (within 1 km) landscape dominated by shrub, grass, or agricultural lands; topographic variation; habitat dispersion; or numbers of human structures. Craig and Craig (1984) found more Golden Eagles nesting along sections of a southern Idaho canyon that was bordered by sagebrush and areas converted to crested wheatgrass (*Agropyron cristatum*) cover than in sections bordered by agricultural lands. Compared to nests of breeding pairs with adult Golden Eagles, nests of breeding pairs with one subadult were surrounded by substantially more intensively farmed land and had more roads and human habitation nearby, suggesting that territories held by subadult-adult pairs were inferior; however, reproductive success of subadult-adult pairs was not dissimilar from that of adult pairs (Steenhof and others, 1983).

In Wyoming, Phillips and others (1984) measured Golden Eagle breeding densities across a gradient of areas dominated by wheatgrass (formerly *Agropyron* spp.) grasslands and sagebrush shrubsteppe. The area with the highest density of eagle breeding pairs was characterized by abundant, diverse types of prey and many suitable nest sites, whereas the area with the lowest eagle density had few suitable nest sites and was fragmented by cropland (crop types were not described). The only habitats in which breeding eagles were absent or rare were areas of contiguous forest, extensive cropland, and flat, desert-like terrain, although these habitats were not surveyed as intensively as others. More recently, Olson and others (2015) found greater Golden Eagle breeding densities in mixed-grass prairie landscapes of eastern Wyoming (93.9 and 100.6 square kilometers [km^2] per breeding pair in High Plains and Northwestern Great Plains ecoregions, respectively) than in big sagebrush-salt desert scrub landscapes of central and western Wyoming (Wyoming Basin Ecoregion; 277.1 km^2 per breeding pair).

A comprehensive "relative nesting density" (RND) model developed by Dunk and others (2019) was used by Bedrosian and others (2019) to predict occurrence of Golden Eagle breeding areas across the Northwestern Plains Ecoregion (includes the Northwestern Great Plains and portions of the Northwestern Glaciated Plains regions), based on habitat attributes associated with known natural nest sites. A detailed summary of the salient aspects of Bedrosian and others' (2019) predictive models is warranted here, given the report's substantial sample sizes of nests, large number of habitat and topographic attributes, and geographic coverage. The sample for the model was derived from 23,991 Golden Eagle nest records, which were screened to avoid duplicating breeding areas of Golden Eagles because such areas often have multiple nest structures (Kochert and Steenhof, 2012; Millsap and others, 2015). Twelve predictor covariates were included in the final RND model, representing topography, vegetation and land cover, and lift (orographic and thermal) for eagle flight (Bedrosian and others, 2019). Orographic lift occurs when an air mass is forced from a lower elevation to a higher elevation as it moves over higher terrain; thermal lift occurs when columns of rising air form through the warming of the Earth's surface by sunlight. Overall, topographic variables and land-cover variables contributed 51.3 and 42.8 percent to the model, respectively, followed by lift (orographic and thermal lift combined, 5.8 percent). Terrain slope (standard deviation of grade, at 120-m scale; positive relationship), which reflected ruggedness, constituted 49.9 percent of the final model's predictive contribution. Bedrosian and others (2019) surmised that the strength of this covariate was linked mostly to high availability of thermal uplift in rugged terrain. Of note, on a smaller geographic scale, Crandall and others [2015] found the eagle's proclivity for terrain ruggedness in south-central Montana to be associated mainly with cliffs for nesting. The second most important (14.6 percent contribution) covariate in the RND model was the proportion of sparsely vegetated area (6.4-km scale; positive relationship) (Bedrosian and others, 2019). Sparse vegetation landforms include badlands, sandstone bands, breaks along river corridors, rock outcrops, and areas where geologic uplifts have permitted downcutting (a geological process by hydraulic action that deepens a channel or valley) by ancient streams with less than (<) 10 percent vegetation cover. Such features may provide available cliff-nesting habitat, as well as small pockets of ponderosa pines (*Pinus ponderosa*) for tree nesting, but still provide less vegetation at a larger landscape scale (Bedrosian and others, 2019). Good examples of these features are found in the Little Missouri River drainage basin of North Dakota and South Dakota (R. Murphy, personal obs., June 17, 2021). The third most important covariate (11 percent) was the proportion of cultivated cropland (6.4-km scale; negative relationship). Because this covariate was highly variable in the dataset of Bedrosian and others (2019), the authors suggested that Golden Eagles preferred habitat that uniformly lacks cultivated cropland, likely because of lack of prey. The fourth most important contributor (6.7 percent) was the mean proportion of eastern cottonwoods (*Populus deltoides*; 1-km scale; positive relationship), likely because Golden Eagles nest in cottonwood trees across much of the region, especially in areas lacking cliff sites. Lastly, the proportion of ponderosa pine (6.4-km scale) contributed 5 percent, but the association was negative, suggesting that Golden Eagle breeding pairs avoided large, contiguous tracts of pines and perhaps other conifers. This avoidance seems to contrast with general knowledge that Golden Eagles in the northern Great Plains often use ponderosa pines for nest sites, but Bedrosian and others (2019) pointed out that such nesting tends to occur at edges of pine forests or in very small or open stands.

A similar modeling approach that was developed for 12 regions of the western United States included the Southwestern Plains Ecoregion (approximating the southern Great Plains; Dunk and others, 2019). This model was less robust than that of Bedrosian and others (2019) for the northern Great Plains because the model for the southern Great Plains was represented by far fewer Golden Eagle breeding areas. Ten covariates were included in the final model. A terrain ruggedness index (standard deviation of grade) contributed 80.9 percent (positive relationship) to the model, and the proportion of steeply sloping landforms contributed 11.0 percent (positive relationship). Terrain likely was an overwhelming positive driver for the model because southern Great Plains landscapes are more level than the Northwestern Plains, on average, and breeding pairs tend to be concentrated at the limited number of available cliff sites (Stahlecker and others, 2022). The importance of terrain in the model for the Southwestern Plains also may explain why the proportion of land cover in cottonwoods and in grasslands were not important (greater than or equal to [≥] 5 percent) contributors to the model. The U.S. Fish and Wildlife Service (FWS) has not completed a Golden Eagle Conservation Strategy for the Southwestern Plains Ecoregion at the time of this writing (2023), so additional analyses including RND model correlation with general environmental attributes, such as those presented in Bedrosian and others (2019) for the Northwestern Plains Ecoregion, were unavailable.

Bedrosian and others (2019) included a map that illustrated results of the Golden Eagle RND model for the Northwestern Plains Ecoregion. Areas with predicted high densities of nest sites include the Missouri River Basin in eastern Montana, the Little Missouri River Basin in western North Dakota, and most of the Powder River Basin of northeastern Wyoming. Areas with predicted low densities include the Missouri Plateau of southwestern North Dakota, the Black Hills of South Dakota and Wyoming, and most of central South Dakota. In the Southwestern Plains (Dunk and others, 2019), areas with high predicted nest-site density are less pronounced and widely scattered, with highest densities predicted in the Palo Duro Canyon of northern Texas and across far northeastern New Mexico and a nearby area of southeastern Colorado. But, again, Dunk and others (2019) did not consider the Southwestern Plains RND model to be robust because of the lower number of reference nest sites. A recent compilation of nest surveys by Stahlecker and others (2022) accurately conveyed Golden Eagle nest-site distribution for most of the southern Great Plains and could be used to improve the predictive distribution model by Dunk and others (2019). Perhaps the most important implication of the RND work for managing Golden Eagle breeding habitat in the Great Plains is that a very high proportion of breeding areas occur on a very small proportion of the landscape (predicted and actual breeding densities in the modeling hold-out dataset were strongly congruent; Dunk and others, 2019). Thus, as stated by Dunk and others (2019, p. 17), "prioritization of conservation actions on a small portion of [the landscape]…could have a disproportionately large benefit to breeding Golden Eagles." Conversely, negative environmental impacts on a small portion of the landscape supporting high breeding densities of Golden Eagles could have profound negative effects at a population level.

RND models in Bedrosian and others (2019) and Dunk and others (2019) generally corroborated the results from recent empirical, local, and regional studies of Golden Eagle habitat. For example, others have identified terrain, wind, and orographic lift as key attributes of home ranges used by Golden Eagles (reviewed in Dunk and others, 2019). In south-central Montana, Crandall and others (2015) found that Golden Eagle breeding pairs selected home-range core areas based mainly on high percentages of terrain ruggedness and intermixed shrub-grassland, which they considered primary prey habitat. For landscapes similar to their study area, the authors recommended that areas with rugged topography surrounded by habitat with adequate prey should be priorities for Golden Eagle conservation. Breeding areas in extremely rugged terrain may be an exception, however, because Crandall and others (2015) found a negative relationship between daily nest survival and ruggedness. Using measures of many environmental and anthropogenic attributes of landscapes encompassing 483 Golden Eagle nest sites in northeastern Wyoming, Tack and Fedy (2015) found evidence of selection for local areas of sharp relief (cliffs and steep landscapes, 200-m scale) encompassed by or adjacent to relatively flat, open landscapes (5-km scale).

Nests and Nest Sites

Nests and nest sites of Golden Eagles are described profusely in the scientific literature; broad syntheses include those in Palmer (1988), Kochert and others (2002), and Katzner and others (2020b). Grubb and Eakle's (1987) detailed measurement of 12 Golden Eagle nest structures (nine on cliff ledges, three in trees) in central Arizona provide a general picture of the species' more typical nests in the western United States (mean plus or minus [±] standard deviation, range): length 176±46 centimeters [cm], 122–264 cm; lining length 94±36 cm, 53–185 cm; width 120±41 cm, 84–203 cm; lining width 79±36 cm, 38–160 cm; height 65±53 cm, 13–201 cm; stick length 58±10 cm, 8–78 cm; stick weight 64±26.7 grams (g), 5–820 g. The authors did not define "lining," which was measured at only eight of the nests. In this section, nest sites are summarized mainly in the context of the Great Plains.

Golden Eagles typically construct their bulky stick nests in large trees and on ledges or in potholes (that is, shallow caves) of cliffs. Substrates that support nests must be substantial. For example, in New Mexico, a Golden Eagle nest in a ponderosa pine measured 4.9 m tall and 1.4 m wide (J. Ligon, unpub. notes *in* Stahlecker and others, 2010), and an unusually large nest on a western Oklahoma sandstone cliff was roughly 4 m long, 2 m wide, and 2 m high, likely totaling about 16 cubic meters (m^3) of nest material (R. Murphy, personal obs., and D. Stahlecker, Eagle Environmental, Inc., Santa Fe, N. Mex., written commun., May 30, 2016). Trees and cliffs account for 53.1 and 40.3 percent, respectively, of nest sites in the northern Great Plains, based on 21,637 nest records with nest-site substrates reported (Bedrosian and others, 2019). Plains cottonwood (*Populus deltoides* subspecies *monilifera*) and ponderosa pine are the primary nest trees used (Bedrosian and others, 2019). Unusually high proportions of nests used by Golden Eagles in northeastern Wyoming and northwestern South Dakota were in trees (86 percent of 170 nests [Menkens and Anderson, 1987] and 86 percent of 35 nests [Datta, 2016], respectively). In northeastern Wyoming, Phillips and Beske (1990, p. 12) reported that "…eagles seemed to prefer nesting in large pines [presumably ponderosa pines] if given the choice between cottonwoods and pines." Green ash (*Fraxinus pennsylvanica*) and Douglas-fir (*Pseudotsuga menziesii*) often support Golden Eagle nests in the northern Great Plains and adjoining areas, and narrowleaf cottonwood (*Populus angustifolia*), limber pine (*Pinus flexilis*), and other juniper (*Juniperus*) species are used occasionally (Bedrosian and others, 2019). Dead or dying trees (that is, snags) sometimes are used to support nests despite lack of shading. Regardless, tree nests of Golden Eagles in the western Great Plains and adjoining areas typically are built in the top one-third of trees that are isolated or near edges of stands (Baglien, 1975, Menkens and Anderson, 1987, Phillips and others, 1990). In northwestern South Dakota, average height of 30 Golden Eagle nests in trees was 15.8 m and ranged from 10.9 to 18.2 m (Datta, 2016).

Cliff nests in both the northern Great Plains and adjoining areas typically are on vertical faces of sedimentary rock formations, especially sandstone, and less so on igneous rock formations, depending on availability (Houston, 1985; Bedrosian and others, 2019). In the southern Great Plains, mainly northeastern New Mexico and northern Texas, Golden Eagles place nests on ledges and in potholes at the top of sandstone escarpments, canyon walls, and mesas (Stahlecker and others, 2010, 2022; D. Stahlecker, Eagle Environmental, Inc., Santa Fe, N. Mex., written commun., October 12, 2021). Where cliffs are unavailable, the eagles may nest in eastern cottonwood trees along broad, intermittently flooded drainages (Stahlecker and others, 2022).

Other natural nest sites used by Golden Eagles in the Great Plains also include river or creek banks; rims of isolated mesas or buttes; rocky hillsides (Bedrosian and others, 2019); hills or small buttes composed of clay, siltstone, or scoria; and pedestals or "hoodoos" of sedimentary rock, especially in badlands (R. Murphy, personal obs., June 2, 2010; D. Stahlecker, Eagle Environmental, Inc., Santa Fe, N. Mex., written commun., October 12, 2021). Nesting on the ground by Golden Eagles has been noted in several parts of the western United States, including nests constructed on small hills or slight rock outcrops in North Dakota (Ward and others, 1983; Coyle, 2008) and Wyoming (Menkens and Anderson, 1987), but ground nesting is rare.

Human-made structures used by Golden Eagles as nest substrates in the Great Plains grasslands and shrubsteppe communities include electrical transmission towers and distribution poles (Steenhof and others, 1993), ledges on mine highwalls (that is, the unexcavated face of exposed overburden and mineral in a surface mine; Postovit and others, 1982; Postovit and Postovit, 1987; Phillips and Beske, 1990), abandoned windmills at livestock watering locations, oil and gas well structures, observation and communication towers, and artificial nesting platforms (Phillips and Beske, 1990). Steenhof and others (1993) provided a detailed case history of nesting by Golden Eagles and other raptor species and Common Ravens (*Corvus corax*) on a newly constructed 500-kilovolt transmission line extending 596 km from south-central Oregon to south-central Idaho. Thirty-seven artificial nest platforms with sticks were installed on nonrandom towers. Golden Eagle pairs nesting on towers increased from one to eight during the first 8 years after construction. Six pairs began nesting on transmission towers in landscapes where other nest substrates for Golden Eagles were unavailable within 3 km and where no nesting occurred before the transmission line was constructed (Steenhof and others, 1993). Seventy-two percent of Golden Eagle breeding attempts documented were on nesting platforms even though only 2 percent of transmission towers had platforms; eagles constructed other nests on tower crossarms, bridges, or within tower latticework. Golden Eagles experienced high nest success on platforms whereas all nesting attempts failed in towers without platforms, largely due to nest damage from strong winds (Steenhof and others, 1993).

Fates of Golden Eagle nesting attempts (attempt defined as the laying of an egg or eggs) at tree nests in the Great Plains may be similar to those at cliff nest sites. In south-central Montana, daily nest survival did not differ between nestlings in 28 tree nests and nestlings in 32 cliff nests distributed across a total of 47 breeding areas (Crandall and others, 2016). Some Golden Eagle breeding areas had both tree and cliff nest sites, and pairs in such areas sometimes switched between types among years (Katzner and others, 2020b). In northeastern Wyoming, apparent success of Golden Eagle nests was 56 percent in trees and 43 percent on rock outcrops (not considered cliffs) and peaks (not defined) (Phillips and Beske, 1990). In addition to availability of suitable nest sites, suitable nearby, prominent perch sites and protected ledges on cliffs for roosting also are important to breeding Golden Eagles (Collopy and Edwards, 1989).

Local geography is one of the most important factors influencing selection of nest sites on cliffs by Golden Eagles (Bedrosian and others, 2019). Such sites tend to be characterized by (1) broad, unobstructed view of the surrounding landscapes; (2) strong updrafts that provide lift to facilitate eagle flight; (3) close proximity to foraging areas; and (4) lack of access for mammalian predators and humans. In Montana, the total area of sagebrush/grassland within 0.4 km of Golden Eagle nests was greater than expected (Baglien, 1975). There were fewer cliffs visually obstructing the view of sagebrush/grassland from nests than expected, and there was more sagebrush/grassland below the 500-cm snowfall line within 0.8, 1.6, and 3.2 km of the nest than expected. Snow could lessen the formation of thermal uplift and could be driven by wind into nest sites, especially those on lee sides of cliffs (Baglien, 1975).

Selection of nest sites on cliffs by Golden Eagles also is driven by factors influencing microclimate and exposure at nests. Katzner and others (2020b) extensively reviewed this subject. Nest-site aspect (that is, directional orientation of nest sites and nests) may be selected at least in part such that exposure to inclement weather is minimized. In general, Golden Eagle nest sites on cliffs at northern latitudes of western North America tend to have southerly orientations, whereas the converse is true for cliff nest sites at southern latitudes. For example, Mosher and White (1976) found that nests in Alaska were oriented more frequently than expected to the south-southeast, Montana nests were oriented more frequently to the south, and Utah nests were oriented more frequently to the north-northwest (total numbers of nests observed by State were 62, 47, and 37, respectively). The authors also noted a slight trend towards northerly orientation for nests in Texas, but evidence of such was weak, perhaps in part because the sample was somewhat small (20 nests). Regardless, at each of the four study areas, the critical period of thermoregulation for nestling eagles (3–6 weeks of age) occurred at a time that corresponded with approximately thermoneutral temperatures (Mosher and White, 1976).

Influences of directional orientation on selection of cliff nest sites by Golden Eagles also can be altered by presence of overhangs and elevation. Overhangs provide shade from direct sun that can otherwise overheat nestlings and also can lessen exposure to cold, snowy conditions, especially in northern parts of the eagle's range (Katzner and others, 2020b). In the southern Great Plains and nearby Colorado Plateau regions, Golden Eagle nests typically are beneath protective overhangs and within shallow caves of sandstone cliffs, features created by subtle differences in weathering among the rock's successive horizontal strata (R. Murphy, personal obs., and D. Stahlecker, Eagle Environmental, Inc., Santa Fe, N. Mex., written commun., December 12, 2020). At a given range of latitude, south-facing nest sites at higher elevations likely are cooler than those at lower elevations (Mosher and White, 1976). Elevation also can affect persistence of snow cover at cliff nest sites; breeding pairs tend to avoid sites that in most years are snow-covered during at least the early breeding season (Baglien, 1975). In general, such sites occur at more northerly latitudes or at higher elevations than found in the Great Plains. Direct exposure to sun in late spring or early summer may trigger thermal stress among nestlings, possibly decreasing their survival as has been reported at cliff nests in southwestern Idaho (Kochert and others, 2019). Young Golden Eagles at nests in southwestern Idaho with southern to western aspects exhibited lower survival when maximum daily temperatures exceeded 32.2 degrees Celsius (ºC) compared to nestlings in nests with northern to eastern aspects, which were shaded in the afternoons. Broods in exposed nests with artificial shade structures exhibited higher survival than broods in exposed nests with no shade structures (Kochert and others, 2019).

Much less attention has been given to orientation of Golden Eagle nests in trees. In Scotland, Golden Eagles exhibited selection for nest trees on hill slopes with northerly rather than southerly exposures (Watson and Dennis, 1992); northerly aspects likely provided the best protection from inclement weather, which came from the southwest, and protected nestlings from hyperthermia because of direct sun exposure.

Perch Sites

Presence of suitable perch sites may dictate the extent to which Golden Eagles use a given locale, especially in areas lacking rugged topography. In general, selection of perch sites by Golden Eagles depends on proximity to important environmental resources (for example, prey), behavioral context (for example, sleeping or preening), season and thermal protection needs, eagle age and breeding status, and access to thermal or orographic lift (Duerr and others, 2019b). For example, Duerr and others (2019a) found that steep slopes were selected for perching year-round by Golden Eagles in eastern North America (primarily along the Appalachian Mountain Range), but that south-facing steep slopes were selected in summer and east-facing steep slopes were selected during migration season. Adults preferred to perch in broadleaf forests during summer and on ridges during fall. Selection for roost-site perches was equivocal, however (Duerr and others, 2019a).

During nesting, Golden Eagle breeding pairs perch close to their nest; after egg-laying through brooding stages, females may roost at the nest site (Collopy, 1984). On nesting cliffs, breeding pairs may benefit from additional ledges for roosting and general perching (Collopy and Edwards, 1989), mostly using sites below cliff rims (Watson, 2010). During the breeding season in Norway, Golden Eagle perches typically were within 100 m of the nest, tended to be slightly higher, and appeared to provide a clear view of the nest (Bergo, 1987).

In the southern Great Plains, resident, preadult-aged Golden Eagles most frequently perched on cliffs, trees, small hills, and structures supporting overhead electrical lines (24.6, 21.2, 16.6, and 10.8 percent, respectively, of all perch events) based on 1,050 randomly selected perch events determined from satellite telemetry (Dwyer and others, 2020b). Perch-site use varied with time of day. Fence posts, electrical transmission-line towers, and trees were used for perching more than expected during morning, afternoon, and night (roosting), respectively. The authors speculated that trees were selected for roosting because they afforded the best protection against strong winds that were prevalent on the study area, and that perching on fence posts during morning was associated with foraging on black-tailed prairie dogs (*Cynomys ludovicianus*) in adjacent livestock pastures. Dwyer and others (2020b) surmised that an observed increase in the eagles' use of transmission structures in the afternoon was due, in part, to thermoregulation because Golden Eagles may perch on crossarms shaded by the power pole. Along electrical distribution lines, poles with transformers and associated equipment were used for perching more often than poles without transformers, even though the former were far less common; this behavior could exacerbate electrocution risk (Dwyer and others, 2020b). In the level, open landscape of northeastern Colorado, overwintering Golden Eagles perched mainly on haystacks and in trees (Marion and Ryder, 1975). Preference for haystacks was thought to be associated with enhanced availability of leporid prey. Preference for powerline poles as perch sites was moderate, and preference for fenceposts was low.

Winter Habitat

Winter habitat of Golden Eagles in the Northwestern Plains Ecoregion (approximating the northern Great Plains) was assessed by Bedrosian and others (2019) based on telemetry data from 556 resident and migrant individuals. Variability in broad, flat areas at a 20-km scale (measured by the standard deviation of a "Weiss plains landform index") was the strongest covariate, constituting a 20.6 percent contribution to the model. Although flatter elevations can generate thermal uplift for hunting and general movement across landscapes, orographic lift provided by updrafts in rugged terrain could serve the same purposes. The measure of variability reported by Bedrosian and others (2019) indicated a high degree of elevational heterogeneity across landscapes at a moderate (20-km) spatial scale, providing both for areas of thermal uplift and areas of orographic uplift. Climate indices contributed 18.4 percent; climate indices included solar-energy influx at ground level and mean number of days greater than (>) 5 ºC. Vegetation covariates contributed 5.4–8.8 percent; variability in shrub cover and mean proportion of crop cover contributed 7.5 and 5.4 percent, respectively. These most likely were positive and negative covariates, respectively, but that information was not provided. Relatively high predictions of concentrated use by Golden Eagles during winter occurred across the transition from plains to mountains along the northern Great Plains' western margin. In general, predictions of relatively high use by Golden Eagles were associated with areas of higher topographic relief, including small mountain ranges and low mountains, such as the Chalk Buttes and Sweetgrass Hills of southeastern and north-central Montana. A map of predicted density of Golden Eagles during winter is included in Bedrosian and others (2019).

Fourteen migrant, adult Golden Eagles tracked by satellite telemetry generally selected riparian and coniferous forest habitats at relatively low elevations while overwintering near the eastern margin of the Rocky Mountains from west-central Montana across the Great Plains to central New Mexico (Domenech and others, 2015). They also selected terrain with east- and south-facing aspects, which were oriented toward prevailing wind directions, and rugged terrain that provided orographic uplift, open viewsheds, and elevated perches. The eagles avoided urban and cultivated agriculture areas. Nonsagebrush shrub, pasture, and grassland also were avoided, although these types were not defined; pasture may have included hayland, and grassland was combined with a pinyon-juniper type for some analyses. Regardless, Domenech and others (2015) speculated that grasslands appeared to be avoided because the eagle's primary prey, "hares" (presumably *Lepus* spp.), likely moved from grasslands to sagebrush during the fall. Domenech and others (2015) also noted that selection of winter habitats by Golden Eagles can be affected by the presence of resident, territorial individuals defending their breeding areas; the eagles' use of coniferous forests, which generally are not used by breeding Golden Eagles, may be a means of reducing such competition.

Winter habitat use by Golden Eagles in the southern Great Plains is poorly documented. Mitchell and others (2020) conducted ground-based surveys of Golden Eagles during winter in the center of the region. The number of eagles observed in a category of habitat consisting of semidesert and grassland/shrubland was greater than expected, based on the habitat's availability; few Golden Eagles were observed in agricultural fields or in grasslands encroached by juniper trees. Preadult-aged Golden Eagles tagged with satellite transmitters in northern Texas and eastern New Mexico tended to be associated with small (generally <16 hectares [ha]), widely scattered colonies of black-tailed prairie dogs during winter (R. Murphy, personal obs., March 2, 2017).

Prey Habitat

In the western United States, Golden Eagles mainly "forage in open habitats such as grasslands or steppe-like vegetation" (Katzner and others, 2020b, unpaginated). The species preys primarily on mammals, less so on birds and reptiles, and rarely on fish (Bedrosian and others, 2017; Katzner and others, 2020b); carrion can form an important part of the diet especially during late fall and winter, coinciding with big-game hunting seasons (Domenech and others, 2015; Watson and others, 2019). During the breeding season, optimal mass for eagle prey ranges from 0.5 to 5.0 kilograms (kg; Watson, 2010; Katzner and others, 2020b). Availability of prey of this moderate size range can determine the species' breeding success and distribution (Schweiger and others, 2015). Two species of jackrabbits (black-tailed and white-tailed [*Lepus townsendii*] jackrabbits) and three species of cottontail rabbits (eastern [*Sylvilagus floridanus*], desert [*Sylvilagus audubonii*], and mountain [*Sylvilagus nuttallii*] cottontails), hereafter referred to collectively as "leporids," constituted more than one-half of the number (that is, frequency) of prey used by Golden Eagles in 35 breeding-season studies conducted across the western United States during 1940–2015 (Bedrosian and others, 2017). A caveat in these collective findings, however, is that most studies were based on prey delivered by breeding adults to their young at nest sites during the latter half of breeding season (roughly, spring through early summer). Clearly, prey resources available during the nonbreeding season are important to breeding and nonbreeding Golden Eagles alike (for example, for overwinter survival). Only six of 45 studies of Golden Eagle diets in the western United States reviewed by Bedrosian and others (2017) were conducted during the nonbreeding season, two of these being old studies (Woodgerd, 1952; Arnold, 1954) with relatively small samples based on stomach contents of shot eagles. Another caveat in studies of breeding-season diets of Golden Eagles is that most have been based on prey remains found at nests, which can be biased compared to prey data collected via camera recordings at nests (Harrison and others, 2019).

Based on nine accounts for the West Central Semi-Arid Prairies and South Central Semi-Arid Prairies ecoregions reviewed by Bedrosian and others (2017), primary prey of Golden Eagles in the Great Plains generally include (1) leporids, specifically white-tailed jackrabbits in the northern Great Plains, black-tailed jackrabbits from the southern Great Plains to southern parts of the northern Great Plains, and cottontail rabbits throughout; and (2) sciurids, most notably the black-tailed prairie dog. White-tailed jackrabbits and black-tailed jackrabbits are sympatric, especially in eastern Wyoming, eastern Colorado, western Nebraska, and southwestern South Dakota. Colonies of the black-tailed prairie dogs are patchily distributed across Great Plains landscapes; in locales where the prairie dog occurs, it tends to be the most important prey of Golden Eagles (for example, in northeastern Wyoming) (Phillips and others, 1990). Because of this irregular distribution, the importance of black-tailed prairie dogs to Golden Eagles can be understated in reports of average Golden Eagle diets. In grasslands west of the Great Plains, especially the Wyoming Basin, black-tailed prairie dogs in Golden Eagle diets are replaced largely by other colonial sciurids, mainly white-tailed prairie dogs (*Cynomys leucurus*) and Wyoming ground squirrels (*Urocitellus elegans*) in western Wyoming (Millsap, 1978, MacLaren and others, 1988), and Gunnison's prairie dogs (*Cynomys gunnisoni*) in grasslands of the Southwestern Plateau Ecoregion (Stahlecker and others, 2009).

Thus, a discussion of the habitat of prey of Golden Eagles across the Great Plains and western shrubsteppe should focus mainly on leporids and sciurids, while acknowledging that Golden Eagles in the region also prey on other species of mammals and a broad array of bird species (Bedrosian and others, 2017). In two studies in south-central Montana, for example, birds accounted for 24 percent (Reynolds, 1969) and 40 percent (R.H. Crandall and C.R. Preston, unpub. data in Bedrosian and others, 2017) of the numbers (that is, frequency, as opposed to percentage biomass) of prey delivered by Golden Eagle pairs to nests. In Wyoming's Bighorn Basin, just west of the Great Plains, birds constituted an annual mean of 9.7 percent of prey used by Golden Eagle pairs during a 7-year period (Preston and others, 2017). Most frequent avian prey were Common Raven, Black-billed Magpie (*Pica hudsonia*), Ring-necked Pheasant (*Phasianus colchicus*), and Greater Sage-Grouse (*Centrocercus urophasianus*).

A comprehensive review of the biology of jackrabbits as prey of Golden Eagles in the western United States was completed by the FWS (Hansen and others, 2017a). The habitat associations of black-tailed and white-tailed jackrabbits generally overlap (Hansen and others, 2017a). Optimal habitats for both species may include open areas with grass and other herbaceous vegetation that provide food, visibility, and freedom of movement; and denser shrub or grass cover that provides a stable source of food and cover from predators and weather (Orr, 1940; Bear and Hansen, 1966; Knick and Dyer, 1997; Flinders and Chapman, 2003; Desmond, 2004; Simes and others, 2015; Hansen and others, 2017a). However, black-tailed jackrabbits tend to associate more with shrubby vegetation and occur at lower elevations, whereas white-tailed jackrabbits tend to associate with grasslands and other open habitats and occur at higher elevations (Lim, 1987; Simes and others, 2015; Hansen and others, 2017a). Open grasslands can provide suitable habitat for black-tailed jackrabbits if scattered shrubs or other densely canopied plants are available to provide cover near food sources or as obstacles when evading predators (Desmond, 2004; Lightfoot and others, 2010; Hansen and others, 2017a; Wagnon and others, 2020). Black-tailed jackrabbits may use dense shrub or weed cover during the day and often inhabit open, grass-dominated habitats for feeding during the night (Fautin, 1946; Johnson and Anderson, 1984). In a shortgrass prairie in northeastern Colorado, Flinders and Hansen (1975) reported that white-tailed jackrabbits selected upland pastures regardless of grazing intensity, and black-tailed jackrabbits selected lowland pastures that were lightly to moderately grazed by cattle and provided denser vegetative cover.

Habitat use by black-tailed and white-tailed jackrabbits varies seasonally (Hansen and others, 2017a). For example, in southern Colorado, Bear and Hansen (1966) reported that white-tailed jackrabbits used grasslands more than they used areas dominated by rabbitbrush (*Chrysothamnus* spp.) or sagebrush and rarely used meadowlands. Grasses and forbs provided most of the white-tailed jackrabbit diet in spring, summer, and early autumn. During the winter, numbers of white-tailed jackrabbits were nearly equal in grasslands and meadowlands (Bear and Hansen 1966). Shrubs (mainly fringed sagewort [*Artemisia frigida*] and green rabbitbrush [*Ericameria parryi*]) provided much of the winter diet. White-tailed jackrabbits use areas during the winter where wind or terrain limit snow accumulation at depths that impede foraging or traveling (Bear and Hansen, 1966; Braun and Streeter, 1968; Hansen and others, 2017a).

Encroachment and expansion of trees and shrubs may replace or degrade semiarid and arid grasslands, shrublands, and savannas in the western United States (DeLoach, 1985; Archer, 1989; Miller and Rose, 1999; Van Auken, 2000; Miller and Tausch, 2001; Hansen and others, 2017a). The changes in the amount or quality of shrub cover and palatable grasses and forbs will have mixed effects on jackrabbits (Hansen and others, 2017a). Cheatgrass and other nonnative annual grasses also may replace or degrade shrublands and grasslands and alter the frequency and extent of wildfires within the western United States (Pellant and Hall, 1994; Reid and others, 2008; Brooks and others, 2004, 2016; Pyke and others, 2016; Hansen and others, 2017a; Fusco and others, 2019). The altered fire regime can destroy jackrabbit habitat and negatively impact Golden Eagles (Knick and Dyer, 1997; Kochert and others, 1999; Heath and Kochert, 2016; Hansen and others, 2017a; Watson and others, 2020). MacCracken and Hansen (1982) indicated that herbaceous vegetation may be more limiting than shrub cover in areas with dense, uniform shrub cover.

Although habitat loss to agriculture is a factor implicated in the population declines of white-tailed and black-tailed jackrabbits (Washington Department of Fish and Wildlife, 2015), conversion of native habitats to agriculture has had mixed effects on the two species of jackrabbits (Simes and others, 2015; Hansen and others, 2017a). Both species depredate agricultural crops, but such damage by white-tailed jackrabbits is rarely widespread (Johnson and Peek, 1984; Simes and others, 2015). Black-tailed jackrabbits have had extensive, negative economic impacts on cropland in the western United States, especially during drought, when jackrabbits likely benefit from having succulent food available during portions of the year when grasses and forbs are dry or unavailable. Where the two species' ranges overlap, black-tailed jackrabbits have partially or completely replaced white-tailed jackrabbits in many areas following agricultural land conversions (Simes and others, 2015; Hansen and others, 2017a).

Mountain, desert, and eastern cottontail rabbits were, collectively, among the three most important species or species group of prey in six studies of Golden Eagle diets from semiarid prairies across the western Great Plains, as summarized by Bedrosian and others (2017). A comprehensive review of the biology of cottontail rabbits as prey of Golden Eagles in the western United States was completed for the FWS by Hansen and others (2017b). Mountain cottontail rabbits typically are associated with sagebrush habitats (Hansen and others, 2017b). Lower slopes of bunchgrass-covered hills and rocky areas (for example, ridges, outcrops, ravines, badlands, and canyons) appear to be selected by mountain cottontails in the Great Plains and other regions in the western United States, as well as riparian areas dominated by tall shrubs, such as willows (*Salix* spp.) (Jones and others, 1983; Hansen and others, 2017b). Jones and others (1983) also noted that, in the northern Great Plains, mountain cottontails exhibit an affinity for stands of coniferous trees. Like the other two cottontail rabbit species discussed herein, mountain cottontails often rest in brushy areas and thickets during the day and may use underground burrows, especially during periods of cold weather and heavy snow cover or to escape predators (Jones and others, 1983). In their review, Hansen and others (2017b) indicated that desert cottontail rabbits inhabit lower elevations in arid and semiarid shrublands, shrub-grasslands, scrub and riparian habitats, and open grasslands with scattered shrub cover. Flinders and Hansen (1975) reported that desert cottontails in shortgrass prairies of northeastern Colorado were more abundant when the intensity of grazing by cattle during summer and winter was relatively moderate, compared with other combinations of grazing intensity by season. Jones and others (1983) noted that desert cottontails sometimes occur in mesic habitats that may also harbor eastern cottontails. In discussing eastern cottontail habitat, Hansen and others (2017b) drew chiefly on literature from the eastern United States because little information on eastern cottontails is available for the western United States. In general, the eastern cottontail is associated with shrublands, shrub-woodlands, abandoned agricultural fields, and anthropogenic features, such as shelterbelts and piles of wood or junk (Hansen and others, 2017b). In western montane areas, eastern cottontails may inhabit shrub-filled gullies and forest edges (Hoffman and Pattie, 1968).

Prairie dog species, especially the black-tailed prairie dog, are important prey used by Golden Eagles in much of the Great Plains (Bedrosian and others, 2017), despite their patchy distribution. In landscapes where black-tailed prairie dogs occur, the species tends to be the most strongly selected prey of breeding Golden Eagles, at least in terms of dietary biomass (Phillips and others, 1990). Black-tailed prairie dog colonies generally occur on open, slightly sloped terrain in shortgrass and mixed-grass prairies; steeper terrain can reduce visibility, a crucial need of prairie dogs, and may be more erodible, to the detriment of prairie dog burrows (Reading and Matchett, 1997). Optimal vegetation height for black-tailed prairie dogs is about 5–20 cm (Clippinger, 1989). Compared to colonies of conspecifics in the southern Great Plains, black-tailed prairie dogs in the northern Great Plains are more often on terrain with southerly aspects, which promotes better growth of herbaceous vegetation than other exposures (Koford, 1958). The prairie dog's extensive burrow systems must be constructed where soil types are unlikely to collapse, such as in alluvial or clay-loam series (Koford, 1958; Reading and Matchett, 1997).

General patterns of prey use by breeding pairs can be inferred from habitat associations encompassing Golden Eagle breeding areas. Prey communities in north-central Utah, reflected by the frequency of various species of prey noted at 254 Golden Eagle nest sites during 1970–2014, were best predicted by environmental variables rather than geographic location (Brown and others, 2021). Golden Eagle use of black-tailed jackrabbits, cottontail rabbit species, rock squirrels (*Otospermophilus variegatus*), and yellow-bellied marmots (*Marmota flaviventris*) could be predicted by grassland, sagebrush, cropland, and forest variables, respectively. For example, leporids occurred most often as prey remains in Golden Eagle nests when the proportion of land cover dominated by grassland cover within 6.4 km reached about 30 percent (the 6.4-km radius was based on a scale of likely foraging habitats from Dunk and others [2019]). Brown and others (2021) acknowledged that factors other than strictly prey abundance may sometimes influence prey use by breeding Golden Eagles (for example, changes in eagle foraging efficiency related to vegetation structure).

Area Requirements and Landscape Associations

Means of and terms used for describing spatial needs of Golden Eagles can differ among studies. In general, an eagle's home range and core area are areas that encompass the greatest concentration of 95 percent and 50 percent of Golden Eagle location records (typically determined by telemetry methods), respectively. A core area could represent a focal area of a key resource, such as the area immediately encompassing a nest or, within an overwintering home range, a cluster of perch and roost sites. In southwestern Idaho, for example, 95 percent of locations recorded from nine Golden Eagles via radio telemetry occurred within a mean of 14.4 percent and 25.3 percent of their breeding and nonbreeding home ranges, respectively (Marzluff and others, 1997). Home-range size among individual Golden Eagles varies greatly especially with (1) prey availability and distribution; (2) age, sex, breeding status, and residency status (for example, a year-round resident, an individual on a migration stopover, or an overwintering migrant); (3) season; and (4) key physical attributes of landscapes, especially topographic features supporting orographic lift and sites for nesting, perching, and roosting, as described in the "Suitable Habitat" section. Moreover, presence of breeding Golden Eagles markedly limits local space use by nonbreeding individuals. Pairs vigorously defend their breeding areas from conspecifics during the breeding season but are more tolerant of conspecifics during the nonbreeding season (Katzner and others, 2020b). An exception is that juvenile Golden Eagles tend to be tolerated by pairs even during the breeding season, perhaps because their unique plumage distinguishes them as noncompetitors for breeding areas (Steenhof and others, 1983; Ellis and Lish, 2006).

Prey availability is an important determinant of raptor habitat quality (Newton, 1979) (note that for Golden Eagles, "prey" also could include carrion, especially roadside carrion from vehicle collisions [Grubb and others, 2018; Slater and others, 2022] and carrion associated with big-game hunting seasons during late fall and winter [Domenech and others, 2015; Watson and others, 2019]). The best illustration of connection between prey availability and habitat quality for Golden Eagles in North America comes from several decades of research at the Morley Nelson Snake River Birds of Prey National Conservation Area in southwestern Idaho, where the number of nesting territories occupied by the species generally declined as abundance of the eagle's main prey, black-tailed jackrabbits, decreased due largely to fire-induced conversion of native sagebrush-rabbitbrush habitat to cheatgrass (Kochert and others, 1999). In the same area, Collopy and Edwards (1989) found size of breeding-season home ranges of four Golden Eagle pairs to be inversely related to amounts of shrub vegetation, which the authors considered to be a proxy for good black-tailed jackrabbit habitat. Home ranges measured 11.6–48.9 km^2 (minimum convex polygons, using location data derived from direct observation). In the same area, Marzluff and others (1997) did not detect a significant effect of habitat quality (again, shrub cover) on home-range size of breeding individuals during breeding and nonbreeding seasons, although sample size, like that of Collopy and Edwards (1989), was relatively small.

Home-range sizes of resident pairs of Golden Eagles tend to differ markedly between breeding and nonbreeding seasons. Although there are no relevant published data from the Great Plains, these contrasts have been observed elsewhere. For example, Watson and others (2014) reported that, based on 95-percent isopleths estimated by a Brownian Bridge movement model, mean home-range sizes of 10 Golden Eagles breeding in the Columbia Basin Ecoregion of Washington and Oregon during breeding versus nonbreeding seasons were 42.1 and 87.0 km^2, respectively. Corresponding 50-percent isopleth estimates of core-area size during breeding versus nonbreeding seasons were 4.9 and 15.0 km^2, respectively. In southwestern Idaho shrubsteppe, breeding- and nonbreeding-season home ranges of Golden Eagles covered 1.9–83.3 km^2 (mean=28.2 km^2) and 13.7–1,700.0 km^2 (mean=344.8 km^2), respectively, based on radio-telemetry data collected from eagles in nine breeding areas and analyzed by using a concave polygon estimator (Marzluff and others, 1997). During the nonbreeding season, some individuals ranged far from their breeding areas apparently to seek better foraging opportunities. Breeding-season home ranges overlapped little among pairs (mean 3.7 percent), likely because of strong territorial behavior, but overlap was greater (mean 22.1 percent) outside of the breeding season. In the same general area, Kochert (1972) recorded a mean nearest-neighbor distance of 4.3 km (range=0.8–16.0 km) between breeding area centers of 56 pairs; centers of Golden Eagle breeding areas seldom are <1 km apart (Kochert and others, 2002). Comparing data from their study to previous studies, Marzluff and others (1997) found that home-range boundaries in each of four breeding areas used by Golden Eagle pairs changed little during circa 20 years.

There are few published studies of area requirements of Golden Eagles in the Great Plains. Crandall and others (2015) used satellite telemetry to track 12 adult Golden Eagles during the breeding season in south-central Montana, which is the region's western margin. Based on 95 and 50 percent kernel density estimates, mean home-range and core-area sizes were 15.8 km^2 (range=3.1–27.3 km^2) and 2.1 km^2 (range=0.1–4.7 km^2), respectively. Top models for predicting selection of home ranges (that is, resource selection at the second-order level; Johnson, 1980) included prey habitat and proportion of pasture as covariates. "Prey habitat" was defined as open areas of mixed sagebrush and grassland, because previous studies indicated that primary species of prey of Golden Eagles on the study area were associated with this habitat type (Crandall and others, 2015). At the core-area scale, strongest covariates in models were prey habitat and terrain ruggedness. The authors found the latter scale to be a stronger predictor of resource selection at the second-order level. The third order of selection (that is, resource selection within the home range; Johnson, 1980) in this study was based on analysis of 15,182 Global Positioning System locations collected from the 12 eagles, and important covariates included aspect, distance to nest, terrain ruggedness, distance to prey habitat, and an interaction between the latter two covariates (Crandall and others, 2015). Overall, the most important covariate for describing resource selection by breeding Golden Eagles was terrain ruggedness. However, the interaction term reflected strong selection for areas of rugged terrain close to prey habitat; probability of use of highly rugged areas declined as distance to prey habitat increased (Crandall and others, 2015).

Golden Eagles that either are floaters or preadult-aged individuals are not tied strongly to specific sites like breeding adults are to nests and nest areas. Size and configurations of home ranges of nine nonmigratory, subadult Golden Eagles tracked by satellite telemetry in the northern Great Plains, especially southeastern Montana, were reported in Bedrosian and others (2019). Home ranges were estimated by a minimum convex polygon method, apparently including all observations for a given eagle during a given season. Mean annual home-range size was 6,513 km^2 (range=1,248 to 54,672 km^2). Mean home-range size during summer (May–August) was 6,182 km^2 (range=99–25,591 km^2) and during winter (November–February) was 6,513 km^2 (range=489–34,989 km^2). The authors reported that no patterns in seasonal home-range size were evident; home ranges of some individuals were larger in winter than in summer, whereas the opposite was true for others (Bedrosian and others, 2019).

In the southern Great Plains, home ranges of 12 juvenile Golden Eagles during fledging through December (that is, between about 2 and 9.5 months of age) averaged 3,070 km^2 (standard error=1,484 km^2), based on 95-percent kernel density estimates (Mitchell, 2017). Although these home-range size estimates imply that juveniles in the region required considerable space, the eagles concentrated their activity in up to 10 "cluster areas" within their respective home ranges, suggesting that much area within home ranges was unused. Indeed, a coarse-level analysis of habitat use indicated that extensive areas of cropland, developed land, and grasslands heavily encroached by juniper were avoided by the eagles. Mitchell (2017) considered that it may be impractical to describe home ranges of juveniles on the study area because movement behavior varied so greatly among individuals.

Apparently, no other reports of spatial needs of juvenile Golden Eagles in the Great Plains are available; however, such data from areas immediately west of the Great Plains may have implications for the region. Dispersal of Golden Eagles from natal areas during their first year of life in the southern Rocky Mountains and Colorado Plateau west of the southern Great Plains was studied by Murphy and others (2017). Most (66.7 percent) juveniles dispersed short (<120 km) distances with relatively little wandering. For 38 of these "short-distance dispersers," cumulative monthly home-range size based on 95-percent minimum convex polygons increased from (medians) 149 to 612 km^2 during November through the following April, when the eagles reached roughly 12 months of age. Concurrently, percentage overlap between successive monthly home ranges varied but reached 57.1–76.1 percent during February through March. During the same period, cumulative monthly home ranges of 10 juveniles that dispersed moderate (120–500 km) distances were comparatively large but varied little among months from (medians) 8,746 to 10,318 km^2; percentage overlap between monthly home ranges increased steadily from 20.4 to 83.0 (Murphy and others, 2017). Overlap of 95-percent kernel density home ranges at ages 12 and 24 months was 42.2 and 26.5 percent for short- and moderate-distance dispersers, respectively, suggesting that Golden Eagles in the Southern Rockies and Colorado Plateau regions are relatively settled by the end of their first year of life, especially if they had dispersed comparatively short distances. Juveniles that dispersed more than 350 km from natal areas moved east to the southern Great Plains and south to desert grasslands in northern Mexico (Murphy and others, 2017).

Fewer relevant, published data on space use by Golden Eagles are available from eagles originating in far northern regions and overwintering in the Great Plains and nearby areas. Fourteen adults that were captured and tagged with Global Positioning System transmitters during fall migration in western and central Montana overwintered from Montana to Texas (one-half in Colorado or New Mexico; four were monitored for two consecutive winters and 13 others for at least one entire winter) (Domenech and others, 2015). Based on 95-percent minimum convex polygon estimates, sizes of winter-season home ranges of 13 eagles monitored for at least 3 months each varied from 814 to 46,648 km^2 (Domenech and others, 2015). The larger home ranges were characterized as having dispersed winter locales (that is, low migratory connectivity), across which individuals altered sizes of areas of use through the season; at the same time, space use in some places was constrained by breeding pairs exhibiting territorial defense. Winter core areas of the same eagles, delineated by 50-percent kernel density estimates, ranged greatly from 444 to 5,420 km^2. Collectively, the 14 eagles studied remained on wintering areas for 31–180 days. Six individuals that were tracked for 2 consecutive years exhibited strong fidelity to their respective winter areas; home ranges estimated by 50-percent minimum convex polygons overlapped by 58–100 percent (Domenech and others, 2015).

Golden Eagle home-range dynamics that have been documented in several other parts of the western United States and elsewhere in the world are summarized by Katzner and others (2020b) and thus are not reviewed herein.

Brood Parasitism by Cowbirds and Other Species

Neither interspecific nor intraspecific brood parasitism are known to occur in Golden Eagle nests (Shaffer and others, 2019; Katzner and others, 2020b). Eggs of the Brown-headed Cowbird (*Molothrus ater*), an obligate brood parasite of passerines, have not been documented in Golden Eagle nests (Shaffer and others, 2019).

Breeding-Season Phenology and Site Fidelity

The Golden Eagle's breeding season in the Great Plains and nearby areas varies with latitude, starting earliest in southernmost areas and later farther north. In the southern Great Plains and nearby Four Corners region of Utah, Colorado, Arizona, and New Mexico, nest initiation (that is, egg-laying) occurs from early February through late March, whereas in Montana and North Dakota, laying occurs from mid- to late March through April (table O1; after the "References" section). At a given latitude, Golden Eagles tend to initiate nesting later at higher elevations in mountains bordering the western Great Plains (Boeker and Ray, 1971). Snow accumulation, severe winters, or prey shortages can delay initiation (Phillips and Beske, 1990; Young and others, 1995; Steenhof and others, 1997). Eggs hatch 41–45 days after laying, and fledging occurs roughly 65 days later (median date), but fledging age can range from 45 days to more than 76 days (Steenhof and others, 2017); renesting rarely occurs. In southwestern Idaho, only 0.01 percent of 674 nesting attempts by Golden Eagles were attributed to renesting (U.S. Geological Survey, unpub. data *in* Katzner and others, 2020b). From three studies reviewed by Kochert and others (2002), renesting at 13 nests occurred an average of 24 days (range 19–30 days) after losses of initial clutches. Regardless, Katzner and others (2020b, unpaginated) stated that "there are no records of [Golden Eagle] pairs producing more than one brood in a year."

Golden Eagles generally show strong fidelity to breeding areas and often reuse nests ("use" of a nest defined as the laying of an egg or eggs, also called a nest attempt), but individuals sometimes change breeding areas (Marzluff and others, 1997; Katzner and others, 2020b). In breeding areas where multiple nest sites are available, pairs often maintain more than one nest, to varying degrees, and may construct new nests within a year (Kochert and Steenhof, 2012; Millsap and others, 2015; Slater and others, 2017). In successive years, a pair of eagles may either reuse a previous year's nest or switch to an alternate (that is, "alternative" [Steenhof and others, 2017]) nest (reviewed *in* Katzner and others, 2020b). The most extensive case history of nest use by Golden Eagles comes from sagebrush shrubsteppe in southwestern Idaho where many potential nest sites on cliffs were available (Kochert and Steenhof, 2012). During a 41-year period, pairs used 75 percent of 454 nests up to four times and 36 percent only once (Kochert and Steenhof, 2012). The eagles used up to 18 nests in a single breeding area; on average, 6.9 nests were used per breeding area. Time between reuse of 300 nests that had been used more than once ranged from 1 to 39 years, and 85 percent of 66 breeding areas held at least one nest that was reused after a lapse of more than 10 years. Seven nests in six territories were empty for at least 30 years before being reused (Kochert and Steenhof, 2012). Distances between nearest alternative nests averaged 191 m (range=1–1,822 m) (Kochert and Steenhof, 2012); distances of up to 6 km have been recorded in other studies (McGahan, 1968). During a study in the northern Great Basin within Utah, where many cliff nest sites were available, 28 Golden Eagle breeding areas were monitored for at least 25 years (Slater and others, 2017). Breeding areas contained 1–8 nests each (average=2.9 nests). Pairs used individual nests within a given breeding area every 3.3 years and initiated nesting in any nest every 1.8 years, on average. They also switched nests during 43.3 percent of consecutive nest attempts.

The comprehensive studies by Kochert and Steenhof (2012) and Slater and others (2017) demonstrated dynamics of nest use by Golden Eagles in areas with high availability of nests sites, exceeding that across the Great Plains, where cliff nest sites often are lacking and potential nest sites in trees are limited (see “Suitable Habitat” section). Where breeding areas occur in the Great Plains, few or no alternative nest sites may be available, although breeding areas with single nests have been known to support pairs indefinitely in the western United States; for example, a nest in California was occupied by Golden Eagle pairs for at least 50 years (Hanna, 1930).

Species’ Response to Management

Because the Golden Eagle is a *K*-selected species, exhibiting delayed sexual maturity and low reproductive output, its population stability tends to be highly sensitive to slight changes in survival, especially for adults (Katzner and others, 2017; Millsap and others, 2022). In the contemporary western United States, anthropogenic mortality is the foremost driver of Golden Eagle population status and trend; anthropogenic mortalities account for about 60 percent of all mortalities and 73 percent of mortalities among individuals >1 year of age, and likely will continue to increase (Millsap and others, 2022). The four most important anthropogenic sources of mortality among Golden Eagles across the western United States are electrocution, collisions, poisoning, and shooting (Millsap and others, 2022); relative importance among these factors is uncertain, however, as credible intervals accompanying estimates overlapped considerably. Other factors that may negatively affect Golden Eagle population status in the western United States, either directly via mortality, injury, or disturbance of individual eagles or indirectly by alteration and loss of habitat, include injury or death due to incidental capture in traps set for other wildlife; habitat fragmentation and disturbance associated with energy development; other land-use changes, such as agricultural or urban development; disturbance from intensive recreational activities in important eagle-use areas; fire-enhanced invasion by nonnative plant species that degrades prey habitat; grazing; and climate change (see individual subsections below). Herein, the terms “disturb” and “disturbance” are used as defined in the Bald and Golden Eagle Protection Act (BGEPA; Title 50 CFR § 22.6): “to agitate or bother a Bald or 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.”

Electrocution

Electrocution on poles supporting electrical distribution lines is one of the most important, widespread sources of direct mortality among Golden Eagles throughout the species’ range (Lehman and others, 2007; Dwyer and others, 2016; Mojica and others, 2018; Millsap and others, 2022). Eighty-two percent of 416 carcasses found along powerlines during surveys in Idaho, Wyoming, Utah, Nevada, New Mexico, and Oregon during a 3-year period were Golden Eagles (Benson, 1981). Fifty-four percent of 61 reported bird electrocutions in Montana between October 1980 and December 1985 were Golden Eagles (O’Neil, 1988). More than 300 cases of electrocution of Golden Eagles and Bald Eagles (*Haliaeetus leucocephalus*) were documented in Texas, Arizona, New Mexico, Oklahoma, Kansas, Utah, Colorado, and Wyoming between 1969 and 1971 (Boeker and Nickerson, 1975). In 1972 and 1973, an additional 250 Golden Eagles were found electrocuted in 14 States, mostly in Utah (32 percent), Nevada (24 percent), Idaho (12 percent), and Montana (10 percent) (Boeker and Nickerson, 1975). Based on cause-of-death findings from Golden Eagles tracked by telemetry during 1997–2016, Millsap and others (2022) estimated that 506 Golden Eagles were electrocuted annually in the western United States (median estimate, based on the sum of median first-year mortality [69] and median after-first-year mortality [437]). However, the estimate was accompanied by considerable uncertainty; the lower and upper 95-percent credible intervals were 20 and 174 for first-year individuals and 231 and 731 for after-first-year individuals.

Electrocutions occur when one part of an animal simultaneously contacts a grounding source (such as grounding lines) and any energized but uncovered component, such as conductors (energized lines), lightning arresters, transformers, and jumpers (that is, wires that connect conductors to one another or to other equipment mounted on poles, especially transformers) (Avian Power Line Interaction Committee [APLIC], 2006). Electrocutions also can occur when two or more energized components are contacted simultaneously. Fleshy parts of the eagle's body (for example, simultaneous contacts of a foot and the hand [manus] of a wing) must make contact for electrocution to occur; feathers are nonconductive except possibly when very wet (APLIC, 2006). Electrocution risk varies considerably among poles depending on the configuration of components; some poles pose far greater risk of electrocution than others, and some pose almost no risk (APLIC, 2006; Dwyer and Mojica, 2022; Mojica and others, 2022).

Electrocution of Golden Eagles on distribution lines is well studied in the United States and elsewhere. Mojica and others (2018) synthesized this information and provided a comprehensive overview of measures to reduce electrocution risk to the species. Drawing directly from findings in their review, the authors identified eight electrocution risk factors for Golden Eagles. Most important was the presence and configuration of electrical equipment, such as transformers and exposed jumper wires on power poles. Poles with equipment (for example, transformers) and poles in sites where distribution lines meet typically pose greatest risk (Harness and Wilson, 2001). The next most important electrocution risk factors presented in Mojica and others (2018) included (1) age—younger age classes of eagles are more vulnerable; (2) morphology—electrocution risk increases with eagle size because the likelihood of contacting two energized points or an energized and nonenergized point simultaneously increases, such as when both wrists of an eagle's outstretched wings touch different conductor wires on a pole crossarm; (3) surrounding land cover and topography—for example, eagles are likely to select poles on terrain that is higher than the surroundings or in areas where other types of perches are scarce; (4) availability of prey—use of a given area by eagles increases, especially when concentrated prey resources exist, such as leporids or colonies of burrowing rodents; and (5) habitat quality—risk is greater in areas of high prey availability or nest sites. Other important electrocution risk factors include season, weather, and eagle behavior (Mojica and others, 2018).

Increasingly, an indirect consequence of electrocutions of eagles and other large birds on power poles is the fire-hazard threat created when a bird is electrocuted on a pole, falls to the ground, and its burning carcass ignites a wildfire (Lehman, 2002; Barnes and others, 2022). Avian electrocution-caused wildfires were found to occur more often than expected in the Mediterranean California Ecoregion than in the Great Plains, semiarid, desert, or forested regions of the United States (Barnes and others, 2022). In addition to human health and safety concerns, wildfires in some areas may facilitate habitat conversions that are unfavorable not just for Golden Eagles, but possibly entire ecosystems; for example, wildfires may result in conversion of native big sagebrush shrubsteppe habitat to that dominated by cheatgrass (Kochert and others, 1999; Neilson and others, 2005; Chambers and others, 2014). The significant adverse implications of this habitat change for Golden Eagles are detailed in the "Suitable Habitat" section and the "Management Recommendations from the Literature" section.

Collisions

Collisions with human-made structures, such as vehicles, wind turbines, and powerlines, account for an estimated 611 (14.4 percent of total) deaths of Golden Eagles annually in the western United States, based on fates of Golden Eagles tracked by telemetry during 1997–2016 (estimated from the sum of first-year and after-first-year medians in Millsap and others, 2022). Katzner and others (2020b) considered vehicle collisions the most common of this mortality type. Vehicle collisions typically occur when eagles are feeding along roads on carcasses of wild ungulates and other animals that have been struck by vehicles (Russell and Franson, 2014; Allison and others, 2017; Grubb and others, 2018; Slater and others, 2022). Eagles mainly are struck as they flush from carcasses (Slater and others, 2022). Incidence of collisions may increase during periods of low prey availability and may occur more commonly during winter, as Phillips (1986) noted in his report of nearly 100 Golden Eagles killed on highways during a single winter near Rock Springs in southwestern Wyoming. Factors that may increase availability of wild ungulate carrion for eagles along highways in the western United States include carcass size (larger carcasses persist longer), ambient temperature (carcasses persist longer when colder), presence of Common Ravens (raven presence may alert eagles to carcasses), eagle density (carcasses are scavenged more quickly when more eagles are present), and whether whole carcasses have been torn open by mammalian scavengers such as coyotes (*Canis latrans*) (Grubb and others, 2018; Lonsdorf and others, 2018; Slater and others, 2022). Although attention on eagle-vehicle collisions has focused on carcasses of large animals, eagles also are struck by vehicles when feeding at carcasses of small prey, especially rabbits, when such are frozen to the pavement (B. Bedrosian, Teton Raptor Center, Wilson, Wyo., written commun., August 12, 2022).

In a comprehensive study of Golden Eagle-vehicle collisions in Oregon, central Utah, and southwestern Wyoming, Slater and others (2022) used cameras to document responses of Golden Eagles at carcasses (mainly deer [*Odocoileus* spp.]) to vehicle traffic; flushing by eagles from a roadkill in response to vehicles was considered a proxy for collision risk. The probability of a carcass being used by eagles increased with increased distance from roads, and conversely, the probability of an eagle flushing from a carcass decreased with increased distance from roads. There was little support for predictions that carcass use decreased with increased traffic volume or when tall vegetation was nearby, or that carcass use increased when live prey was likely to be less available (due to snow cover), when carcasses were in areas with many eagle sightings, or when carcasses were in areas identified as roadkill hotspots based on expert elicitation and available data (Slater and others, 2022). Based mainly on expert elicitation, Lonsdorf and others (2018) also reported that carcass distance from road edge was a key risk factor. Lonsdorf and others (2018) developed a model for estimating the extent of Golden Eagle-vehicle collisions in a hypothetical Wyoming county during fall–winter, based mainly on expert-selected levels of eagle density, road traffic volume, and carcass abundance. Modeled eagle mortality increased in concert with carcass numbers especially at low levels of traffic volumes (15–35 vehicles per hour); at high traffic volume (65 vehicles per hour), model-based mortality was limited because of the frequent disturbance caused by traffic, which reduced time that eagles spent at carcasses. Other factors considered to influence the risk of Golden Eagles to vehicle collision included traffic speed and extent of carcass removal by highway maintenance crews (Lonsdorf and others, 2018).

Powerlines and fences pose collision risk to Golden Eagles across the western United States. During 1994–97, 5 percent of 61 deaths of Golden Eagles tracked by telemetry at the Altamont Pass Wind Resource Area (APWRA) in California were attributed to fence collisions, compared to 3 percent to vehicle collisions (Hunt and others, 1999). Golden Eagles are most at risk of collision with fences and overhead powerlines wherever these structures cross high-quality foraging habitat or migration paths (Watson, 2010). The Golden Eagle was among the most commonly reported species documented in 88 collisions by raptors with telephone lines and electrical distribution and transmission lines in California (Olendorff and Lehman, 1986). The authors noted that these collisions most likely occurred during periods of high winds or poor visibility, or when raptors were distracted while in pursuit of prey. Fences partly hidden by tall vegetation can be particularly dangerous in this regard. In south-central Montana, carcass remains of 23 Golden Eagles were found beneath mid-spans of a distribution line, suggesting they were killed by collisions rather than electrocution (Harness and others, 2003). Three of the carcasses were beneath consecutive mid-spans that crossed a draw near an in-use Golden Eagle nest and <1.6 km from a black-tailed prairie dog colony; the draw likely was a routine travel and hunting corridor for eagles (Harness and others, 2003).

Golden Eagles seem unusually vulnerable to collisions with wind-turbine blades (Hunt and others, 1997; Smallwood and Thelander, 2008; Smallwood and others, 2008, 2009a, 2009b; Noguera and others, 2010). In the United States, the Golden Eagle is thought to be one of a few bird species for which collisions with turbines may account for more than 1.5 percent of annual fatalities (Beston and others, 2016). Beston and others (2016) developed a prioritization system to identify avian species (428 species evaluated) most likely to experience population declines in the United States from wind facilities based on the species' current conservation status and the species' expected risk from wind turbines. The Golden Eagle scored a 4.72 out of nine, where nine indicated high risk, and Beston and others (2016) estimated that 2.4 percent of the Golden Eagle breeding population in the United States is exposed to wind facilities. In a radio-tracked population of Golden Eagles at APWRA in California, the annual mortality rate from collisions with wind turbines varied from 35 to 42 percent of 26 and 100 total fatalities, respectively (Hunt and others, 1997; Hunt and Hunt, 2006). The high rate of collisions was attributed to having a dense breeding population of eagles and close proximity of the wind-energy facility to an important foraging area of the eagles. Katzner and others (2016) estimated that at least 25 percent of the Golden Eagles killed at APWRA originated elsewhere, mostly from areas >100 km away; the authors considered the area to be an ecological sink, reliant on continental-scale immigration to maintain population stability although they did not explicitly indicate whether any eagles breeding on the area originated as immigrants. Based on a spatially explicit demographic model that combined empirical demographic data with data on breeding habitat distribution, prey resources, and planned renewable energy sites, Wiens and others (2017) found evidence of strong dependence on immigration to maintain Golden Eagle population stability in a region of renewable-energy development in southern California. Pagel and others (2013) reported that at least 79 Golden Eagles were killed at wind-energy projects in the western United States during 1997 through June 2012 (excluding mortality at APWRA), but the authors believed this total greatly underrepresented the actual number killed in the western United States because rigorous monitoring and reporting of eagle mortalities at the time was generally lacking.

The growing demand for wind energy to reduce carbon emissions has raised concerns about the increase in Golden Eagle mortality associated with the proliferation of wind-energy development (Millsap and others, 2022). Wind-energy development in the United States accelerated from 40 to 122 gigawatts between 2010 and 2020 and was predicted to reach 224 gigawatts by 2030 (U.S. Department of Energy, 2021). Compared with other major regions of North America, the Great Plains provides the highest quality wind potential for onshore wind-energy development (fig. 1 *in* U.S. Department of Energy, 2021).

Poisoning—Lead Toxicosis

Poisoning by heavy metals and pesticides, mainly lead and anti-coagulant rodenticides, respectively, is a leading anthropogenic cause of Golden Eagle deaths in North America. Millsap and others (2022) estimated that 427 Golden Eagles die annually from poisoning in the western United States, based on recoveries of eagles tracked by telemetry during 1997–2016. Lead toxicosis, likely the single most important cause of Golden Eagle poisoning, stems mainly from ingestion of spent lead ammunition associated with animal carcasses. The most unbiased evidence of deaths from lead toxicosis comes from 386 Golden Eagles monitored via telemetry during 1997–2013 (FWS, 2016a); cause of death could be determined for 97 of 139 of the eagles that died and were recovered. Based on use of a Bayesian model to extrapolate the results, an estimated 3 and 5 percent of 6,029 total annual deaths and 321 total annual anthropogenic-related deaths, respectively, of Golden Eagles resulted directly from lead toxicosis (table 8 *in* FWS, 2016a), although much uncertainty was associated with the estimates. The potential effect of sublethal levels of lead toxicosis on vulnerability of Golden Eagles to other sources of mortality, such as collisions or starvation, may be more significant than direct mortality but difficult to assess (Kramer and Redig, 1997; Herring and others, 2017; Katzner and others, 2020b). For example, elevated blood lead levels were detected in Mute Swans (*Cygnus olor*) that died from various collisions (O'Halloran and others, 1989).

Blood samples collected from Golden Eagles in both western and eastern North America commonly show elevated lead levels. Categories of elevated blood lead include subclinical (0.2–0.6 part per million [ppm]), clinical but treatable (0.61–1.2 ppm), and generally lethal (>1.2 ppm; Kramer and Redig, 1997). Roughly 30–56 percent of Golden Eagles captured on migration or during winter in North America have exhibited elevated lead levels (see detailed review in Katzner and others, 2020b). Blood lead levels did not differ between migratory and resident Golden Eagles captured during winter in Montana (Domenech and others, 2021), probably because individuals in both groups had been scavenging remains of big-game animals shot with lead ammunition by hunters. Lead levels also can be measured in liver tissues. For example, 23 percent of 31 Golden Eagles found dead in Alberta, Saskatchewan, and Manitoba had high lead exposure, as measured in liver and kidney tissues (Wayland and Bollinger, 1999). However, blood and liver samples tend to indicate acute exposure, which can be somewhat temporary (Harmata and Restani, 1995). Bone samples from eagle carcasses, especially femurs, provide a means of measuring chronic lead exposure. Slabe and others (2022) reported that 46 percent of 206 Golden Eagles sampled from across North America during 2010–18 had lead levels in bone samples that were greater than levels classified as chronic poisoning. Adult individuals exhibited chronic lead poisoning more often than subadults and juveniles. Based on blood lead levels and liver lead levels, acute poisoning was evident in 9 percent of 383 individuals and 7 percent of 163 individuals, respectively. Lead levels detected in feathers indicated that 35 percent of 23 individuals sampled experienced acute lead toxicity at least once during their lives. The authors estimated that liver lead levels in 4.9 percent of Golden Eagles that died had exceeded severe poisoning thresholds (Slabe and others, 2022). Findings on bone lead levels indicated that the eagles are repeatedly exposed to lead, which accumulates in their bodies over time, thus creating demographic constraints. Lead poisoning suppresses annual population growth rates of Golden Eagles by an estimated 0.8–3.8 percent (Slabe and others, 2022). Lead exposure among nestling Golden Eagles may be substantial when eagles nest near agricultural lands where rodents are shot to protect crops and for recreation, negating the potential for high nestling growth rates in such areas (Herring and others, 2020). Herring and others (2020) reported that 34 percent of 258 nestling Golden Eagles sampled in agricultural areas in four western States had blood lead levels that have been shown to impair flight in adult eagles (Ecke and others, 2017). Four percent had levels exceeding subclinical poisoning. Based on stable isotope signatures, ammunition was the source of lead in 45 percent of the poisoning cases in general and was the source in 89 percent of cases where severe clinical poisoning was indicated. Moreover, nestlings remained in nests for several weeks after blood sampling and then fledged, presumably acquiring more lead.

Fortunately, the principal cause of lead toxicosis among Golden Eagles, as well as many other species of predatory and scavenging birds, is well documented and reasonably well understood; reviews of the issue include but are not limited to Church and others (2006), Haig and others (2014), Golden and others (2016), and Pain and others (2019), but literature on the subject is copious. Game animals shot by hunters with lead ammunition can retain lead residues and fragments of the projectiles, or even retain somewhat intact projectiles such as shot pellets used for bird hunting. Golden Eagles that either kill and eat such game animals or scavenge on their carcasses can directly consume the lead deposits (reviewed in Golden and others, 2016; Katzner and others, 2020b). Golden Eagles also may consume lead residues when scavenging carcasses of ground squirrels (mainly *Urocitellus* spp.) and prairie dogs killed by recreational shooters (Harmata and Restani, 1995, 2013; Katzner and others, 2017; Herring and others, 2020) and game bird carrion left by hunters (Bedrosian and others, 2019). Evidence implicating consumption as the primary avenue for lead toxicosis is robust (Golden and others, 2016; Katzner and others, 2020b). Inhalation of anthropogenic lead in the atmosphere can be a route of exposure (Katzner and others, 2017). Also, livestock or pest species (for example, feral pigs [*Sus scrofa*]) are sometimes killed with lead ammunition, and lead-contaminated parts of their carcasses may subsequently be consumed by Golden Eagles. In some areas of western North America, blood lead levels among scavenging bird species, including Golden Eagles, have been shown to peak annually in concert with hunting seasons (Pattee and others, 1990) and to decrease significantly after widespread bans are placed on use of lead ammunition for most hunting activities (Kelly and others, 2011).

Poisoning—Rodenticides and Other

Golden Eagles in the western United States may be incapacitated or killed by anti-coagulant rodenticides (ARs) when the eagles ingest prey (including scavenged items) that have consumed the rodenticides or ingest prey that have consumed remains of other animals laden with rodenticides (that is, secondary poisoning, such as capturing and feeding on a Common Raven that recently had scavenged remains of a poisoned prairie dog). The FWS (2016a) estimated the cause of mortality for 97 Golden Eagles that were recovered via telemetry after death in North America between 1997 and 2013. Based on use of a Bayesian model to extrapolate results, poisoning, excluding lead toxicosis, annually caused 1,025 (credible interval=316–2,266) deaths of Golden Eagles in North America, representing 17 and 30 percent of total annual deaths and total annual anthropogenic-related deaths, respectively. Although not directly reported in FWS (2016a), potentially lethal levels of ARs were documented in nearly all cases for which cause of death was attributed broadly to poisoning (R. Murphy, personal obs., and B. Millsap, U.S. Fish and Wildlife Service, Albuquerque, N. Mex., written commun., September 17, 2021).

In rural areas of the western United States, rodenticides are used chiefly to control or locally eradicate prairie dogs and ground squirrels (mainly *Urocitellus* spp.) that are thought to depredate crops, reduce herbaceous forage for livestock, and create burrows that may interfere with farm operations or inflict livestock with leg injuries (Golden and Gober, 2010; Katzner and others, 2020b). For example, in some States (for example, Nebraska; Schumacher and others, 2016), private landowners are required to prevent black-tailed prairie dogs from expanding colonies into neighboring land. Contemporary rodenticides are referred to as second-generation because target species developed resistance to the original suite of chemical rodenticides (Buckle and others, 1994). According to Thomas and others (2011, p. 916), the newer class of rodenticides includes chemicals that are more acutely toxic at lower doses; the authors stated that "greater acute toxicity increases the potential for primary poisoning amongst nontarget species while the longer tissue half-lives [of the rodenticides] enhance the potential for bioaccumulation in nontarget predators in particular, and so may increase the risk of secondary poisoning." Moreover, rodents may live for several days and continue to eat poisoned bait after consuming high, even lethal, doses such that predators and scavengers sometimes ingest exaggerated levels of poison when consuming small amounts of contaminated prey. Regardless, eagles and other raptor species that ingest ARs exhibit hemorrhaging from internal organs especially the heart, lungs, brain, and subcutaneous regions (Newton and others, 1999). ARs were detected in 81 percent of 133 total Bald Eagle and Golden Eagle carcasses examined at the Southeastern Cooperative Wildlife Disease Study laboratory for necropsy during 2014–18, and ARs were determined to be the cause of death in 4 percent of the cases (Niedringhaus and others, 2021). Brodifacoum, a widely used, highly lethal anticoagulant rodenticide that poses one of the highest risks of secondary poisoning to birds in general (Erickson and Urban, 2004), was the principal AR detected (81 percent of 133 total eagles tested). In the United States, brodifacoum is available to the general public but must be dispensed only by certified pesticide applicators.

In general, poisoning of Golden Eagles by pesticides in the western United States has occurred for at least a century (Bortolotti, 1984). Compared to Bald Eagles, Golden Eagles in the western United States generally have exhibited low or no detectable exposure to organochlorine pesticides, especially dichlorodiphenyltrichloroethane (DDT) and its metabolite dichlorodiphenyldichloroethylene (DDE), because Golden Eagles prey mainly on mammals (Reichel and others, 1969; Katzner and others, 2020b). Evidence of limited exposure to DDT and DDE is reviewed in Katzner and others (2020b) and briefly summarized here. Golden Eagle eggshell thickness did not change significantly after DDT was introduced. During 1964–75, DDE residues in tissues and eggs of Golden Eagles remained below levels that could hinder reproduction, and DDE residues were low but detectable in Golden Eagles captured and tested in the western United States from the early 1990s through 2013 (Katzner and others, 2020b). Moreover, organochlorine pesticides were not implicated in deaths of 125 telemetered Golden Eagles in the western United States and for which cause of death was determined, although deaths of three were attributed to multiple substances, including lead (Millsap and others, 2022). Other classes of pesticides and other toxins have become a greater concern to Golden Eagle conservation in recent decades. During 1985–95, 87 percent of 144 pesticide-related Golden Eagle deaths documented in the United States stemmed from pesticide use in violation of legal specifications on the label (Mineau and others, 1999). Golden Eagle mortality accounted for 17 percent of 734 total raptor deaths attributed to pesticides (usually by carbofuran). Eagle mortalities were not associated with labeled use of pesticides, possibly because of the minimal overlap of the Golden Eagle's distribution with intensive agricultural areas. However, Golden Eagles died after eating waterfowl that were accidentally poisoned in agricultural fields in the United States and Canada (Mineau and others, 1999). Golden Eagles in the western United States are sometimes poisoned when scavenging on carcasses laced with restricted-use or banned toxic substances, such as strychnine, thallium, and aldicarb, to control livestock predators (Russell and Franson, 2014; Katzner and others, 2020b). For example, Golden Eagles tracked by telemetry in a domestic sheep (*Ovis aries*)-ranching area of the southern Great Plains died by ingesting a restricted-use, acutely toxic carbamate insecticide and nematicide with aldicarb as its active ingredient (Murphy and others, 2023), which is a poison that likely had no use other than killing predators indiscriminately because no cropland occurred in the remote landscape (R. Murphy, personal obs., and D. Stahlecker, Eagle Environmental, Inc., Santa Fe, N. Mex., written commun., October 31, 2021). Russell and Franson (2014) listed eight other toxins or classes of toxins that were implicated in deaths of Golden Eagles from the United States during 1975–2013, based on 1,427 carcasses submitted for necropsy to the U.S. Geological Survey's National Wildlife Health Center. Mercury, a toxic heavy metal, was not included despite its broad distribution in the environment. A review of the subject in Katzner and others (2020b) indicates that although exposure to mercury is commonly detected in feathers, tissues, and blood of Golden Eagles in western North America, mercury levels tend to be low; for example, Harmata and Restani (2013) reported that only one of 70 Golden Eagles in southwestern Montana had a mercury level (0.5 ppm) in its blood above that considered background level in piscivorous birds (0.4 ppm). A toxicant that may be of concern to Golden Eagles on a local scale in rural areas in the western United States is the barbiturate pentobarbital; used for veterinary euthanasia, it may be ingested by eagles scavenging exposed carcasses of target animals and is acutely toxic (Russell and Franson, 2014; Wells and others, 2020). Organophosphate pesticides, which are typically used in agriculture to control insect pests, were implicated in poisoning of two of 117 Golden Eagles found dead in the United States (Russell and Franson, 2014). Scott and Bollinger (2015) reported that 16.6 percent of 78 Golden Eagles found dead in Saskatchewan between 1992 and 2012 were poisoned by organophosphate or carbamate compounds, and that these were the most frequently documented forms of toxicosis. An important caveat regarding these studies in general is that the use of incidentally found Golden Eagle carcasses to assess causes of eagle deaths may be biased in that such birds die in places where they are likely to be found, whereas a sample of eagles that die while being tracked by telemetry and are promptly recovered wherever they die is relatively unbiased (Millsap and others, 2022).

Shooting

Historically, shooting was a notable source of mortality for Golden and Bald eagles in much of the western United States and was done mainly to protect the young of livestock and big game (Roberts, 1932; Dixon, 1937; Woodgerd, 1952; McGahan, 1968; Camenzind, 1969; Baglien, 1975; Beecham and Kochert, 1975; Clapp and others, 1982; Schueler, 1982). Despite some indications that shooting of Golden Eagles declined after the Bald Eagle Act was amended in 1962 to include protection of the Golden Eagle (Phillips, 1986), the extent to which Golden Eagles continue to be shot appears substantial. Based on multistate model estimates derived from 126 Golden Eagles tracked by telemetry and for which cause of mortality could be determined between 1997 and 2016, about 670 Golden Eagles are killed annually by shooting in the western United States (Millsap and others, 2022), representing about 28 percent of all anthropogenic mortality (table 3 *in* Millsap and others, 2022). Shooting was the most important overall source of mortality among older Golden Eagles (Millsap and others, 2022). In Scotland where Golden Eagles were shot to protect gamebird populations, an estimated 3–5 percent of the annual mortality among adult Golden Eagles was attributed to shooting; some breeding areas had been vacated, and eagle age at first breeding had decreased (Whitfield and others, 2004). The population was vulnerable to decline, but modeling predicted that the population would increase if the shooting ended (Whitfield and others, 2004).

Golden Eagles and Bald Eagles have a central role in the religions and cultural histories of many western Tribes (Murray, 2009, 2011; Murray and others, 2009; Smith, 2016). For some of these Tribes, feathers and other parts of Golden and Bald eagles are essential for religious and ceremonial purposes (Murray and others, 2009; Smith, 2016). In the western United States, motivations for some Golden Eagle shootings may be linked in part to a widespread, black-market trade of eagle feathers and body parts (Kovacs, 2013).

Incidental Trapping

Golden Eagles are sometimes incidentally captured in leg-hold traps and snares set for mammals either for predator control or fur harvest. Katzner and others (2020b) reported that, in eastern North America, six of 95 Golden Eagles tracked by telemetry were captured in leg-hold traps or snares, and that some Golden Eagles photographed during migration or at carrion sites had either broken-off snares dangling from their neck or leg-hold traps attached to a foot. Most trap deaths of Golden Eagles occur during winter, perhaps because the eagles are most likely to be scavenging then (Katzner and others, 2020b). Based on cause-of-death findings from Golden Eagles tracked by telemetry during 1997–2016, Millsap and others (2022) estimated that 279 Golden Eagles were caught in traps annually in the western United States (median estimate, based on the sum of first-year [juvenile] and after-first-year mortalities). Relying on information provided on labels of museum study skins, Bortolotti (1984) reported that traps accounted for 17 of 38 Golden Eagle deaths due to known causes in Canada, Alaska, and the contiguous United States west of the Mississippi River during 1900–80; 15 of the 17 deaths were females.

Legs and feet of eagles captured in leghold traps may appear uninjured or only slightly injured when first examined (Durham, 1981). However, blood vessels in the limited soft tissues of the lower leg are easily damaged by constriction in a leghold trap such that vascular supply is impaired, leading to thrombosis or broken blood vessels (Durham, 1981). In subsequent weeks, the epithelium of the foot or leg gradually deteriorates and falls off, and the extremity becomes black and brittle; the eagle dies even if under veterinary care. Snares and leghold traps with offset jaws also can cause this damage (Durham, 1981). Some eagles may survive with only one foot, but it is rare; the plantar surface of a raptor's foot is prone to deterioration when used alone for perching. Even if eagles are released or escape from leg-hold traps, they likely incur irreversible damage of soft tissues and ultimately lose the extremity or die even when under clinical care (Durham, 1981). Regardless, the underlying cause of incidental captures and deaths seems to be presence of exposed bait (Katzner and others, 2020b).

Energy Development

Energy development constitutes an important, widespread land-use change in the contemporary western United States (Copeland and others, 2011). The growth in this development has been referred to as "energy sprawl," characterized by steadily increasing fragmentation associated with infrastructure, such as roads, well pads, wind turbines, and high-voltage transmission lines. Copeland and others (2011) and Pocewicz and others (2011) used lease and license data to predict future development of oil, gas, wind, solar, and geothermal energy sources in western North America. About 9–24 percent

(2.9–8.9 million ha) of grassland and shrubland in the western Great Plains was predicted to be developed, and most of this development was for conventional oil and natural gas extraction (Copeland and others, 2011; Pocewicz and others, 2011).

Mining, including oil and gas extraction, can negatively affect Golden Eagles. The extent of such impacts varies, depending on type of mining activity, size of the resource being mined, and regulations for the reclamation and recovery of a given site (Postovit and Postovit, 1989). Aside from possible disturbance of Golden Eagle breeding pairs and their nests, incursions by humans, roads, and miscellaneous infrastructure associated with mine development in remote areas can prevent eagles from using important foraging areas and can disturb eagles at traditional roost sites including those of nonbreeding and overwintering individuals (Call, 1979). Large-scale surface mining, like most coal-mining operations, tends to be more detrimental to breeding eagles than local-scale mining, such as oil and gas extraction, especially because nest buffer zones are difficult to establish in surface-mine landscapes (Call, 1979). Coal-mining activities may have limited Golden Eagle productivity at two of 39 breeding areas monitored in eastern Utah (Bates and Moretti, 1994). At one of the breeding areas, escarpments supporting three Golden Eagle nest structures collapsed after underlying coal was removed; one nest remained and produced young the following year, then also fell. Anticipating the spauling event (that is, deterioration and collapse), the mining corporation obtained a permit from the FWS that allowed the nests to be damaged or destroyed (Bates and Moretti, 1994). In parts of Wyoming, potential nest sites are limited for Golden Eagles, and those available may be destroyed by surface coal mines (Phillips and others, 1984). Conversely, coal-mine highwalls can provide nest sites for Golden Eagles in areas otherwise lacking nest sites (Fala and others, 1985).

Compared with coal mining, infrastructure for oil and gas extraction can be developed rapidly with less regulatory oversight, especially on privately owned lands (Postovit and Postovit, 1989). Significant disturbance begins with exploration for oil and gas reserves (Postovit and Postovit, 1989). Human presence, such as traffic, and habitat fragmentation, especially by roads, drilling pads, storage tanks, and miscellaneous buildings, are chief concerns, yet evidence of negative impacts of these disturbances is mixed. Some individual eagles may become habituated to oil and gas development and could be attracted by availability of perching and nesting sites on development infrastructure (Smith and others, 2010). In Utah and Wyoming, occupancy of nests by Golden Eagles declined when oil and gas development occurred within 800 m but increased when roads not associated with oil and gas development were within 2 km (Smith and others, 2010). Wallace (2014) detected no relationship between occupancy of territories by Golden Eagles and density of oil and gas infrastructure in Wyoming and believed that occupancy probably was influenced more by environmental factors not measured except for strong evidence of a positive relationship with nest height. Squires and others (2020) also found no evidence that Golden Eagles avoided oil and gas infrastructure when selecting territories and nest sites across Wyoming, and the eagles tended to nest closer than expected to unpaved roads associated with oil and gas infrastructure. However, the habitat selected by the eagles coincided closely with areas having the highest potential for oil and gas development and thus risked increasing fragmentation (Squires and others, 2020). Apparently, no before-after-control-impact (BACI) studies of effects of oil and gas development on Golden Eagles or their prey have been published.

Electrical distribution lines can be extensive in areas with high densities of oil and gas wells, posing electrocution risk to eagles if not constructed per raptor-safe guidelines (APLIC, 2006). For example, two Golden Eagles tracked by telemetry were electrocuted on distribution lines only 2 and 39 days, respectively, after entering the portion of southeastern New Mexico that overlaps the Permian Basin (Murphy and others, 2023), where oil-well densities reach 19–56 wells per km^2 (Scanlon and others, 2017).

Rapidly increasing development of wind energy in western landscapes, including the Great Plains, has multiple consequences for Golden Eagles (besides mortality risk, as detailed in the “Collisions” subsection). Wind-energy development can break up the eagle’s airspace with infrastructure that alters eagle behavior, but more importantly, it fragments extensive landscapes with access roads, electrical transmission corridors, and cleared areas for turbines (Fielding and others, 2006; Diffendorfer and others, 2019; Ott and others, 2021). These changes affect the quality and quantity of eagle nesting and prey habitat (Kuvlesky and others, 2007; Katzner and others, 2013) and the security of migration corridors (Bedrosian and others, 2018) while possibly increasing the eagle’s vulnerability to disturbance and persecution (Diffendorfer and others, 2019; Bedrosian and others, 2019). Wind-energy projects also can cause Golden Eagles to alter migration flight behavior (Johnston and others, 2014) and avoid otherwise suitable habitat (Walker and others, 2005). Breeding pairs of Golden Eagles may be displaced when wind-energy projects are constructed, as in Wyoming, yet breeding density in surrounding areas may not change (Young and others, 2010). In the APWRA during 2019–21, Wiens and Kolar (2021) documented a higher percentage (29 percent of 16 pairs) of mixed-age (that is, subadult/adult) territorial pairs of Golden Eagles than in the broader surrounding region, where only 3 percent of 122 territorial pairs included subadults; the authors suggested that these differences potentially indicate higher rates of adult mortality or displacement at territories overlapping with the APWRA. As a region, the Great Plains poses the greatest total area of onshore, high-wind potential in the United States (National Renewable Energy Laboratory, 2017). By 2012, about 5 gigawatts of wind-energy capacity existed in the northern Great Plains, and 32 gigawatts were planned for development (Fargione and others, 2012). In a 65,000-km^2 area of the southern Great Plains, 5,835 wind turbines were operating by early 2022 and another 5,314 turbines were being planned based on an index of development by Stahlecker and others (2022). However, extant or planned turbines were within 3.2 km of Golden Eagle nests in only five of 123 nesting territories occupied by the eagle sometime during 2015–20, suggesting that opportunities remain for avoiding development within Golden Eagle territories (Stahlecker and others, 2022).

Other Land-Use Changes

Urbanization is another land-use change with negative implications for Golden Eagles, which typically avoid human population centers. For example, declines in Golden Eagle numbers in southern California are due largely to urbanization (Kochert and Steenhof, 2002). Scott (1985) documented a marked decline in the breeding population of Golden Eagles in San Diego County, California, during 1928–81, coinciding with rapid urban and suburban growth. Based on satellite telemetry data, Tracey and others (2018, 2020) found evidence of strong and moderate avoidance of urban and suburban areas, respectively, by Golden Eagles in southern California; even areas that were about 1.3 km from urban areas were typically avoided. Some areas that appeared to provide suitable habitat for Golden Eagles were too small to be occupied or were not considered by the authors to be functionally connected to other eagle habitat (Tracey and others, 2018). Urban expansion in the Rocky Mountain Front caused the abandonment of some historically occupied Golden Eagle nests (Phillips, 1986). For example, along the Rocky Mountain Front of central to south-central Colorado, the number of nests used annually by Golden Eagles declined from 44 to 22 percent during 1968–72, a change attributed mainly to accelerated commercial and urban development (Boeker, 1974). Concurrent change in the percentage of nesting territories occupied by breeding pairs apparently was not investigated, however. Golden Eagles occasionally inhabit fringes of urban areas such as in the Reno, Nevada, area (White and others, 2018).

Major airports in western States can attract eagles because they can offer extensive, open grassy areas between runways and taxiways, and in approach zones; humans generally are restricted to terminal areas, and eagles can become habituated to humans who are in service vehicles and aircraft away from buildings. Eagles can collide with aircraft, endangering human safety especially when striking cockpit windshields or entering engines (Sodhi, 2002); due to their heavy mass, they pose greater risk to aircraft than most other bird species of concern at airports (Washburn and others, 2015). Dolbeer and Wright (2008) reported seven Golden Eagle strikes with civil aircraft in the United States between 1990 and 2007, including two strikes that resulted in damage to the aircraft and three strikes that had a negative effect on the aircraft flight. Although collisions with aircraft are a minor source of Golden Eagle mortality, such collisions increased by 400 percent in the United States during 1990–2013 and pose human safety hazards (Washburn and others, 2015).

In general, areas that have been converted to agriculture in the western United States, which are vast in extent, are avoided by Golden Eagles as discussed above in the "Suitable Habitat" section, although the term "agriculture" is used loosely in references cited. Yet, certain cropland types may serve as valuable habitat for Golden Eagle prey at least during parts of the year. For example, extensive wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) fields of the Great Plains provide waste grain that attracts great numbers of migrating and overwintering waterfowl, such as the Snow Goose (*Chen caerulescens*) (Alisauskas and Ankney, 1992; Mowbray and others, 2020), and such concentrations of waterfowl provide prey for Golden Eagles (Katzner and others, 2020b). However, habitat for waterfowl and other species of wildlife that may serve as prey for Golden Eagles in much of the Great Plains is rapidly disappearing mainly because of conversion of grasslands to intensively farmed, monoculture landscapes and the concomitant loss of remaining prairie wetland habitats (Higgins and others, 2002). Conversion of native grasslands and shrublands to cultivated crops is projected to increase over the next century in the Northwestern Great Plains and Northwestern Glaciated Plains ecoregions (Sleeter and others, 2012; Sohl and others, 2012; Bedrosian and others, 2019), which will greatly alter and reduce habitat for breeding and nonbreeding Golden Eagles and their prey (Bedrosian and others, 2019).

Some western landscapes are used for military training. In Colorado, Golden Eagles, Ferruginous Hawks (*Buteo regalis*), and Swainson's Hawks (*Buteo swainsoni*) combined showed significant behavioral changes resulting from military activities in their home ranges (Andersen and others, 1990). Compared to birds that had not been exposed to military activities, birds that had been exposed to military activities showed greater shifts in their home-range centers, greater increases in their home-range size (July–August), and more frequent and greater movements outside of their territories. Effects of armored vehicle training, artillery firing, and helicopter training on raptors and habitat were studied during 1990–94 on a 56,022-ha area associated with the Snake River in southwestern Idaho (U.S. Department of the Interior, 1996). Vehicle use had a long-term, negative effect on Golden Eagles by reducing native vegetation and igniting fires, both of which led to invasion by cheatgrass and loss of shrublands, reducing the quality of foraging habitat. Other disturbances, such as noise created by military vehicles and ordnance tests, caused short-term disruptions in eagle behaviors that were not considered significant. In northern Utah, military helicopter operations did not negatively impact nesting Golden Eagles (Grubb and others, 2010).

Afforestation, specifically the establishment of conifer plantations, may replace expanses of open habitat that are valuable to Golden Eagles, as has been reported in Scotland (Marquiss and others, 1985; Watson, 1992; Whitfield and others, 2001). Negative effects of conifer plantations on eagles may not begin to be evident for about the first decade after trees are planted (Marquiss and others, 1985). Moreover, if trees are planted in degraded habitat with little eagle prey available, a short-term benefit is that prey populations may increase with the early successional plant growth that occurs following the end of a former, detrimental land-use practice, such as overgrazing (Watson, 1992). Productivity of Golden Eagles may decline in landscapes where such plantations are established, but the relationship between the areal extent of plantation cover and variation in eagle productivity remains unclear (Whitfield and others, 2001).

Although not technically a land-use change, outbreaks of introduced disease organisms can have dramatic effects on prey of Golden Eagles. In prairie dog colonies, bubonic plague caused by the introduced, flea-transmitted bacterium *Yersinia pestis* may abruptly shift the suitability of landscapes for Golden Eagles where prairie dogs constitute its primary prey. For example, on Thunder Basin National Grassland in northeastern Wyoming, 13 of 19 Golden Eagle territories produced young in 1 year, but plague decimated the local population of black-tailed prairie dogs following the breeding season; the next year, only one of 19 territories produced young (Bedrosian and others, 2019). In the same National Grassland, the total area occupied by plague has declined by as much as 99 percent (from 10,604 to 47 ha) in a single year, with recovery taking more than a decade (Davidson and others, 2022). Across 40–50 km^2 in northern New Mexico, Golden Eagles declined significantly during a plague epizootic among an estimated 100,000–150,000 Gunnison's prairie dogs (Cully, 1991). Both Gunnison's and black-tailed prairie dogs can incur nearly 100 percent mortality from plague outbreaks and are considered major amplifying hosts of the disease, which may become epizootic in scale (Barnes, 1993). Due to serious human health concerns posed by plague, entire colonies of prairie dogs have in some cases been eliminated by humans to prevent disease transmission (Barnes, 1993). However, in a study of black-tailed prairie dogs, Cully and others (2010) suggested that decreased colony size and increased distance between colonies that persist after plague outbreaks may reduce the likelihood of subsequent outbreaks.

Recreational Activity

Disturbance of Golden Eagles by people engaged in recreational pursuits near Golden Eagle's nests is a growing problem on public lands in the western United States (Steenhof and others, 2014; Spaul and Heath, 2016). Such recreational activities are mainly hiking, camping, rock-climbing, shooting, mountain biking, and driving off-highway vehicles including snowmobiles (Steenhof and others, 2014; Spaul and Heath, 2016; Katzner and others, 2020b). Disturbances range from short-term or infrequent to long-term or chronic. Golden Eagles, like many species of raptors, can be particularly sensitive to such disturbances during the breeding season, especially during courtship through early nestling stages (Newton, 1979). Wherever Golden Eagle pairs reside at their nesting territories year-round, courtship, including selection and refurbishing of nests, is likely to be underway at least 1 month before eggs are laid (Katzner and others, 2020b). Disturbance from recreation may cause Golden Eagles to not lay eggs or lessen care of their young; in extreme cases, breeding pairs may temporarily abandon their eggs or young nestlings, which then quickly become vulnerable to loss. For example, Golden Eagle nestlings <3 weeks of age can die from heat stress if adults leave their nest site and fail to shade their young from direct sun on extremely hot (>32 ºC) days (Kochert and others, 2019); or, when flushed suddenly from nests, eagles may inadvertently crush their eggs or cause nestlings to fall from nests (Fyfe and Olendorff, 1976). Golden Eagle pairs in Alaska fed less food to their young and spent less time at their nests when people camped nearby (Steidl and others, 1993, *in* Katzner and others, 2020b). Using a modeling approach, Pauli and others (2017) found that negative impacts of recreation on Golden Eagle breeding success could have long-term, population-level implications. Slight (1–2 percent) annual increases in pedestrian and off-highway vehicle use could hasten population declines, despite predicted habituation by some eagles and influences of natural selection favoring tolerance of recreation activity (Pauli and others, 2017). Whether caused by recreation activities or other sources, disturbance has caused major losses in Golden Eagle reproductive success and territory occupancy in some regions (Camenzind, 1969; Boeker and Ray, 1971; Scott, 1985).

Recreational activity associated with off-highway vehicles may negatively affect Golden Eagle reproductive success. Spaul and Heath (2016) published a comprehensive study of recreational disturbance. The authors found that in southwestern Idaho, 23 nesting territories with high levels of off-highway vehicle use within 1.2 km were less likely to be occupied; probability of nest initiation was reduced by early-season pedestrian and other non-motorized use; and nest attendance was reduced when pedestrians, who often arrived by off-highway vehicles, were active near eagle nests. Steenhof and others (2014) assessed whether the proportion of territories and pairs producing Golden Eagle young in southwestern Idaho changed over time where off-highway vehicle use increased. From the late 1960s to 1999, the proportion of territories that produced Golden Eagle young was similar across southwestern Idaho. After a dramatic increase in off-highway vehicle use from 1999 to 2009, Golden Eagle occupancy and success of territories near recreational trails and parking areas declined, and the proportion of these territories producing young differed significantly from territories that were not affected by off-highway vehicles (Steenhof and others, 2014).

D'Acunto and others (2018) used simulation modeling (Bennett and others, 2009) to compare simulated flushing responses of incubating Golden Eagles and altered flight behavior of foraging eagles to two trail-closure strategies in each of three landscapes with differing cover types (avoided, neutral, and preferred habitat preferences) and trail configurations (low, moderate, and high trail densities) in southwestern Idaho. The two trail-closure strategies included a scenario with a 600-m restrictive buffer around the nest and a scenario with closure of all but the most popular trails to human recreation. The trails were used by pedestrians and off-highway vehicles. The restrictive-buffer strategy was best at reducing flushing by incubating eagles, and the closure of all but the most popular trails was best at reducing alteration of flight behavior by foraging eagles. Overall, trail density was more important than human activity levels on trails, for both incubating and foraging eagles simulated, indicating that there is a threshold of activity at which trail closures are no longer effective in limiting disturbance.

Golden Eagles also may be disturbed at traditional roost sites and preferred foraging sites, which could occur independent of breeding season or independent of breeding status of individual eagles (Katzner and others, 2020b). Repeated disturbance events may lead to avoidance of important eagle-use areas. Disturbance of raptors in general also can be caused by research activities (Rosenfield and others, 2007).

Fire

Recurrent fire played a major role in the evolution of grasslands such that native grasslands may be considered fire-dependent, especially mixed-grass prairies; other key drivers were climate and defoliation by a variety of grazing animals especially American bison (*Bison bison*) (Higgins, 1986; Bragg, 1995; Samson and Knopf, 1996). However, outcomes of large (that is, >400 ha) wildfires occurring under unnaturally hot, dry conditions, especially with heavy fuel loads (including woody fuels) may not be favorable for habitat of important prey of Golden Eagles or for eagle nest-site availability in locales where cliff nest sites are unavailable. The frequency and total area of large wildfires in the Great Plains have increased significantly in recent decades after being almost nonexistent for roughly 100 years (Donovan and others, 2017). Between 1985–94 and 2005–14, the mean number of annual large fires in the Great Plains increased from 33.4 to 116.8. Total area burned increased by 400 percent, from thousands to millions of hectares burned annually between the two periods, due mostly to fires in the far western Great Plains. In part, wildfires are increasingly difficult to control in the region due to shortages of trained staff equipped to suppress fires and to reduce fuel loads in landscapes becoming increasingly drier and hotter because of climate change (Donovan and others, 2017).

Fire, whether wildfires or prescribed fires for management purposes, may affect Golden Eagles chiefly by altering vegetation composition that may benefit some prey species and hinder others and by changing vegetation structure in ways that influence physical access to and thus vulnerability of prey. Changes in vegetation composition or structure could range from immediate or short-term to gradual and long-term. One consequence of such effects on prey may be shifts in Golden Eagle territory occupancy and reproductive success. A case history in southwestern Idaho reported by Kochert and others (1999) illustrated these concepts. During a 6-year period, the extent of area burned by wildfire within the territory core (that is, the area within 3 km of a territory's nest centroids) of 27 of 36 Golden Eagle nesting territories was at least moderate (that is, ≥11–29 percent of the territory core burned). Although territory occupancy rate did not change after the fires, pairs at nine territories maintained greater occupancy rates by expanding into neighboring, vacated territories (Kochert and others, 1999). Moreover, reproductive success (that is, the mean number of fledglings produced) of the pairs that usurped adjacent, vacant territories did not decline after the burns, whereas reproductive success of pairs that were not adjacent to vacant territories declined significantly. Reproductive success at 15 extensively burned territories (>30 percent of the area within 3 km of the nest centroid burned), relative to nine unburned territories, decreased 2–3 years postburn, was lowest from 4 to 6 years postburn, and returned to the 1-year postburn level in 10–11 years. The time lag in effect of the burns was attributed to a temporary concentration of prey in remaining unburned habitats, and the recovery was attributed in part to regrowth of shrubby vegetation (Kochert and others, 1999). A concurrent study in the same southwestern Idaho area (Marzluff and others, 1997) provided evidence that Golden Eagles may have been able to partly compensate for the effect of burns by concentrating their foraging efforts in remnant shrub habitats, by ranging over wider areas, foraging in other habitats (for example, agricultural and riparian areas), or by selecting alternate prey. However, Marzluff and others (1997) and Kochert and others (1999) noted that the carrying capacity for eagles in the study area might be reduced when eagles expand their territories into vacant neighboring areas.

In grasslands, an immediate effect of fire can be a sudden flush of vulnerable prey for raptors as fire removes concealing vegetation, as has been reported, for example, for White-tailed Hawks (*Buteo albicaudatus*) (Kopeny, 1988) and Swainson's Hawks (Murphy and Smith, 2007). In years following fires in grassland and shrubsteppe habitats, composition of species of prey may change, with important consequences for Golden Eagles including breeding dynamics (Davis, 2019; Heath and others, 2021). In southwestern Idaho, Davis (2019) investigated whether wildfires, outdoor recreation, and habitat loss affected Golden Eagle occupancy, reproduction, and diet. After large-scale wildfires, Golden Eagles shifted prey use from primarily leporids to a higher proportion of alternative prey including sciurids, snakes, yellow-bellied marmots, and galliforms than in unburned areas. Pedestrian recreational use decreased in territories that had been burned, but the rate of confirmed egg-laying increased; the author suggested that the decrease in pedestrian use had an interactive, positive effect on Golden Eagle reproduction. After extensive wildfires in southwestern Idaho during 1981–86, the mean proportion of unburned shrub habitat within 3 km of centroids of Golden Eagle nesting territories in 2014 was 0.22, compared to 0.73 in 1979, before the wildfire period (Heath and others, 2021).

Black-tailed jackrabbits and mountain cottontails had constituted the chief prey of breeding Golden Eagles during the preburn years. During the postburn years, however, Golden Eagle diets shifted dramatically in response to changes in prey populations coinciding with postburn habitat transformation (Heath and others, 2021). Composition of prey in diets of breeding eagles became more diverse, with less use of the shrub-associated leporids and greater use of Piute ground squirrels (*Urocitellus mollis*), Rock Pigeons (*Columba livia*), Mallards (*Anas platyrhynchos*), and American Coots (*Fulica americana*). Heath and others (2021) noted that Mallards and American Coots seldom occurred in the breeding-season diets of Golden Eagles in the preburn years. During postburn years, Golden Eagle nesting attempts were more likely to fail and nestling survival decreased, on average; nestling survival was positively and negatively associated with the proportion of black-tailed jackrabbits and Rock Pigeons in diets, respectively. Twenty-three eagle nestlings tested positive for plaques indicative of the disease trichomonosis. Rock Pigeons are a vector for *Trichomonas gallinae*, which is a disease-causing protozoan that is lethal to Golden Eagle young (Heath and others, 2021).

The role of fire in facilitating invasion by nonnative plant species, resulting in decreased prey abundance and thus declines in local to regional populations of Golden Eagles, was reviewed in the “Breeding Habitat” section. In forests, fire may create access to tree nest sites for Golden Eagles and create openings for foraging (Katzner and others, 2020b). Fire also may reverse invasion by native juniper (several species) in parts of the Great Plains and areas to the west where juniper has expanded into grasslands and big sagebrush shrubsteppe during the last circa 150 years (Miller and Rose, 1999). In these regions, junipers can ultimately develop into dense woodlands, which provide limited foraging opportunities for Golden Eagles because suitable prey are limited; the species is neither physically nor behaviorally adapted for hunting in such tall, heavy cover. However, invasive junipers may occasionally provide nest sites for Golden Eagles.

Fire, especially its frequency, is crucial for sustaining habitat of some native wildlife species that may serve as Golden Eagle prey in the Great Plains, particularly in mixed-grass prairies where, before settlement of Euro-Americans in the early 1900s, fires occurred roughly every 5–10 years (Bragg, 1995). Along with periodic, intensive grazing by bison, recurrent fire maintained short, herbaceous vegetation that helped support extensive colonies of black-tailed prairie dogs south and west of the Missouri River, and Richardson’s ground squirrels (*Urocitellus richardsonii*) north and east of the Missouri River (Murphy, 1993). Both rodent species constitute primary prey of Golden Eagles in the Great Plains (reviewed in “Prey Habitat” section). Without recurrent fire, northern prairies can revert to brush-dominated communities, causing prairie dog and ground squirrel abundances to decline, as well as populations of other species of upland wildlife that Golden Eagles prey on, such as Sharp-tailed Grouse (*Tympanuchus phasianellus*) (Murphy and Smith, 2019) and white-tailed jackrabbits (Simes and others, 2015). Recurrent fires can be important to Golden Eagles in grasslands elsewhere in the western United States. For example, in grass/shrubland foothills of San Diego County, Calif., Golden Eagle nesting territories were less common in areas where no fires occurred during 1920–80 than in areas that experienced fire in one to three decades during the same period (Brown, 1985).

Grazing

Grazing by livestock is one of the most widespread land uses of the Great Plains (Sutton, 1984). In the region’s grasslands and shrubsteppe to the west, livestock grazing may affect Golden Eagles by altering the structure and composition of vegetation (Milchunas and others, 1989; Samson and Knopf, 1996; Holechek and others, 2006) in ways that influence abundance and availability of sciurids and leporids, which are the focal prey groups of this subsection. For example, in California, Hunt and others (1995) suggested that Golden Eagles used grazed grasslands for foraging because their primary prey (ground squirrels) in that region favored grazed areas that had reduced grass height.

The geographic focus of this subsection is native grasslands of the shortgrass and mixed-grass ecosystems as delineated in Samson and Knopf (1996), where perennial grasses are dominant plant species. The native shortgrass-shrubsteppe, especially in Montana and Wyoming, also is considered here. This subsection does not consider the substantial total area of the Great Plains that had been cultivated for many years and later planted with various mixtures of nonnative and native perennial grasses and tall forbs, such as alfalfa (*Medicago sativa*) and yellow sweetclover (*Melilotus officinalis*), under the Conservation Reserve Program, and then grazed by livestock after enrollment in the program ended (Morefield and others, 2016). However, such areas can be important for potential Golden Eagle prey, such as ducks and upland gamebirds, even when grazed by cattle (Geaumont and others, 2017; Rischette and others, 2021).

There are key differences between the shortgrass prairie plant communities and the more mesic, mixed-grass prairie plant communities; these differences influence the effects of livestock grazing on vegetation structure and composition. Mainly, shortgrass communities, typically dominated by blue grama (*Bouteloua gracilis*) and often buffalograss (*Bouteloua dactyloides*), are somewhat resilient to all but the most intensive, long-term livestock grazing (Milchunas and others, 1989) because they are characterized by a short, simple, aboveground structure. Moreover, diets of cattle are roughly similar to those of the American bison with which shortgrass plant communities evolved (Plumb and Dodd, 1994; Milchunas and others, 1998). Mixed-grass communities are characterized by greater plant diversity and biomass and evolved with fire as a far more important evolutionary influence, together with grazing by bison (Bragg and Steuter, 1996). Long-term, season-long grazing of mixed-grass prairie tends to ultimately shift dominant plant species composition toward the more grazing-adapted shortgrass prairie species (Smart and others, 2007), and cattle grazing becomes more concentrated in low, mesic sites (Plumb and Dodd, 1994). Regardless, the quality and quantity of native prairies of the mixed-grass ecosystem have diminished substantially mainly through conversion to agriculture, invasion by nonnative plant species, and expansion of woody vegetation (Bragg and Steuter, 1996; Samson and others, 2004), even on lands set aside for conservation purposes (Grant and others, 2020). Historically (that is, before settlement by Euro-Americans), average fire-return intervals are thought to have been roughly 20–25 years for shortgrass systems (Zouhar, 2021) and 5–10 years for mixed-grass systems (Bragg, 1995). Basic understanding of grazing as an evolutionary driver of the composition, structure, and resilience of shortgrass and mixed-grass prairies and the interaction between fire and grazing, especially on mixed-grass prairies, is key to sustaining these systems as rangelands that provide many ecosystem services (Samson and others, 2004), which include Golden Eagle habitat and functional predator-prey relationships.

In general, overgrazing by cattle and other livestock likely has contributed to declines of white-tailed and black-tailed jackrabbits (Hansen and others, 2017a). Jackrabbit habitat in western regions that are too dry to be cultivated has especially deteriorated from excessive livestock grazing that typically leads to a loss of grasses and increases in shrub cover (Brown and others, 2020). Such changes in grasslands may favor black-tailed jackrabbits up to certain thresholds. In the Great Plains, the extent of increases in shrub cover associated with long-term grazing by cattle may depend on the species of shrub and potential abiotic influences, especially lack of fire. For example, long-term, heavy grazing by livestock was thought to be the chief cause of increased mesquite (*Prosopis* spp.) cover across semiarid grasslands of the far southern Great Plains and areas to the west; grazing reduced the aboveground biomass of graminoids, which comprised the fine fuels that carried fires (Van Auken, 2000). Juniper cover in shrubsteppe west of the Great Plains increased in response to decreased fire frequency stemming from fine fuels reduction because of long-term livestock grazing, a change that initially favored black-tailed jackrabbits (Gruell, 1996, 1999). As reviewed under the “Prey Habitat” section, black-tailed jackrabbits tend to be common in open grasslands with scattered shrub or dense tufts of tall, herbaceous vegetation (Hansen and others, 2017a). In shortgrass prairie of northeastern Colorado, black-tailed jackrabbits were most abundant in areas that received light or moderate grazing pressure by cattle during summer compared to areas that were heavily grazed during summer or moderately grazed during winter (Flinders and Hansen, 1975). Within grazing units, black-tailed jackrabbits selected lowland areas where vegetation cover was heaviest. However, in another area of Colorado, densities of black-tailed jackrabbits were greater on heavily grazed areas than areas with taller vegetation (Sanderson, 1959).

Compared to black-tailed jackrabbits, white-tailed jackrabbits tend to prefer areas with more herbaceous vegetation (Simes and others, 2015). In southeastern Colorado, white-tailed jackrabbits exhibited no clear relationship to varying levels of grazing intensity, although they preferred open areas over shrub-dominated areas (Flinders and Hansen, 1975).

Little has been published on responses of cottontail rabbits to cattle grazing in the western Great Plains. In shortgrass prairie of southeastern Colorado, desert cottontail rabbits were most abundant in areas with moderate levels of cattle grazing pressure during summer and areas with moderate grazing pressure during winter, compared to areas that were heavily and lightly grazed during summer (Flinders and Hansen, 1975). Within grazing units, the rabbits typically were observed in edges of vegetation types, areas with fourwing saltbush (*Atriplex canescens*) or rabbitbrush, or areas with rock outcrops or gullies. Browsing of fourwing saltbush by cattle appeared to stimulate the shrub’s growth and density, thereby increasing cover for cottontail rabbits (Flinders and Hansen, 1975).

In the United States, the black-tailed prairie dog’s range closely corresponds to the extent of the mixed-grass and shortgrass prairie regions, and thus the prairie dog often coexists with cattle there, including landscapes used by Golden Eagles. Indirectly, cattle presence has dramatically reduced the availability of black-tailed prairie dogs as prey for Golden Eagles because of efforts by humans to eliminate the prairie dog as a competing herbivore (Hoogland, 2013).

Black-tailed prairie dogs can be attracted to areas characterized by short vegetation structure resulting from heavy, repeated grazing by cattle, as observed in mixed-grass prairies of northeastern Montana (Knowles, 1986). Conversely, prairie dog colonies provided grazing opportunities for American bison (Coppock and others, 1983; Detling, 2006) and may do so for cattle, as noted by Curtin (2006) in western New Mexico and by Augustine and Derner (2021) in northeastern Colorado, especially after periods of high vegetation production. However, neither attraction may be apparent, as was the case in a shortgrass prairie in northeastern Colorado (Guenther and Detling, 2003; Detling, 2006). Knowles (1986) studied relationships between livestock (mainly cattle) and black-tailed prairie dogs on mixed-grass prairie and prairie-shrubland at Charles M. Russell National Wildlife Refuge and Fort Belknap Indian Reservation in northeastern Montana. Prairie dog colonies occurred in areas of intensive grazing by domestic livestock, mainly cattle, and in areas where human activity had created topsoil disturbance, or where there was a combination of these two. Developments for livestock (including wells, small reservoirs, salt licks, and calf feeders) were found at 62 percent of 112 prairie dog colonies on the refuge and 60 percent of 42 colonies on the reservation (Knowles, 1986). Cattle appeared to prefer 65-ha quarter-sections with prairie dogs over quarter-sections without prairie dogs, although presence of water sources on some of the former may have biased this comparison. Prairie dog abundance was greatest on an area with a history of rest-rotation grazing, where intensive grazing began at the beginning of April each year (Knowles, 1986).

In a shortgrass prairie in southwestern South Dakota, there were 235 prairie dog burrows per ha in an area grazed by cattle for 4 years, but a similar, nearby area without cattle grazing had 106 burrows per ha (Uresk and Bjugstad, 1983). The authors speculated that dispersing prairie dogs may recognize and select heavily grazed areas. Plant production on the prairie dog-only area was 24 percent greater than on cattle-only area. On shortgrass prairie managed by rotational cattle grazing in northeastern Colorado, desert cottontails were favored by changes in vegetation composition linked to grazing by black-tailed prairie dogs (Hansen and Gold, 1977). Some evidence suggests that reducing cattle stocking rates or excluding cattle increases the distribution and density of native, cool-season grass species, especially needle grasses (*Nassella* spp. and *Hesperostipa* spp.) and wheatgrasses (*Pascopyrum* spp.), and reduces prairie dog colony size in shortgrass and mixed-grass areas (Sharps and Uresk, 1990).

Climate Change

Climate may affect abundance, productivity, or distribution of Golden Eagles, especially by influencing the availability of prey. Tack and others (2020) used dynamic occupancy models to examine spatial variation in Golden Eagle distributions during late summer in the western United States; the authors reported that adult and subadult Golden Eagles selected productive landscapes (based on an index of gross primary productivity) and avoided drought-stricken landscapes and landscapes with an extensive human footprint. Steenhof and others (1997) reported that weather influenced Golden Eagle reproduction in southwestern Idaho; the percentages of successful laying pairs and mean brood size were positively related to jackrabbit abundance and inversely related to the number of extremely hot spring days. Based on data from Christmas Bird Counts (Bock and Root, 1981), Paprocki and others (2014) reported that Golden Eagle winter distribution in western North America shifted northward 7.74 km per year during 1975–2011. The authors reasoned that in general, some raptor species may exhibit such shifts in response to warming winters because intraspecific competition for nest sites forces males to winter farther north or because migration distances or tendencies to migrate vary among individuals. Under projected greenhouse gas emission scenarios described by the Intergovernmental Panel on Climate Change (2000), Langham and others (2015) categorized the Golden Eagle as a climate-endangered species, indicating that the species would lose >50 percent of its current breeding-season distribution by 2050 without the potential to expand its range into new areas.

Factors limiting Golden Eagle populations in arid parts of the western United States may suggest broader consequences of a warming climate for the species in coming decades. In desert grasslands and chaparral habitats of western Arizona, Golden Eagle nesting chronology was closely linked to precipitation patterns, which affected reproductive periods and abundance of prey (Millsap, 1981). During 4 years of severe drought and concomitant declining plant productivity in west-central California, the proportion of Golden Eagle pairs that initiated nests (that is, laid eggs, defined as breeding rate) and productivity (defined as the number of fledglings produced per occupied territory) declined by 93–95 percent (Smith and others, 2020). During the next year, however, breeding rate increased to 63 percent of pairs following normal precipitation during the preceding winter. Productivity increased but to a lesser degree. The increased reproductive success was correlated with measures of primary productivity during the current year and total precipitation during June and July in the previous year (Smith and others, 2020). In the arid, southwestern half of the Four Corners region of Utah, Colorado, Arizona, and New Mexico, juvenile Golden Eagles tended to disperse earlier and farther from natal areas than did juveniles in the more northerly semiarid half of the region, possibly because provisioning by breeding pairs declined due to shrinking prey availability as summer progressed; these early, long-distance dispersers exhibited the lowest survival rate among juveniles studied in the region (Murphy and others, 2017). Murphy and others (2017) predicted that long-distance dispersals of juveniles will increase in proportion because of increased aridity of landscapes associated with climate change. In the western United States between 1997 and 2016, starvation appeared to be the most important cause (natural or anthropogenic) of mortality among juvenile Golden Eagles (Millsap and others, 2022).

In boreal regions, climate change is causing an increase in shrub cover and a northward advancement of the tree line; greater shrub and tree cover could impede hunting by Golden Eagles, leading to decreases in eagle density, occupancy, or productivity (McIntyre and others, 2006; Morneau and others, 2015; Miller and others, 2017; Herzog and others, 2019). Where afforestation is occurring on the breeding and wintering grounds, Golden Eagles and their prey may benefit from forestry management practices and fires that create openings in forests and reduce dense understories, such as in eastern North America (Miller and others, 2017) and boreal habitat in Sweden (Moss and others, 2014). Marcot and others (2015) predicted that Golden Eagle habitat in northwestern Alaska will decline by as much as 20 percent by 2100 due to habitat alteration related to climate change; major increases in shrub and forest cover are among changes predicted. Conversely, some increases in shrub cover at high latitudes could provide more foraging habitat (McIntyre and others, 2006). Moreover, Golden Eagles may have greater access to prey if openings are created in the contiguous, dense tree cover of boreal forests owing to increased frequency and extent of fire and insect outbreaks associated with climate change (Bonan, 2008).

Incidence of some forms of ectoparasitism at Golden Eagle nests may increase with rising temperatures. Parasitism of Golden Eagle nestlings by Mexican chicken bugs (*Haematosiphon inodorus*), a hematophagous member of the Cimicidae family (Hemiptera), was first documented in far southern parts of the eagle's breeding range in the western United States (southern California and northeastern New Mexico) during the 1950s–70s (Lee, 1954, Platt, 1975). In 1984, Grubb and others

(1986) documented the parasite in a Bald Eagle nest in Arizona. Observations by McFadzen and others (1996) of Mexican chicken bugs at raptor nests in southwestern Idaho during the early 1990s represented a significant northerly range shift, which coincided with a period characterized by warm winters (Heath and others, 2012). Two decades later, the parasite had become common at Golden Eagle nests in southwestern Idaho, especially those with southerly exposures or at nests of pairs that bred late in the season, suggesting a link between parasitism incidence and higher temperatures (Dudek, 2017). In a recent study in the southern Great Plains, Mexican chicken bugs caused significant mortality among juvenile Golden Eagles just before and during fledging (Murphy and others, 2023). Low survival of Golden Eagles during preadult years was attributed mainly to this parasitism and powerline electrocution; the estimated probability of death due to each factor was 0.346 (Murphy and others, 2023).

The increasing frequency, size, and intensity of wildfires attributed generally to climate change in the western United States (Marlon and others, 2009; Abatzoglou and Williams, 2016) may have negative consequences for Golden Eagles. For example, increased fire frequency and severity has contributed to a loss of Golden Eagle nesting territories in eastern Washington (Watson and others, 2020). The most extensive case history of effects of wildfires on Golden Eagle habitat and prey resources is that for shrubsteppe landscapes of the northern Great Basin, especially southwestern Idaho, which was reviewed under the "Breeding Habitat" and "Prey Habitat" sections. In general, the potential for such landscapes to support Golden Eagle breeding populations has been diminished by fire-induced conversion of sagebrush-dominated communities to cheatgrass monotypes that provide relatively little prey.

As a highly mobile species, Golden Eagles may counteract the effects of high temperatures by moving. Golden Eagles in the Mojave Desert avoided high summer temperatures by moving to cooler, higher elevation montane grasslands, scrublands, and forests (Braham and others, 2015). In the Four Corners region of Utah, Colorado, Arizona, and New Mexico, most subadult and some nonbreeding adult Golden Eagles either spend summers in more northerly States, especially Wyoming, or intermittently use high elevation areas (R. Murphy, personal obs., and D. Stahlecker, Eagle Environmental, Inc., Santa Fe, N. Mex., written commun., June 23, 2014). Increasing temperatures also appear to be altering Golden Eagle migration phenology; individuals from boreal regions of North America are delaying the start of spring migration by about 10 days and advancing fall migration by about 20 days (Maynard and others, 2022).

Management Recommendations from the Literature

Millsap and others (2022) suggested that management to successfully conserve Golden Eagles in the Great Plains and across the western United States must focus primarily on mitigating anthropogenic mortality. Mitigating anthropogenic mortality might not be necessary for a given subregion or locale for which survival and cause-of-death data indicate that the annual rate of population growth exceeds that of a stable population, in locations where significant increases in anthropogenic mortality are not imminent, or where other potential limiting factors are unlikely to hinder population growth; south-central Montana might be a current example (Crandall and others, 2019). However, such populations can serve as a critical source of individuals that disperse and recruit to depleted populations, and efforts to protect these populations are warranted (Millsap and others, 2015).

The main sources of anthropogenic mortality (for example, shooting, collision, electrocution, poisoning) constitute illegal take of Golden Eagles, where take is defined as "pursue, shoot at, poison, wound, kill, capture, trap, collect, molest, or disturb" individual eagles, their parts, nests, or eggs (50 CFR § 22.26 and 22.27). Take of Golden Eagles and Bald Eagles is prohibited under the BGEPA (16 U.S.C. § 668-668d). The Migratory Bird Treaty Act (16 U.S.C. § 668a) and State and Tribal laws may provide additional protections. However, the FWS (2009) can issue permits authorizing incidental take that occurs during otherwise lawful activities that cannot practicably be avoided; incidental take also has been referred to as nonpurposeful take. Any take authorized by a permit from the FWS must be compatible with the eagle preservation standard, with preservation meaning "consistent with the goals of maintaining stable or increasing populations in all eagle management units and the persistence of local populations throughout the geographic range of each species" (FWS, 2016b, p. 91497). Using a risk-averse approach, the FWS limits annual permitted take to a level below the estimated, sustainable take limit; additional take must be mitigated because models suggest such take could prompt a population decline (FWS, 2016b; Millsap and others, 2022). Moreover, if a Golden Eagle is taken under permit, the loss must be offset by saving 1.2 Golden Eagles from mortality elsewhere or by adding 1.2 Golden Eagles to the population (FWS, 2016b); the 1:1.2 offset ratio is a risk-averse alternative to a 1:1 standard. As an example of compensatory mitigation, replacement of components on hazardous electrical distribution poles to minimize eagle mortality risk is considered a quantitatively defensible means of offsetting losses of Golden Eagles (see "Electrocution" subsection under the "Management Recommendations from the Literature" section). Thus, complex management of take of individual Golden Eagles, the species' *K*-selected life history strategy, and the species' large home ranges and wide-ranging behavior distinguish conservation of Golden Eagles from that of most other species of nongame birds that rely on grasslands and shrubland habitats in the western United States.

Electrocution

Golden Eagle electrocutions are an ongoing conservation concern across the western United States. Mojica and others (2018) reviewed the topic of Golden Eagle electrocutions and provided several recommendations, including retrofitting techniques, such as separating or insulating energized and grounded parts, and redirecting eagles away from energized parts by reducing opportunities for perching (for example, Marshall, 1940). Effective mitigation of electrocutions begins with pinpointing high- and moderate-risk poles in the landscape. Identifying high- and moderate-risk poles can be done at the scale of individual electrical utilities but is more effective at regional scales (Mojica and others, 2018). Dwyer and others (2016) developed a regional model of power-pole density throughout Colorado and Wyoming. Distribution poles were densest in areas with greater road lengths, high numbers of oil and gas wells, and flat terrain, and in areas developed for agriculture or human residences. Dwyer and others (2016) suggested that areas where high pole densities overlap with Golden Eagle habitat could be prioritized to mitigate electrocution risk.

Distribution poles that either have recorded incidences of electrocution or that otherwise pose electrocution risk because of various combinations of exposed electrical contact points can be retrofitted or modified in ways that minimize risks (APLIC, 2006). APLIC (2006) recommended that new poles should be designed to avoid electrocutions. Risk of electrocution at a pole can be minimized by isolating energized components far from each other and from grounding sources, or by insulating energized components. To protect birds as large as eagles, APLIC (2006) recommends 150 and 100 cm as minimum horizontal and vertical distances, respectively, between contacts. As a last resort, perches can be used to try to redirect eagles away from risky equipment, but effectiveness of this measure has been mixed (Dwyer and Doloughan, 2014).

Models that predict power-pole density have been developed to aid in the mitigation of electrocutions across most of the Golden Eagle's range in the western United States (Dwyer and others, 2016, 2020a; Bedrosian and others, 2020), although model accuracy can be inconsistent among regions (Dwyer and others, 2020a). As a next step, power-pole density models have been compared to spatial models of Golden Eagle distribution, such as nest-site density models. Bedrosian and others (2020) classified their modeled predictions of Golden Eagle nest-site density and those of power-pole density across most of the United States portion of the northern Great Plains, then examined spatial overlap of these model results. Areas posing greatest risk covered 1.1 percent of the region, whereas low-risk areas covered 53.6 percent. Based on these results, the authors estimated that (1) retrofitting poles in the areas of highest predicted risk would avert electrocutions greater than three times than if the same retrofitting effort had been expended in randomly selected areas, and (2) electrocutions would be reduced 89 times greater than if the retrofitting was done in low-risk areas. The authors recommended that areas identified as high and very high risk be targeted as conservation action priorities, with strong likelihood of benefits to Golden Eagles. Mojica and others (2022) provided detailed guidance on optimal selection of individual power poles for retrofitting, with the goal of maximizing credits for compensatory mitigation of Golden Eagle mortalities. Compensatory mitigation is a conservation mechanism used by the FWS whereby authorized incidental take (that is, a population debit) is offset by a conservation benefit that increases a species' survival, productivity, or fitness (that is, a population credit). Mojica and others (2022) estimated that retrofitting a high-risk pole yields 5.3 times more conservation benefit for Golden Eagles than retrofitting a low-risk pole.

Electrical utility companies are legally responsible for fatalities of Golden Eagles at their respective powerlines, with potential for fines under the BGEPA. However, the FWS urges utilities to avoid prosecution by developing Avian Protection Plans, in cooperation with the FWS, to outline utilities' commitment to minimizing powerline electrocutions (APLIC and FWS, 2005). The plans are binding but can be modified and improved upon in consultation with the FWS.

Collisions

Collisions incurred by Golden Eagles from vehicles may be less difficult to resolve than those associated with wind turbines (discussed later in this section). To mitigate the incidence of Golden Eagles being struck by vehicles while at or near carcasses along roads, county and State highway departments, highway patrol officers, public and private conservation entities, and concerned citizens may collaborate to identify areas with historically high occurrences of carcasses (that is, hotspots) (Lonsdorf and others, 2018). Carcasses associated with vehicle collisions often are spatially and temporally aggregated (Santos and others, 2017). Slater and others (2022) identified wildlife-vehicle collision hotspots by compiling data from encounters of banded Golden Eagles, winter eagle locations, wildlife-vehicle collision records, and big-game winter ranges. Efficiency of carcass-searching strategies in terms of economics (costs versus benefits) may be improved by modeling, as demonstrated by Santos and others (2018). The subset of such areas that overlaps high-quality eagle habitat can then form the basis for planning a carcass-removal program to curtail eagle-vehicle collisions. For example, based on types of carcasses scavenged by Bald Eagles and other scavenger species (ravens and coyotes) along northern Arizona highways during winter (Grubb and others, 2018), management of carcass consumption and removal may be focused on carcasses of animals ranging in mass from roughly 15 kg (such as a mid-size pronghorn [*Antilocapra americana*]) to 300 kg (male elk [*Cervus elaphus*]), because these moderate- to large-sized carcasses persist for long periods (3–23 days). The chance that an eagle at a roadside carcass will be struck by a vehicle increases with carcass persistence, although many other factors influence this probability (Grubb and others, 2018;

Lonsdorf and others, 2018), and vulnerability of Golden and Bald eagles possibly differ. Elk carcasses monitored by Grubb and others (2018) were consumed by scavengers in 11.9 days (range=3–41), on average, versus 3.0 (range=3–12) and 5.5 (range=2–4) days for carcasses of American pronghorn and mule deer (*Odocoileus hemionus*), respectively. Elk carcasses were consumed faster when partially cut open and made more accessible; if fully skinned, they were rapidly consumed by a broad host of scavengers. Grubb and others (2018) recommended that carcasses be removed entirely from road rights-of-way and ideally moved to open areas with little human activity, both to minimize the risk of eagle-vehicle collisions and to hasten consumption (and thus availability) of carcasses by scavengers. Complete removal of carcasses, however, may be impractical in many cases. Based on documented responses of Golden Eagles to traffic when at carcasses, Slater and others (2022) recommended moving carcasses at least 12 m from roads, acknowledging that right-of-way fencing, property boundaries, and other factors may limit the distance carcasses can be moved. Regardless, carrion is important to Golden Eagles during winter, when little prey may be available, and Slater and others (2022) recommended that carcasses should be relocated by whatever means rather than disposing or completely removing them.

The total number of vehicle-animal collisions (and potential for Golden Eagle-vehicle collisions) associated with some long (for example, 1–10 km) roadway segments can be reduced by installing tall fences along edges of rights-of-way, on both sides of roads (McCollister and van Manen, 2010). Underpasses and overpasses can be constructed to allow terrestrial wildlife to move from one side of a highway to the other (McCollister and van Manen, 2010). Benefits of these measures for wildlife would extend beyond eagles. Other means of reducing the incidence of carcasses on roads include dedicated signage, especially signs with lights that flash between evening and early morning or during seasonal migrations of big game, prompting drivers to reduce vehicle speeds and increase their vigilance (Sullivan and others, 2004). Electronic systems have been developed to detect the approach of large animals to roadway areas and alert drivers well before they reach the areas (Nandutu and others, 2022).

Reducing the incidences of collisions of Golden Eagles with various types of utility lines, wires, cables, and wire fences is challenging because, for this wide-ranging species, locations of such collisions are unpredictable and widespread such that isolated mortalities may not merit mitigation (Harness and others, 2003). Exceptions that could merit mitigation include funnels in topography, such as narrow canyons, valleys, or draws (mainly, risk in local movements), or mountain passes (mainly, risk during migration). In these situations, Harness and others (2003) recommended making utility lines more conspicuous to raptors by marking them with avian flight diverters (for example, Janss and Ferrer, 1998). In open, fenced areas with concentrations of prey, Golden Eagle collisions with barbed-wire fences for livestock could be reduced by adding markers, as has been done successfully for Greater Sage-Grouse (Stevens and others, 2012; Van Lanen and others, 2017). To prevent injuries and mortalities associated with fence collisions by raptors and other wildlife, van der Leek and others (2020) recommended removal of barbed-wire fencing wherever feasible and performing regular fence maintenance, in addition to fence marking.

Incidences of collisions by Golden Eagles with turbine blades at wind-energy projects can be difficult to stop once projects become operational. Some losses might be offset by decreasing unrelated human-caused mortality among Golden Eagles elsewhere, if the relative effectiveness of such actions can be quantitatively verified (FWS, 2013). However, avoiding or minimizing risk via preconstruction planning is crucial, starting with plans for siting of the entire wind-energy projects and of turbines within projects to avoid areas used by Golden Eagles. The FWS's (2013) Eagle Conservation Plan Guidance details measures for siting, constructing, and operating wind-energy projects in ways that are consistent with regulations under the BGEPA, including the preservation standard, which provides the Secretary of the U.S. Department of the Interior with the authority to issue eagle take permits only when the take is compatible with the preservation of each eagle species and is consistent with the goal of stable or increasing breeding populations. Although compliance with the Eagle Conservation Plan Guidance is voluntary, the plan can help wind-project developers minimize incidental take of eagles and provide site-specific recommendations that support applications for eagle incidental take permits (FWS, 2013). Permits for incidental take of eagles are not required for wind projects; mitigation can be implemented if unpermitted take occurs but then a permit for take is required and is likely accompanied by a penalty that leads to additional mitigation.

As part of preconstruction surveys to assess potential risk presented by a proposed wind project, the FWS recommends surveying for nests of Golden and Bald eagles within at least 3.2 km of the proposed project's footprint, which is defined as a minimum convex polygon that encompasses the entire project area (FWS, 2013). This 3.2-km recommendation was issued in 2020 (FWS, 2020) and supersedes the recommendation of 16.1 km in FWS (2013). Second, at least 2 years of surveys of eagle activity time on a proposed project footprint are recommended to support an estimate of eagle exposure to the total rotor-swept area (that is, total square meters covered by spinning blades) of proposed turbines; fixed-radius (800 m) point-count surveys (Ralph and others, 1993) are the recommended survey method. Third, focused surveys are recommended to identify possible eagle concentration areas such as roost sites or to account for migration activity. Fatality rate can be estimated using Bayesian models to predict fatality based on exposure (in terms of eagle minutes from point-count surveys) and collision probability based on published studies (New and others, 2015, 2020). A higher fatality rate estimate might be lowered by not siting turbines in areas of projects that contribute high levels of exposure to the estimate. In the end, the level of risk of a proposed project is categorized by the FWS (2013). Projects categorized as high risk have low potential to avoid or mitigate negative effects on eagles based on high estimates of fatality, especially if the losses cause estimated sustainable take from the local-area population to be exceeded, or if there is an important eagle-use area or migration concentration site within the proposed project footprint (FWS, 2013). A local-area population is that consisting of Golden Eagles within 175 km of a given site of interest; 175 km is the 90th quantile value in the distribution of published natal dispersal distances (Millsap and others, 2014; FWS, 2016a). Take is managed at this scale to avoid small-scale declines that could be triggered when the population-rescue effect provided by incoming dispersers is significantly diminished by excessive mortality (FWS, 2016a). Improved estimates of fatalities enable a better assessment of an individual facility's risk and can potentially reduce the need for mitigation while still protecting Golden Eagles (New and others, 2020).

The FWS (2013) recommended development of an Eagle Conservation Plan to accompany applications for eagle take permits. These plans outline measures to avoid and minimize risk via options for siting and operating turbines, thus complying with regulatory requirements anticipated in permits. Compensatory mitigation actions to offset eagle mortality caused by collisions with wind-turbine blades have been difficult to recommend, mainly because of challenges in quantifying the effectiveness of such actions (Allison and others, 2017; Mojica and others, 2018). To date, retrofitting of power poles to save Golden Eagles from electrocution has been the only satisfactory approach in the western United States. Examples of potential alternate approaches to offsetting blade-strike losses of Golden Eagles at wind-energy projects include removal of animal carcasses from roads to reduce eagle-vehicle collisions (Tetra Tech, Inc., 2012; Lonsdorf and others, 2018); reducing risk of lead toxicosis by use of nontoxic alternatives to lead ammunition for big-game hunting and by removal of gut piles of big game killed by lead ammunition (Cochrane and others, 2015; Allison and others, 2017); and boosting prey populations to increase Golden Eagle productivity and survival (Allison and others, 2017).

Hunt and Watson (2016) reviewed and synthesized factors that tend to place Golden Eagles and other raptor species close to wind turbines, creating potential for raptor mortality. The authors indicated that attention should be given in the placement of wind-energy projects, including considerations related to prey abundance, nest sites, perches, and updrafts. The authors made six recommendations for minimizing the potential for raptor mortality. One recommendation was to design turbines that pose less risk. Hunt and Watson (2016) do not elaborate on this idea, but a simple example of design change is painting one of three blades on a turbine black to minimize "motion smear" to facilitate earlier detection of blades by approaching birds. At a 68-turbine wind-energy project in Norway, this measure reduced overall bird mortality by 71 percent (May and others, 2020); mortality among raptors, including White-tailed Eagles (*Haliaeetus albicilla*), was particularly reduced. Bladeless wind turbines, which pose little risk to birds, are an example of a major design shift that may vastly reduce bird mortality risk, but they currently are not as efficient in generating electricity when compared with standard, horizontal-axis turbines (Bardakjian and others, 2017). Fatalities of Golden Eagles and other raptor species at APWRA have been reduced by replacing smaller, older generation turbines with larger, more efficient, more widely spaced turbines that pose lower collision risk per megawatt produced (Smallwood and Karas, 2009; Smallwood, 2017). Given that Golden Eagles never perched on operating wind turbines at APWRA, Smallwood and others (2009b) recommended removing vacant wind towers, repairing broken towers, and synchronizing turbine operations within a row to reduce hazardous use of the rotor zone and bird collisions. The authors also recommended leaving large gaps between groups of turbines to allow birds to travel and forage without having to fly close to wind turbines.

Further recommendations by Hunt and Watson (2016, p. 93) included making habitat less attractive to Golden Eagles and other raptors at established wind-energy projects with high levels of raptor mortality because, as the authors stated, raptors "…are distributed largely in accordance with the distribution of prey (or carrion) and the physical circumstance that contribute to its acquisition (Newton 1979, 1998)." Nest sites, perches, and propensity for orographic or thermal uplift also influence raptor prevalence. The preferred alternative to making habitat unattractive to raptors is to not develop wind-energy projects in high-quality raptor habitat (Hunt and Watson, 2016). Hunt and Watson (2016) noted that overlooking the abundance of prey, especially California ground squirrels (*Otospermophilus beecheyi*), was a major error in the decision to develop wind-energy projects at the Altamont Pass in California, leading to blade-strike deaths of dozens of Golden Eagles annually. Using Golden Eagle nest models for Wyoming, Tack and Fedy (2015) predicted that areas of potential wind-energy development were not necessarily correlated spatially with Golden Eagle nesting habitat. Although their model could provide a general framework for assessing potential development, they recommended on-the-ground assessment of potential risk of wind-energy development on Golden Eagles and other wildlife.

Ideally, the operation of specific wind turbines can be stopped immediately when Golden Eagles or other bird species of special concern approach, which is a procedure known as informed curtailment (McClure and others, 2021). This procedure has been executed by positioning human observers in towers or on vantage points in landscapes, each of whom can directly halt operation of selected hazardous turbines or communicate with a facility manager who can do so, as described in de Lucas and others (2012); however, effectiveness of this approach has varied (Allison and others, 2017). For example, the mortality rate of Griffon Vultures (*Gyps fulvus*) in Spain was reduced by 50 percent, while energy production was reduced by 0.07 percent annually (de Lucas and others, 2012). Evidence from studies by McClure and others (2021, 2022) indicated that automated technology may substantially advance informed curtailment to reduce losses of eagles due to turbine collisions at wind-energy projects. At a Wyoming wind-energy project where automated curtailment was used, the annual rate of eagle fatalities declined by 2.85 eagles per year, yet fatalities concurrently increased by 2.26 eagles per year at a nearby project used as a control site where no curtailment measures were used (McClure and others, 2021, 2022). Total fatalities of eagles at the project with automated curtailment were reduced by 85 percent. McClure and others (2021) conveyed that the automated technology should be used only in combination with other onsite mitigation measures and after first foregoing development in what appear to be high-risk areas, but they acknowledged that use of the technology seems justified in situations where preconstruction surveys had underestimated risk to Golden Eagles and high levels of postconstruction mortality occur.

Poisoning—Lead Toxicosis

Among major sources of anthropogenic mortality for Golden Eagles, lead poisoning may be among the least complex in terms of underlying physical and biological mechanisms but may be the most difficult to abate from a sociopolitical perspective (Shields, 2022). Lead poisoning of wildlife in general persists because of public misconceptions, misinformation, and inadequate legislation banning the use of lead ammunition, including on the National Wildlife Refuge system (Shields, 2022); however, it cannot be used for most forms of hunting in California, and bans of lead ammunition for all hunting are being considered in Minnesota (State of Minnesota, 2021) and New York (State of New York, 2021).

As Golden and others (2016, p. 178) succinctly concluded, “Lead can be replaced in ammunition by alternative metals that are currently available and present limited environmental threats. Scientific literature shows spent lead ammunition to be the primary pathway for widespread lead exposure to scavenging birds in the United States.” Lessons learned from the transition of traditional lead shot to nontoxic (mainly steel) shot for hunting waterfowl should be valuable in this regard (Friend and others, 2009). A Federal ban on use of lead shot for waterfowl hunting was initiated in 1986 by the FWS (1986) and became nationwide in scope by 1991; a detailed chronology of the transition is presented by Friend and others (2009). Canada similarly established a nationwide ban on the use of lead shot for the hunting of waterfowl and several other species of migratory gamebirds in 1999 (Stevenson and others, 2005). Hunters’ concerns about efficacy of steel shot were allayed by early peer-reviewed studies that demonstrated generally comparable effectiveness of lead and steel shot for harvesting waterfowl, despite some differences in ballistics and shot patterning (Friend and others, 2009). For example, Humburg and others (1982) found no differences between lead and steel shot in numbers of ducks bagged and shots missed per 100 shots fired by hunters, or in crippling rates of ducks. Mikula and others (1977) found similar results with the exception that lead shot was more effective at shooting distances >32 m. The Cooperative Lead Poisoning Control Information Program was formed in 1974 to work with States to facilitate broader use of steel shot and thus diminish involvement by the FWS in the process (Roster, 1983). Programs to educate the public about lead poisoning of waterfowl and the values of nontoxic shot met with mixed success initially, but improvements in steel shot’s performance and availability, plus lowered costs, eventually helped further the transition to nontoxic shot (Friend and others, 2009).

Despite extensive efforts by primarily nongovernment conservation organizations, there has been little success in North America to effectively transition to wholesale use of nonlead ammunition for hunting other animals, due mainly to societal factors that slowed the change to nontoxic shot for waterfowl (Friend and others, 2009). In this vein, big-game animals shot by hunters, in particular, are primary potential sources of lead consumed by Golden Eagles. Relevant here are findings by Bedrosian and others (2012), who reported that the incidence of lead poisoning among Bald Eagles during the big-game hunting season in Wyoming decreased as the percentage of successful hunters using nonlead ammunition increased. Copper bullets are a nontoxic alternative with equally effective ballistics for big-game hunting (Knott and others, 2009; Kanstrup and others, 2016). Since 2007, Arizona Game and Fish Department has provided free, nonlead ammunition for big-game hunting within the area of the State that overlaps a core foraging range of the California Condor (*Gymnogyps californianus*) (Sullivan and others, 2007; Sieg and others, 2009; Arizona Game and Fish Department, 2019), because lead toxicosis incurred through scavenging of lead-contaminated carcasses is the primary factor limiting recovery of this Federally endangered species (Pattee and others, 1990). Hunter compliance in Arizona has exceeded 80 percent annually (Sieg and others, 2009). Meanwhile, big-game hunters who continue to use lead ammunition have been encouraged to reduce potential lead exposure by removing gut piles (that is, internal organs plus other parts of animals typically not retained by hunters) of harvested animals from the field; incentives for doing so have included raffle tickets for sporting goods. In the program’s initial year (2007), 62 percent of successful hunters in Arizona used nonlead ammunition, and 21 percent used lead ammunition but removed gut piles; thus, hunters delivered an 83-percent reduction in lead exposure (Sieg and others, 2009). These efforts to reduce exposure to lead continue and likely benefit coexisting Golden Eagles as they commonly reside in, disperse or migrate through, and overwinter in the State (Murphy and others, 2017; Glinski, 2021). The Utah Division of Wildlife Resources (2021) established a similar program in 2011. Cochrane and others (2015) developed a model to predict effectiveness of voluntary use of nonlead rifle ammunition and gut-pile removal in reducing incidence of lead toxicosis among Golden Eagles in Wyoming. The authors estimated that without these mitigating measures, 3.2 percent of the State population of Golden Eagles would die annually from ingesting lead during a 1-month big-game hunting season, although their estimate bore much uncertainty.

Recommendations for reducing or eliminating lead ammunition for hunting have been reiterated many times in the published literature. Authors of a recent paper on prevalence of lead detected among Golden Eagles migrating in Montana repeated a simple but key theme: Government wildlife agencies, nongovernment conservation organizations, and hunting groups should conduct outreach programs to encourage hunters to voluntarily substitute nontoxic forms of ammunition for lead ammunition (Domenech and others, 2021). Friend and others (2009) presented a three-legged stool approach, requiring equal investment in biological, socioeconomic, and legislative actions for addressing lead poisoning of wildlife, and laid out the most essential considerations for developing biological justifications for abating lead. Cromie and others (2019) outlined a comprehensive route for transitioning from traditional lead ammunition to nontoxic alternatives. Their plan included the following steps: (1) creating urgency, (2) building coalitions, (3) creating a vision for change, (4) communicating that vision, (5) removing barriers to enable action, (6) creating short-term or geospatial wins, (7) building on the change, and (8) embedding change in culture and regulation. Sustainability of hunting was listed as a value that most stakeholders identified with, and potential for negative human health impacts stemming from exposure to lead ammunition was integral in generating broad engagement. Barriers enabling action proved to be the most challenging step. These generally included disbelief by hunters that a problem exists and their dislike of alternatives; lobbying by a formidable industry (stemming in part from concern over economic implications); lack of or inadequate policy action; and stumbling blocks in trying to change behaviors (Cromie and others, 2019). Clearly, Golden Eagles would benefit from the development of far-reaching public engagement in resolving this issue for a broad scope of concerns. A compendium of papers focused on risks of lead ammunition to human and environmental health in Europe (Delahay and Spray, 2015) lends strong support for such an approach.

Poisoning—Rodenticides and Other

The extent of exposure of Golden Eagles and other raptors to rodenticides is tied mostly to the behavior of users of rodenticide baits, with problems stemming mainly from inappropriate placement and subsequent mismanagement (for example, not removing and burying poisoned rodents daily). Tosh and others (2011) found that farmers using ARs in the United Kingdom poorly adhered to label restrictions even though they had received best-practices guidelines and generally had some awareness of potential for poisoning of nontarget wildlife. The farmers seldom checked or covered bait stations and rarely searched for and removed carcasses of poisoned rodents. Tosh and others (2011) concluded that this behavior occurred mostly because farmers lacked time, and the authors recommended stronger efforts to improve awareness but particularly to demonstrate how best practices can be applied more efficiently, yielding increased financial benefits for farmers. In the Great Plains of southern Saskatchewan, Proulx (2011) recommended use of an integrated pest control program to control Richardson's ground squirrels in ways that reduce risk of secondary poisoning of wildlife, rather than continuing widespread use of strychnine and the AR chlorophacinone. Such a program would involve farmers, conservation groups, Government agencies, and professional wildlife managers in developing and implementing monitoring and preventive measures, and integrating mechanical, physiological, biological, and chemical control methods. On Thunder Basin National Grassland in Wyoming, a detailed comprehensive plan for the conservation and management of black-tailed prairie dogs included use of certified ARs but in only very limited situations after other options, such as translocation, are exhausted as described in a decision tree (U.S. Forest Service, 2015). To protect migratory birds and the U.S. Forest Service's sensitive species that are associated with prairie dog colonies, lethal control may be restricted by including timing limits, partial control of a prairie dog colony, reduction in prairie dog density rather than complete removal, and combined use of nonlethal and lethal tools. Expansion of colonies onto adjoining privately owned lands or within 1.6 km of residences are examples where lethal control may be used after all other options have been exhausted (U.S. Forest Service, 2015).

Stone and others (1999) warned against using physiologically persistent ARs, especially brodifacoum, if exposures to wildlife are likely to occur. Instead, warfarin or other nonpersistent ARs should be used unless resistance to these is evident in involved locations (Stone and others, 1999). To reduce primary exposure of wildlife to ARs, van den Brink and others (2018) recommended (in addition to protecting baits) using pulsed baiting (that is, placement of AR bait in an infested area and allowing bait to be consumed and rodents to die before rebaiting [pulse]) instead of perpetual baiting; not initiating baiting until a rodent infestation begins; limiting use by nonprofessionals; and not using ARs in areas where potential nontarget wildlife is abundant. However, the authors pointed out that reduced primary exposure does not necessarily lead to reduced secondary exposure. For the latter, integrated pest management is recommended, founded on nonchemical control, strategic habitat management, and use of lure crops and supplemental feeding in farmlands. van den Brink and others (2018) noted that integrated pest management approaches can be difficult to develop because of misconceptions regarding its efficacy (for example, that it is too expensive, time-demanding, and generally ineffective). The authors recommended that integrated pest management should be incentivized by communicating risks posed by ARs to wildlife and the likelihood that pest rodents will develop resistance to ARs. Lastly, van den Brink and others (2018) recommended improving knowledge of the effects of sublethal secondary poisoning, such as influences on survival and productivity; without improved knowledge, regulatory and mitigation actions to control use of ARs are difficult to defend.

Golden Eagles can be killed via secondary poisoning from sodium pentobarbital, consumed while scavenging on domestic livestock that had been euthanized with the drug (Wells and others, 2020). Burial has been a recommended means of disposing of carcasses, but such carcasses are sometimes unearthed by various animals and subsequently poison scavengers, including Golden and Bald eagles (Russell and Franson, 2014). In a review of secondary pentobarbital poisoning, Wells and others (2020) summarized the state of knowledge on carcass disposal methods and conveyed that the FWS (reference not provided) recommended burial depth of at least 1–2 m. The authors also stated that incineration (not simply burning) may be a better way of disposing carcasses of animals euthanized via sodium pentobarbital. Regardless, immediate disposal of contaminated carcasses is recommended, and improper disposal may result in wildlife mortality events (Wells and others, 2020).

Shooting

Shooting is a pervasive source of Golden Eagle mortality in the western United States despite legal protections developed under State statutes and the Federal BGEPA (Katzner and others, 2020b; Millsap and others, 2022). Causes and motives behind the shootings are myriad, such that a multifaceted strategy is merited (Madden and others, 2019). First, conservation agencies and organizations could expand efforts to educate the public on the biology, societal value, and cultural and ecological importance of Golden Eagles (Parry-Jones and others, 2007). Another step is to increase numbers of law enforcement personnel or reprioritize tasks of extant personnel (Morse, 1973) to enhance vigilance and investigate shootings of Golden Eagles and other protected bird species. This step also could include use of eagle decoys and advanced, technological surveillance methodologies such as drones, which have been used as an antipoaching tactic for protecting other wildlife (Mulero-Pázmány and others, 2014). Lastly, agencies and organizations can take some practical steps to improve the effectiveness of programs to reward persons who provide information that assists law enforcement and help elevate prosecution rates (under the BGEPA, rewards of up to $2,500 can be paid to persons who provide information leading to convictions of violators [26 U.S.C § 668a]). Although other possible considerations, such as increased prosecutorial discretion and prosecution rates and increased fines and lengths of incarceration for prosecutions, are beyond the scope of this document, Millsap and others (2022) suggested that biologists, law enforcement agents, and prosecutors consider that the biological effects of shooting Golden Eagles in the western United States cost between $10,275,200 and $25,688,000 annually, based on their estimate of annual mortality attributed to shooting and the current cost of offsetting the loss of a Golden Eagle via powerline retrofitting ($15,200–$38,000). Thus, societal costs of Golden Eagle shootings may be far greater than fines imposed.

On extensive conservation lands in southwestern Idaho, patterns of the illegal shooting of nongame wildlife documented by Katzner and others (2020a) may help wildlife law enforcement officers improve existing surveillance strategies to apprehend violators. The authors did not provide direct recommendations, but their observations can inform actions, especially law enforcement strategies, for conserving Golden Eagles in open landscapes. First, shootings of raptors (species not specified) were closely associated with powerlines and transmission lines near roads; it seemed that such shootings occurred opportunistically when the targets appeared conspicuously in the viewshed, while perching on poles and towers that supported lines (Katzner and others, 2020a). These opportunistic shooters seemed to be different people than recreational shooters, at least in part because the latter went to specific areas to shoot. Greatest levels of shooting occurred close to urban areas where high road densities overlapped high densities of distribution lines and ground squirrels (prey). Thus, distribution lines in these areas posed both risk of electrocution and shooting mortality (Katzner and others, 2020a).

Native Americans can obtain eagles and their parts in two ways (Smith, 2016). First, Native Americans can obtain eagles or their parts from the National Eagle Repository in Colorado. The supply of eagles and their parts at the repository is limited, and the repository does not fulfill the demand of many Tribes whose religious ceremonies require a pure eagle (that is, an eagle that has been taken with care and did not die through poison, disease, electrocution, or vehicle collision) (Smith, 2016). Requests for eagles or their parts may take several years to fulfill. Second, the FWS may issue a permit authorizing a Native American of a Federally recognized Tribe to take a Golden Eagle or a Bald Eagle for religious purposes. The application for this permit requires an individual to specify the species to be taken, the location of the take, the Tribe name, and the religious ceremony for which the eagle is to be used. The FWS has never issued a permit for take of a Golden Eagle to a Native American Tribe in the Rocky Mountain and Great Plains regions, but the agency has issued annual or periodic take permits for tribes of the Southwest (for example, the Hopi, Navajo, and Taos Pueblo Tribes; Smith, 2016). To lessen the possibility that eagles or their parts are acquired illegally by Tribal or non-Tribal members through shooting or other means, greater support may be needed to administer and operate the National Eagle Repository. An alternative, proposed by Kovacs (2013), is to amend the FWS regulations to allow issuance of permits for possession of eagle parts directly to Federally recognized Tribes instead of individual Tribal members and to recognize the importance of indigenous cultural property, community property, and Tribal self-determination in sustaining the eagle resource while satisfying religious and ceremonial needs of Tribes.

Incidental Trapping

Any eagle or other raptor captured in a leghold trap, especially if held in the trap overnight, should be considered seriously injured and submitted for veterinary examination and care (Durham, 1981; Martel and others, 1991). Eagles have survived after amputation of digits damaged by leghold traps (Martel and others, 1991), but an eagle with a foot amputation should not be released (Durham, 1981).

Less is known about the incidence of eagle injury and mortality resulting from incidental capture in snares. Vantassel and others (2010) reported advancements in snare design that reduce risks to nontarget animals by including breakaway devices and loop stops, which are changes that may make such snares more publicly acceptable compared to leghold traps. Relaxing snares have a device that allows the snare loop to loosen, releasing constriction pressure, when a captured animal stops pulling. However, it is unclear whether such improvements translate to decreased risk among eagles (Vantassel and others, 2010). Breakaway lock devices are designed to release snares when force is applied, such as when a large domestic dog (*Canis lupus familiaris*) is incidentally captured, but levels of force required are far greater than an eagle could exert; for example, snares used in Montana must release with more than 158.8 kg of pressure (Montana Fish, Wildlife and Parks, 2021)

The presence of exposed bait (sight bait or open bait), including carrion, is the underlying cause of incidental captures of Golden Eagles in traps and snares set for furbearers and predator control (Durham, 1981; Katzner and others, 2020b). The risk of incidental capture of Golden Eagles and other raptors in traps and snares can be minimized by placing exposed baits far away from traps or using lures instead of exposed baits (Durham, 1981). Trapping regulations in Great Plains States typically prohibit placement of exposed baits within specified distances of traps and snares, and some also stipulate a maximum size of bait allowed. Examples of allowable minimum distances in Great Plains States include 7.6 m in North Dakota (North Dakota Game and Fish Department, 2021) and 9.1 m in South Dakota (South Dakota Game, Fish and Parks, 2021). Bait size cannot exceed 57 grams in New Mexico (New Mexico Game and Fish Department, 2022) and 454 grams in Montana (Montana Fish, Wildlife and Parks, 2021).

Energy Development

The extent and rapid expansion of energy development in the Great Plains and shrubsteppe regions pose a complex challenge to the preservation of Golden Eagles and other biota that are already considered sensitive or vulnerable, threatened, and endangered (Copeland and others, 2011; Ott and others, 2021). The cumulative impact of energy development and other adverse landscape changes (for example, invasions by nonnative plant species, conversion of rural areas to residential areas, and climate change) is particularly challenging. Environmental impacts of energy development may be ameliorated through proactive planning that prompts stakeholders to avoid siting conflicts and develop appropriate mitigation actions to sustain biodiversity well before projects are initiated (Copeland and others, 2011; Ott and others, 2021). Kiesecker and others (2009) suggested that the impacts of energy development should, ideally, be offset by resource gains that are at least net neutral (that is, no net loss of resources of concern).

Environmental effects of mining in the United States are regulated by the Surface Mining Control and Reclamation Act (30 U.S.C. 1201 et seq.), which includes provisions that prevent or mitigate impacts of mining on Golden Eagles and other raptor species. To ensure compliance with Federal laws and regulations, before mining development begins, the proposed mining and reclamation operations must include a description of Golden and Bald eagle nests and prey areas within the affected area to minimize adverse impacts. Call (1979) emphasized the importance of educational programs to increase awareness among mine personnel of (1) the presence and basic life histories of eagles and other raptors likely to be encountered; (2) the protections for raptors per Federal and State laws; and (3) permitting considerations. Special concerns may range from potential effects of disturbance caused by extended operations or loud noise near nests during sensitive periods, to possible nest-site damage, injury, or death of raptors incidental to mine operations; spatial and temporal buffers can be used to avoid and minimize these and other negative impacts. Call (1979) specified that mining operations should be buffered by at least 0.8–1.6 km from nests in use by eagles, depending on amount of screening vegetation and terrain. Call (1979) also called attention to (1) the importance and protection of roost sites and foraging sites; (2) the potential for conflicts caused by an influx of new personnel or mine area recreationists not cognizant of raptor protection needs; (3) the need for flexibility in mine rehabilitation policies to permit highwalls or other possible nest-site habitat to be retained after mine operations are completed; and (4) avoiding all but the most essential road construction.

Reclaimed surface-mining lands in the western Great Plains and shrubsteppe, especially landscapes disturbed by strip-mining to extract coal, may provide habitat that could support prey of Golden Eagles even though vegetation on reclaimed areas may differ from predevelopment conditions and support a different prey community. On seven reclaimed coal surface mines in Wyoming, shrub cover averaged 11 percent 6 years after reclamation compared with 33 percent on undisturbed (that is, control) sites; annual forbs were prevalent initially but were replaced by perennial grasses (Parmenter and others, 1985). Vertebrate recolonization was rapid and correlated with shrub growth, but species diversity was lower than on control sites; black-tailed jackrabbits were among species that ultimately resided on reclaimed areas but shrub density apparently was too low for the area to support Uinta ground squirrels (*Urocitellus armatus*) (Parmenter and MacMahon, 1992). The authors concluded that flora and fauna of reclaimed areas and control areas were not very similar. Krzyszowska Waitkus (2022) provided a detailed case history of the reclamation of the largest surface coal mine in the United States, which is in northeastern Wyoming. Lands reclaimed after mining for coal in Wyoming must, by State law, have a shrub density of 1 shrub per m^2 on at least 20 percent of the area, resembling native shrubsteppe habitat that had been destroyed. Booth and others (1999) measured densities of shrubs that had been seeded on 14 reclaimed areas in three regions of Wyoming; seedings had been either perennial grasses with big sagebrush and fourwing saltbush or grasses with only fourwing saltbush. Ten to 15 years after seedings, shrub density and composition generally reflected the species seeded. When big sagebrush was part of the seeding mixture, seeding rates between 60 and 1,000 shrub seeds per m^2 exhibited a positive, linear relationship with shrub density up to 0.6 shrub per m^2. Booth and others (1999) recommended planting diverse mixes of shrubs at high seeding rates to reclaim shrubsteppe areas mined in Wyoming. Although these and other studies indicate that grass-shrub vegetation can be established on reclaimed surface mines in western landscapes inhabited by Golden Eagles, there apparently is little published information indicating that local abundances of key prey of Golden Eagles are restored.

Golden Eagle nests containing nestlings have been moved successfully from areas actively being mined for coal to more secure sites (Postovit and others, 1982; Fala and others, 1985). After a Golden Eagle nest near coal-mining operations in Wyoming blew down from a tree while containing a nestling, Postovit and others (1982) moved the nest to a platform 2.5 km away by shifting the nest up to 1,375 m from one temporary nest platform to another, with 6–10 days between moves. They used 500 hours of visual and telemetry observations collected before moving the nest to identify a well-used area within the pair's home range to which to move the nest; the young eagle ultimately fledged. Golden Eagle nests also have been relocated from mine highwalls (Fala and others, 1985).

As with other forms of energy development, negative impacts of oil and gas development on wildlife habitat in the Great Plains generally can be minimized by incorporating comprehensive site assessments and conservation provisions into the development planning process to target areas of relatively low ecological value for development (Ott and others, 2021). Higher quality habitat should be distinguished and, ideally, either avoided through development permitting processes or required through permitting to incorporate planning and implementation of comprehensive mitigation (Ott and others, 2021). Plans for minimizing disturbance to eagles should consider potential for impacts from seismic surveys during early exploration. Without careful planning, new roads for gas and oil-well access can quickly become extensive and negatively affect Golden Eagles (Smith and others, 2010); to reduce disturbance and potential for persecution of eagles, roads should be closed to vehicle use by the public when wells are decommissioned (Bedrosian and others, 2019). Reducing disturbances associated with roads is especially important as access roads to oil and gas wells have increased considerably in association with new advances in hydraulic fracturing and horizontal drilling (Thompson and others, 2015). During initial drilling, a well site can cover several hectares with equipment, supplies, and mud and settling pits around the drill pad, although this site footprint can be much reduced soon after drilling begins (Kroepsch, 2018). Wherever possible, Thompson and others (2015) and Preston and Kim (2016) recommended that multiple wells should be drilled from a common pad via horizontal drilling methods, reducing fragmentation caused by scattered pads and the associated access roads and power lines. Brine disposal and oil waste pits associated with oil and gas development can attract and kill wildlife, possibly including eagles, but open pits are now illegal or require protective coverings in several Great Plains States (Ott and others, 2021). To restore habitat for Golden Eagles after oil and gas extraction has ceased, waste pits should be removed and the sites reclaimed as part of orphaned-well remediation.

Copeland and others (2009) published a spatially explicit predictive map of oil and gas development across the western United States to help support conservation planning for sensitive species of wildlife, using the Greater Sage-Grouse as an example. In the Great Plains, significant development was predicted to occur from parts of north-central Montana to southwestern North Dakota, northeastern Wyoming, northeastern and south-central Colorado, and southeastern New Mexico; Texas was not included, but development in the Permian Basin of southeastern New Mexico likely would extend into the adjoining area of Texas (Copeland and others, 2009). To support an ecoregional conservation strategy for Golden Eagles in the Northwestern Plains Ecoregion, approximating the northern Great Plains, Bedrosian and others (2019) created a more refined, detailed, and updated predictive map of Golden Eagle risk to oil and gas development, using models for both winter and breeding seasons and identifying detailed, area-specific risk potential along a gradient from low to high. Risk was defined as the combination of hazard, exposure, and vulnerability. Across the region, 54,358 wells were active as of 2016; 40.9 percent were in a very-high risk category, and 73.8 percent were in a moderate-to-very-high category of risk for breeding-habitat. Percentages of Golden Eagle winter habitat in the highest-risk and moderate-to-very-high risk categories were 27.9 and 65.1 percent, respectively. Highest risk of development to breeding eagles was in the Powder River Basin of northeastern Wyoming. Great risk also was within and near the Little Missouri Grasslands of North Dakota and Cedar Creek basin of eastern Montana and western North Dakota. Some high development areas such as parts of north-central to northeastern Montana did not overlap large areas of high-quality breeding habitat for Golden Eagles (Bedrosian and others, 2019). Development risk by land ownership was private lands, 66.1 percent and 68.2 percent for breeding and winter seasons; Tribal lands, 14.0 and 8.7 percent; U.S. Bureau of Land Management, 7.3 and 7.8 percent; State and local governments, 5.3 and 6.9 percent; and U.S. Forest Service, 4.7

and 6.0 percent. Risk on private lands was proportional to land area but was greater than expected on all Government-owned lands except Tribal lands.

In contrast to coal mining, oil and gas development in the Great Plains is likely to increase in extent, and production in currently developed areas may increase via advanced hydraulic fracturing and horizontal drilling methods (Thompson and others, 2015; Kroepsch, 2018; Bedrosian and others, 2019). The best means of avoiding impacts to nesting, wintering, and migrating Golden Eagles may be to try focusing development on habitat of modest quality for eagles; development could be focused more on energy corridors and siting wells in areas previously altered by human activity (Preston and Kim, 2016), although Wallace and others (2019) acknowledged that the presence of Golden Eagle habitat is unlikely to influence broad-scale siting of fossil-fuel development in general. Instead, mitigation of impacts is more likely to succeed if focused on the design and configuration of developments including minimization and strategic placement of powerlines, roads, and oil pits as well as pumping infrastructure. Construction of new infrastructure in energy fields is an opportunity for agencies to require best management practices, like covering oil pits with netting and minimizing the extent of oil pads and roads, although no-surface occupancy buffers are required in many Government agency plans (Wallace and others, 2019).

Wind-energy development is a concern for the conservation of landscapes used by Golden Eagles in the western United States, including in the Great Plains. Although much attention has been given to the direct impacts of wind-energy development on Golden Eagles and other wildlife (see “Collisions” subsection), a greater understanding of indirect impacts (including habitat alteration) is needed to improve avoidance and mitigation measures and create robust impact assessments (Katzner and others, 2013). Displacement of Golden Eagles from landscapes could pose a more significant threat than direct mortality, as Fielding and others (2006) considered in Scotland. For wind energy and other forms of renewable energy, greater investment is needed in refining best management practices to conserve wildlife in general. Katzner and others (2013) recommended testing the assumption that renewable-energy development causes less ecological harm than fossil-fuel use and examining the full suite of scenarios under which this assumption can and cannot be met. Sandhu and others (2022) developed a predictive model for turbine-scale simulation of Golden Eagle movements that offers a generalizable, probabilistic, and predictive tool to assist in estimating the potential for conflict between soaring Golden Eagles and wind turbines, thereby reducing the need for site-specific data on Golden Eagle movements.

Utility-scale, solar photovoltaic projects have been developed across landscapes used by Golden Eagles, mainly in the southwestern United States (Copeland and others, 2011), but the southern Great Plains presents much opportunity for its development (Braham and others, 2015; Sengupta and others, 2018; Smith and others, 2020). Braham and others (2015) suggested that general knowledge of space use by Golden Eagles can serve a reasonable proxy for preconstruction surveys for evaluating potential effects from solar and other forms of renewable-energy development. Particular consideration should be given to patterns of increased ranging behavior that Golden Eagles may exhibit outside of the breeding season and that nonbreeding Golden Eagles may exhibit in general; resource managers should be aware that the eagle’s use of habitat can be complex and standard buffers used to protect eagles may be insufficient (Braham and others, 2015). As Braham and others (2015, p. 230) simply stated, “the more space that an individual eagle uses, the more likely it is to encounter renewable energy projects.” Management for species such as Golden Eagles that may regularly use solar-energy areas lacking protective conservation measures can be improved by developing and implementing range-wide conservation plans that call attention to jurisdictional boundaries and mitigate for use of space beyond these (Braham and others, 2015). In parts of the Great Plains and nearby shrubsteppe where much solar-energy development is anticipated, some lands that are used for livestock grazing and that also provide habitat for Golden Eagles may one day support utility-scale solar-energy development that accommodates increased biodiversity while remaining compatible with livestock grazing, as Nordberg and others (2021) envisioned for Australia; however, benefits of such changes to Golden Eagles are unclear.

Other Land-Use Changes

Golden Eagles prefer to nest far from human activity, including urban and suburban development (Kochert and others, 1999; McIntyre, 2004). Urbanization impacts the availability and suitability of nest sites and prey habitat (Losee, 2019). Along the western edge of the Rocky Mountains, Berry and others (1998) recommended protecting Golden Eagles and other diurnal raptors from the expansion of urban and suburban development. Cooper and others (2021) indicated a need for multidecadal studies that incorporate historical and contemporary nesting observations to better understand how the Golden Eagle’s tolerance of urban development has changed over time. When planning and developing lands beyond the urban fringe, White and others (2018) emphasized the importance of considering ecosystem and societal services that raptors provide.

Eagle-aircraft collisions at airports may be reduced by nonlethal hazing with pyrotechnics, reducing vegetation cover for prey by mowing or herbicides, or installing perch deterrents (Sodhi, 2002; Washburn and others, 2015). Capture and translocation of Golden Eagles from airports may alleviate the risk of collision but perhaps only temporarily. For example, a subadult male Golden Eagle that was captured at Colorado’s Denver International Airport was fitted with a satellite transmitter and then released about 200 km north of the airport in Wyoming in September 2014 (B. Massey and B. Allen, U.S. Department of Agriculture, Wildlife Services, Denver, Colo., written commun., August 20, 2022). The eagle returned to the airport in July 2018 and then resided there intermittently despite efforts by the U.S. Department of Agriculture's Wildlife Services to reduce availability of prey in the area. Perch deterrents had been installed by the airport, but the eagle often perched and roosted on communication towers and navigation aids to within 300 m of runways (R. Murphy, personal obs., April 21, 2021). More research is needed to improve strategies for reducing eagle collisions with aircraft (Washburn and others, 2015).

Military training activities can have direct short-term effects and indirect long-term effects on Golden Eagles and other raptors (U.S. Department of the Interior, 1996). The U.S. Department of the Interior (1996) indicated that management recommendations for lands that include military training activities should consider conserving existing native vegetation, reversing increasing dominance of nonnative vegetation, rehabilitating deteriorated areas, and minimizing disturbance to vegetation, prey, and Golden Eagles and other raptors. Grubb and others (2010) reported that heli-skiing and military helicopter operations did not negatively impact nesting Golden Eagles in northern Utah. The authors recommended caution in applying recommendations elsewhere without first considering circumstance-specific characteristics of any situation, including the type, level, and frequency of the anthropogenic activity; the effects of intervening topography and vegetation; potential habituation by Golden Eagles to existing activities; and local density and distribution of Golden Eagles. Grubb and others (2010), however, urged managers to not ignore results that are inconsistent with expectations; ignoring scientifically valid results undermines the integrity of natural resources management and may result in the resource (in this case, Golden Eagles) being more vulnerable to future threats.

Bubonic plague plays a critical role in regulating the presence of prairie dog populations (Barnes, 1993; Bedrosian and others, 2019). To control fleas in prairie dog colonies, Barnes (1993) recommended dusting of burrows with an acceptable and effective pulicide (flea-killing agent). In high-quality Golden Eagle habitat, Bedrosian and others (2019) recommended burrow dusting with the insecticide deltamethrin (a pyrethroid) to kill fleas or providing oral vaccinations against bubonic plague to prairie dogs to help reduce the extent of colony collapses.

Recreational Activity

Recreational activities may directly cause disturbance take (as defined in the BGEPA; Title 50 CFR § 22.6) of Golden Eagles, especially breeding pairs and their young, but such take often can be avoided or minimized by either completely banning access or by implementing spatial or temporal buffer zones around Golden Eagle nests within which activities are restricted, possibly for only certain periods (Suter and Joness, 1981; Steidl and others, 1993; Whitfield and others, 2008; Martin and others, 2011; Spaul and Heath, 2016, 2017). Buffer distance recommendations for Golden Eagles mainly come from expert opinions (Suter and Joness, 1981; Whitfield and others, 2008; Martin and others, 2011); published empirical data for buffer distances specifically for Golden Eagles may be limited to Spaul and Heath (2016, 2017). Given disturbance prohibitions under the BGEPA, experimental or manipulative research is nonexistent, although Grubb and others (2010) were able to test responses of Golden Eagles to helicopters used for heli-skiing as part of a Final Environmental Impact Statement's no-effect Record of Decision on this activity on Federal lands, and Steidl and others (1993) recommended an 800-m nest buffer based on observed responses of Golden Eagle pairs with nestlings to the investigators' campsites 400 or 800 m from nests in Alaska. Moreover, some buffer recommendations may not be specifically for mitigating recreation disturbance but can apply nonetheless, such as buffers for some construction activities (Suter and Joness, 1981). Information from other eagle species also can be helpful in refining recommendations for Golden Eagles; compared to Golden Eagles, recreation disturbance and its mitigation for Bald Eagles has been well-studied (Buehler, 2020).

Ideally, decisions on the size and configurations of spatial buffers to mitigate disturbance of eagles and wildlife in general are based on observations of distances and sometimes heights or angles at which the animals respond to disturbances by exhibiting either alert or alarm behavior (also termed vigilance or flight, respectively) (Knight and Skagen, 1988; Taylor and Knight, 2003; Gill, 2007). In canyons surrounded by shrubsteppe in southwestern Idaho, Spaul and Heath (2017) documented distances at which breeding Golden Eagles flushed from their nests in response to recreationists passing by in motor vehicles. Eagles flushed at greatest distances when recreationists stopped their vehicles and walked. Based on their data, Spaul and Heath (2017) indicated that a 650-m buffer from nest sites could reduce nest-flushing events prompted by these disturbances by 77 percent; 1,000-m buffers could reduce the events by 100 percent. The authors, however, recommended buffer distances from nest sites greater than 650 m to provide more protection for eagles early in the breeding season especially during nest initiation. Notably, use of no-stopping zones for vehicles on trails near Golden Eagle nests was recommended as a viable means of controlling disturbance (Spaul and Heath, 2017), based on observations that nest attendance by pairs declined as occurrence of pedestrians in nesting focal areas increased; 66 percent of the pedestrians arrived in trucks or sport utility vehicles and 30 percent arrived via off-road vehicles, whereas only 4 percent arrived on foot. No-stopping zones also were considered an acceptable alternative to complete closures of trails because recreationists may be more likely to comply with the former (Spaul and Heath, 2017).

Spaul and Heath (2016) used data from the same area to predict occupancy of territories, nest initiation, and nest survival defined as the probability of producing at least one nestling. Probability of territory occupancy was reduced by off-road vehicle traffic; probability of nest initiation was reduced by pedestrian activity early in the breeding season;

and nest survival probability decreased with sharp peaks in off-road vehicle use. Nest attendance was reduced by presence of pedestrians, most of whom arrived in motor vehicles. Canyons where eagles nested were esthetic landscape components, prompting recreationists to stop their vehicles and hike, thus reducing suitability of the habitat for eagles (Spaul and Heath, 2016). However, presence of camping areas, shooting areas, and trailheads did not influence occupancy and nest success, probably because these were static features to which eagles were habituated, whereas pedestrian use was irregular and pedestrian behavior was unpredictable (Spaul and Heath, 2016). Overall, the extent of pedestrian traffic was the most important negative influence on nest attendance. Pedestrians arrived near eagle nests in vehicles, indicating that human-eagle contacts are more likely as road and trail networks are increasingly developed to further recreation opportunities.

As of 2012, motor vehicles were excluded from only 4 percent of the 104 million ha entrusted to the U.S. Bureau of Land Management (Steenhof and others, 2014). Steenhof and others (2014) called for development and implementation of plans to better manage off-highway vehicle use throughout the Golden Eagle's range in the western United States. Such management should include seasonal trail closures, buffer zones around nests, and appropriately sited areas designated for staging off-highway vehicle recreation. Land managers also should establish and enforce adherence to refuge zones where off-highway vehicle use is to be prohibited or regulated in specified ways to protect Golden Eagles (Steenhof and others, 2014). More broadly, Spaul and Heath (2016) urged land managers to explicitly incorporate Golden Eagle habitat protection into plans for developing access for recreation in western landscapes that could be occupied by the Golden Eagles, and to regularly revisit and update such plans as human use of recreation areas continues to increase.

Relevant work in Spain by González and others (2006) to establish protective buffers around nests of the congeneric Spanish Imperial Eagle (*Aquila adalberti*) also was based on direct observations of behavioral responses to intrusions by campers, hunters, and ecotourists. A 500-m critical inner buffer zone and an 800-m vulnerable buffer zone were selected because reactions of the eagles increased sharply when the pedestrians were within 450 m of nests but became negligible when pedestrians were more than 800 m away. However, the authors recommended adjusting configurations of zones to protect nest sites that are highly visible (González and others, 2006).

Buffering isolated nests of Golden Eagle can be relatively straightforward, but nesting territories typically have two or more eagle nest structures, including one nest that is being used in a given breeding season and others that are considered alternative nests (Kochert and Steenhof, 2012; Millsap and others, 2015; Slater and others, 2017). For example, 28 Golden Eagle territories in Utah had a mean of 2.9 nests, with a range of one to eight (98 percent of all nests were on cliffs; Slater and others [2017]). On average, alternative nests were 0.5 km apart and each was used every 3.3 years. Conservation plans for breeding Golden Eagles often focus on one nest in a territory, typically one that was recently used or has been most often used, if known, in territories having more than one nest, but Kochert and Steenhof (2012) and Millsap and others (2015) emphasized the importance of protecting alternative Golden Eagle nests as well. Thus, if a spatial nest buffer of 1 km, for example, encompassed each nest in the average territory with multiple nests, the collective buffered areas would encompass a much larger area than needed for a single nest and would be configured far differently especially when considering that some individual nests may be spaced more than 2 km from others. Resource managers could decide to annually buffer all nests within a territory, which would greatly benefit the eagles because nearly all nests tend to be within the core areas of territories that are often used by the breeding pairs (Watson and others, 2014; Millsap and others, 2015). Such an approach also seems appealing because Golden Eagles are long-lived birds that reuse nests over years (Watson and others, 2014). However, resource managers must balance the needs of outdoor recreationists, in part because public support for natural resource conservation, including eagles, is positively influenced by contact with wild places (Martin and others, 2011). This need might be addressed to some extent by using temporal buffers that limit recreational use to the nonbreeding season, and to a greater extent by annually identifying and buffering the used nests in Golden Eagle territories with multiple alternative nests.

Martin and others (2011) used an adaptive management framework to balance restrictions on hiking near breeding Golden Eagles at Denali National Park, Alaska. Using a predictive model based on a combination 20 years of data from eagle nesting territories plus expert opinion, and accounting for model uncertainty, stochasticity, and imperfect detection of snowshoe hares (*Lepus americanus*), the authors found that Golden Eagle productivity markedly increased when hiking in their breeding territories was restricted. Detection of snowshoe hares was included as hares are the eagle's main prey in that region, especially just before and during incubation (McIntyre and Adams, 1999), and responses of Golden Eagle breeding pairs to recreational disturbance may be accentuated by low prey availability (Martin and others, 2011). Adaptive optimization based on several model alternatives for decision-making was used to manage hiking disturbance.

Based on results from simulation modeling, D'Acunto and others (2018) reported that managers should consider both trail density and the level of human recreation activity before implementing mitigation strategies to reduce exposure of nesting eagles to chronic disturbance by nature-based recreation. The simulation models provided evidence that managing the volume of human recreation, in addition to reducing the density of trails around occupied Golden Eagle nests, is important for reducing disturbance during incubation and increasing the likelihood of successful breeding (D'Acunto and others, 2018).

Most guidance for avoiding disturbance of Golden Eagles focuses on territorial pairs, especially during the breeding season. Preadult-aged eagles and adult-aged individuals that are not attached to territories, including floaters and overwintering adults from northern regions, have received relatively little attention in this arena. Also, as Golden Eagles seldom roost communally (Katzner and others, 2020b), disturbance at roosts is not a major concern for Golden Eagles but is a concern for Bald Eagles (Buehler, 2020). During winter in northern Colorado, Holmes and others (1993) observed that Golden Eagles more readily flushed from pedestrians than vehicles; mean flushing distances were 225 and 82 m, respectively. The authors suggested use of buffers around important foraging areas of overwintering raptors in general.

Various other disturbance buffers have been recommended for Golden Eagles, mostly based on expert opinion of distances at which disturbance occurs. For example, up to 24 experts in Suter and Joness (1981) estimated distances that sensitive Golden Eagles would react 20 percent of the time by flushing from or, in some cases, abandoning their nests in response to each of six categories of human disturbance activities. Experts also considered whether responses occurred during egg-laying, incubation, or brood-rearing periods, or during nest construction for some categories. For example, off-road vehicle traffic, defined as the passing of one noisy vehicle per hour, was believed to cause nest abandonment 20 percent of the time during the egg-laying period when it occurred at a distance of 457 m (median response from 15 experts; range=91–2,414 m). However, Suter and Joness (1981) considered that, during breeding season, an essential activity that involves few people who are present for only a few minutes, no less than 500 m from nests, and only during moderate temperatures might be acceptable; construction and other similarly noisy, extended activities should be kept at least 1 km away. Recommendations from four experts for Golden Eagle nest buffers ranged from 0.2 to 1.6 km line of sight; a 400-m buffer was recommended for prey concentration areas, such as ground squirrel colonies. Suter and Joness (1981) added that these recommendations are not absolute and could be modified based on expert knowledge. They also warned that buffer zones could attract humans who seek to closely examine or photograph nests, remove eggs or nestlings, or conduct on-site protests because buffers may impede some form of development.

Heights of nests on cliffs could influence responses of Golden Eagles to recreational disturbance caused by recreation and other activities. However, Spaul and Heath (2016) found no relationship between nest survival and heights of cliff nests (mean=34.8 m) or nest-to-trail heights between trails and cliff nests (mean=74.4 m). By comparison, territory occupancy rates of Golden Eagles breeding in an oil and gas field of Wyoming increased with height of cliff nests (range=5–30 m; table A.3 *in* Wallace [2014]). Rock-climbing would likely be a marked exception, however, as climbers create both visual and auditory disturbance close to nests (Richardson and Miller, 1997). Rock-climbing is an example of disturbance of cliff-nesting raptors that can be curtailed by temporal buffers covering all or at least the most sensitive part of the nesting season. For example, climbing within 800 m of Peregrine Falcon (*Falco peregrinus*) nests at Devil's Tower, Wyoming, was prohibited during February 1 through July 15 (S. Johnson, personal commun. *in* Richardson and Miller, 1997). Temporal buffers to protect Golden Eagles and other raptors from disturbances during the breeding season should encompass at least the courtship through the early nestling stages, considered by Newton (1979) to be the most sensitive period. Knowledge of regional nesting chronology is important when creating these temporal buffers. In the southern Great Plains, corresponding dates are mid-January through early May, based on the interquartile range of nest-initiation dates estimated by backdating from nestling ages at 17 nesting territories (Murphy and Stahlecker, 2022).

Fire

Prescribed fire often is used to help restore and maintain native prairie communities in the Great Plains, especially on lands set aside for conservation purposes. However, wildfires can cause significant habitat conversion and risk to Golden Eagles and other wildlife (Bedrosian and others, 2019). In the interest of Golden Eagle conservation, Bedrosian and others (2019) recommended evaluating current wildfire risk information and availability of fire-suppression crews and equipment in areas of interest. Fire-response plans by land-management entities should include maps of high-priority breeding habitat for Golden Eagles. Bedrosian and others (2019) examined wildfire risk to Golden Eagles across the Northwestern Plains Ecoregion, which approximates the northern Great Plains, by overlapping their models of Golden Eagle winter and breeding habitat with a probabilistic model of wildfire risk from the U.S. Forest Service (Short and others, 2016). The authors reported that current risk of large fires in the eagle's habitat is relatively low compared to other western ecoregions. Areas of the northern Great Plains where eagle habitats have high probabilities of fire and high fire intensity were identified. Overall, risk was fairly high for the best quality breeding habitat and winter habitat, which constituted 3.0 and 3.1 percent of the northern Great Plains area, respectively; 22.5 percent of breeding and 20.6 percent of summer habitat were in moderate-to-high risk categories (Bedrosian and others, 2019). Season-based fire risk among subregions within the northern Great Plains also was reported. Risk was greatest in regions with wooded hills and wooded riparian corridors and least in regions having greater agricultural land cover. In general, fire risk was proportional to landowner size, with the greatest proportion of risk for lands managed by the FWS, U.S. Bureau of Land Management, and U.S. Forest Service.

Bedrosian and others (2019) pointed to loss of occupied eagle nests and nesting habitat and to direct mortality of nestlings and fledglings as the key negative consequences of wildfires on Golden Eagles in the northern Great Plains. The authors stated that fires in high-quality breeding habitat for Golden Eagles should be actively fought and extinguished.

Clearly, frequent fire in shrubsteppe west of the Great Plains has markedly diminished Golden Eagle habitat values by triggering widespread conversion of native habitat to cheatgrass-dominated landscapes (Pellant and Hall, 1994; Reid and others, 2008; Brooks and others, 2016; Pyke and others, 2016; Hansen and others, 2017a; see "Breeding Habitat" section). Conversely, suppression of frequent fires in native mixed-grass prairies of the Great Plains can contribute to invasion by nonnative perennial grasses, especially Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*), and proliferation of woody vegetation (Grant and others, 2011), and these changes may reduce habitat quality for prey of Golden Eagles, such as Sharp-tailed Grouse and white-tailed jackrabbits (Simes and others, 2015; Murphy and Smith, 2019). Fire may enhance expansion of colonies of black-tailed prairie dogs in shortgrass prairie during drought periods (Augustine and others, 2007) and in mixed-grass prairie when combined with brush control (Milne-Laux and Sweitzer, 2006).

Grazing

Grazing by livestock mainly affects Golden Eagles in the Great Plains and other western grassland and shrubsteppe landscapes by indirectly influencing availability of the eagle's prey. Knowledge of this interaction and management recommendations related to grazing are limited, except that livestock grazing generally is believed to be positive for the Golden Eagle and its primary prey (Bock and others, 1993); however, sustained, intensive livestock grazing generally is believed to have negative consequences to Golden Eagles (Bedrosian and others, 2019). Bock and others (1993) categorized the Golden Eagle as a species positively affected by grazing based on the known association of the species' preferred prey (that is, jackrabbits) with shrubby vegetation. Perhaps the most valuable aspect of livestock grazing to Golden Eagles in the Great Plains is that the practice is central to sustaining a land use that provides valuable habitat for the Golden Eagle and its prey on a major geographic scale; on privately owned lands at least, the grazing tradition may help avert land-use conversions to cropland (Higgins and others, 2002; Bedrosian and others, 2019). Nonetheless, pressure to convert Great Plains grazing lands to cropland persists, prompting some ranchers to concentrate cattle on increasingly limited spaces (Higgins and others, 2002). State and Federal natural resource programs have provided technical and financial resources for ranchers to develop livestock grazing systems that improve and sustain grassland health while increasing ranch income, and set-aside conservation programs (including grassland easements) are available to help perpetuate native prairies that can be used for livestock grazing in the region (Riley, 2004; Savage and others, 2014).

Livestock grazing can alter the structure and composition of grassland vegetation in ways that may influence the species composition, abundance, and availability (or vulnerability) of prey for Golden Eagles (Bedrosian and others, 2019); fire may still be an interacting abiotic factor in some contemporary landscapes. The influences of these two defoliating forces vary across the grasslands and shrubsteppe habitats within the Golden Eagle's range, especially from east to west, making all but the coarsest recommendations from the literature for livestock grazing impractical; other variables such as nonnative plant species and herbicide use can further confound recommendations from the literature. Moreover, grazing by livestock generally varies in terms of timing (season), duration, and intensity, and stocking rate prescriptions vary with local soil type (Butler and others, 2003). Thus, livestock grazing recommendations from the literature that benefit Golden Eagles may be little more than crude generalizations, and inconsistent use of terms used for describing livestock grazing intensity in the literature could further undermine their value (see "Species' Response to Management" section). Rather than attempt to provide grazing intensity recommendations from the literature for select species of Golden Eagle prey, it may be more useful to consider the general vegetation structure and composition that support prey species of interest and then endeavor to tailor grazing prescriptions to attain that condition. Moreover, grazing need not be the only management tool to achieve vegetation structure and composition goals.

Shortgrass prairies of the Great Plains typically are more resilient to the vagaries in livestock grazing than are mixed-grass prairies and are less degraded by lack of fire (see "Species' Response to Management" section). Herbaceous vegetation of short stature is favored by black-tailed jackrabbits if there also are scattered shrubs or dense tufts of herbaceous vegetation (Hansen and others, 2017a). White-tailed jackrabbits prefer less shrub cover and more herbaceous vegetation but may otherwise not exhibit preferences for grazing intensity levels, at least in the semiarid western Great Plains (Flinders and Hansen, 1975; Lim, 1987; Simes and others, 2015; Hansen and others, 2017a). Short-statured prairie with little vertical obstruction is preferred by black-tailed prairie dogs in either shortgrass or mixed-grass prairies, and grazing by cattle generally creates vegetation structure that favors the prairie dog (Uresk and Bjugstad, 1983; Knowles, 1986; Sharps and Uresk, 1990; Reading and Matchett, 1997). Annual, season-long grazing at high levels of intensity may promote a shrub-dominated community especially in some mixed-grass prairies, which may ultimately become unsuitable for either jackrabbit species (Brown and others, 2020). Cottontail rabbits generally tolerate relatively moderate levels of grazing if edges created by rockpiles or dense shrubs are present (Flinders and Hansen, 1975), but populations decline with prolonged heavy grazing (MacCracken and Hansen, 1982, 1984; Hansen and others, 2017b). In shortgrass prairie of Colorado, light-to-moderate grazing by cattle on fourwing saltbush resulted in denser growth of the shrub and increased cover for cottontails (Flinders and Hansen, 1975).

Livestock, especially cattle, can influence Golden Eagles by reducing tree nest sites (Call, 1979). Livestock may concentrate their activity beneath trees and hasten the death of trees by compacting soils, exposing roots, rubbing against boles of trees year after year, and grazing seedlings or sprouts from roots as they emerge. The problem is acute in landscapes where nest trees are scarce and cliff nest sites are absent (Call, 1979). A steady decline in availability of cottonwood trees for Golden Eagle nest sites in the Great Plains has been attributed to these impacts, along with decreased high flow events, hydrogeomorphic changes, and fire exclusion along rivers (Auble and Scott, 1998; Rood and others, 2007). Fencing to exclude livestock can protect cottonwood trees that support current or future Golden Eagle nests (Call, 1979).

Eagles may drown in water troughs for livestock after becoming immersed and unable to fly or climb out of the steep-sided structures (Craig and Powers, 1976; Bedrosian and others, 2019; Katzner and others, 2020b). Drowning risk can be reduced by fitting troughs with escape ramps, keeping water levels high, or draining troughs when livestock are removed from the area (Natural Resources Conservation Service, 2012; Kauffman and others, 2019). Draining also would eliminate breeding opportunities for mosquitoes that may transmit West Nile Virus, to which Golden Eagles are vulnerable (Nemeth and others, 2006).

Depredation of livestock by Golden Eagles, especially lambs in open-range settings, continues in some parts of the Great Plains and shrubsteppe regions but may be reduced by lambing at ranch buildings or in pens covered with netting, using guard dogs, removing dead livestock that can attract eagles, and placing scarecrow devices in prominent places and accompanying these with human activity and harassment; the last approach may be most effective (O’Gara and Rightmire, 1987). Based on a survey by Phillips and Blom (1988), chronic depredation of lambs from Colorado to Montana could generally be attributed to resident Golden Eagles, especially where dense breeding populations of Golden Eagles overlapped lambing areas. Capture and relocation of depredating individual eagles has been ineffective (O’Gara and Rightmire, 1987).

Climate Change

A species’ physiology, habitat associations, interspecific relationships, unique life history attributes, and response to disturbances influence its sensitivity to climate change (Case and others, 2015). As reviewed under the “Species’ Response to Management” section, climate change may adversely affect Golden Eagles mainly by decreasing prey availability through broad-scale reductions in primary productivity that accompany increasing aridity. Patterns of reduced territory occupancy and infrequent breeding observed among Golden Eagles inhabiting arid portions of the species’ contemporary range in the conterminous western United States could shift northward. Replacement of big sagebrush communities by cheatgrass may be hastened by more frequent fire than occurred historically (reviewed in Katzner and others, 2020b), although evidence of this is not entirely clear (Larson and others, 2017). Golden Eagle productivity may decline due to increased incidence of nestling mortality stemming from hyperthermia associated with intensified sun exposure and increasing temperatures predicted by climate-change models; Kochert and others (2019) recommended using an adaptive management framework to further evaluate the effectiveness of using artificial shade structures to reduce this mortality.

Although carbon emissions that drive climate change can be reduced by increased development and use of renewable energy, this energy transition may negatively affect Golden Eagles indirectly, especially via habitat loss and fragmentation (Katzner and others, 2013; Diffendorfer and others, 2019), and directly, in the case of wind energy, by blade-strike mortality (Smallwood and Thelander, 2008; Katzner and others, 2013; Pagel and others, 2013; New and others, 2020). Adaptive management plans are necessary to create a balance between renewable-energy generation, climate-change mitigation, and Golden Eagle conservation (New and others, 2020). Currently, Golden Eagle population size in the western United States appears to be tentatively stable but could decline with slight increases in anthropogenic mortality such as that likely to occur in association with increasing wind energy, unless other anthropogenic mortality is mitigated to boost survival or if productivity can be markedly increased (Millsap and others, 2022). However, even under optimistic projections of carbon emissions, the Golden Eagle’s North American range could be more than halved within the next few decades if climate-driven changes in the environment continue unabated, even though there may be a net increase in total numbers of eagles in a few western States (Langham and others, 2015). Thus, although more aggressive actions are needed to reduce greenhouse gas emissions worldwide, the most important conservation measure for Golden Eagles may be to anticipate (through modeling and expert elicitation) and plan adaptively for distributional shifts (Langham and others, 2015). Ideally, this planning approach would include increased effort to conserve currently suitable habitat that likely will remain suitable under predicted climate-change scenarios, while also identifying and proactively conserving habitat that may be colonized by Golden Eagles as climate-change advances. Elevation may be more important than latitude in this regard; climate-change impacts on birds in general are likely to be more severe in regions of relatively level topography, such as the Great Plains, than in montane regions such as the nearby Rocky Mountains (Peterson, 2003). Uncertainty inherent in climate-scenario predictions may be best addressed adaptively by continuous assessment of Golden Eagle distribution and demography and by linking the science to conservation planning and implementation (Langham and others, 2015), although some decisions in bird conservation planning for climate change in general cannot await rigorous modeling (Peterson, 2003). Consideration also should be given to possible climate-driven changes in habitat attributes of concern to Golden Eagle conservation; for example, risk of invasion by cheatgrass, which may be driven by more than just temperature (Bradley, 2009), and afforestation in some of the northernmost parts of the species’ range (Marcot and others, 2015).

Measures to sustain agricultural and rangeland resources can reduce carbon emissions and contribute to climate adaptation, while improving habitat of prey for Golden Eagles. Range management practices with carbon sequestration potential include rotational grazing to improve drought tolerance and increase long-term grassland productivity (Delgado and others, 2011). Other examples of agricultural and range management practices that may contribute to carbon sequestration and provide habitat for prey of Golden Eagles could include windbreaks for livestock protection or soil erosion control, riparian forest or grassland buffers, conservation tillage practices, diversified crop rotation, transitions to perennial crops, increased use of cover crops, wetland restoration for easement credit, and change from corn to switchgrass (*Panicum virgatum*) as bioenergy crops (Delgado and others, 2011). In the northern Great Plains, marginal lands (that is, lands on which food currently is not produced) pose significant potential for carbon sequestration by widely establishing switchgrass on tracts under private or Tribal ownership, excepting those with permanent conservation status (Dolan and others, 2020). Under conservative and aggressive model scenarios, an estimated 14 and 23 million ha, respectively, could be converted to switchgrass during roughly the next 40 years (fig. 1 *in* Dolan and others, 2020). Dolan and others (2020) recommended assessing tradeoffs of such a massive carbon sequestration project and its effects on habitat for biodiversity, ecosystem health, and societal values (Dolan and others, 2020), including effects on Golden Eagles; given the dense, tall structure of switchgrass, prey availability may be relatively low (see “Prey Habitat” section).

Climate-change models have raised concerns about the effects of increasing temperatures and changing precipitation patterns on raptor populations, especially those species that nest in hot environments and exposed locations (Wichmann and others, 2005; Kochert and others, 2019). Despite considerable current scientific expertise on the biology and management of Golden Eagles, rigorous assessments of climate-change consequences for the species apparently have not been published. Such assessments should be multifaceted, incorporating vulnerability considerations including exposure, sensitivity, and adaptive capacity (Dawson and others, 2011). A consequence of northward shifts in a species’ wintering distribution is that a greater burden is placed on natural resource managers in northern areas, who become responsible for managing an increasing proportion of a species’ wintering population (Paprocki and others, 2014).

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Table 01. Nesting chronology of Golden Eagles (*Aquila chrysaetos*) recorded across the Great Plains and adjoining areas. Dates above parentheses are medians and those within parentheses are ranges.

[*n*, number of nests; --, no data; ~, approximately]

Location	*n*	Laying dates	Hatching dates	Study
Southwestern Montana	9	(March 17–April 11)	(April 28–May 24)	Baglien, 1975
Southwestern North Dakota	--	(March 27–May 1)[a]	~May 8–June 12[b]	Stewart, 1975
Western South Dakota	--	(~March 6–April 18)[c]	(~April 17–May 30)[b]	South Dakota Ornithologists' Union, 1991
Northeastern Wyoming	86	March 20 (February 24–April 12)	May 1[b] (April 10–May 25)	Phillips and Beske, 1990
Southeastern Wyoming	7	(March 20–April 4)	(May 2–May 31)	Schmalzried, 1976
Northeastern Colorado	11	(March 10–April 1)	(April 21–May 13)	Olendorff, 1973
Four Corners region[d]	53	March 1[e] (February 1–March 31)[e]	April 14[f] (March 16–May 13)	Murphy and others, 2017
Southern Great Plains region	17	March 2[e] (January 28–March 23)[f]	April 13[f] (March 11–May 4)	Murphy and Stahlecker, 2022

[a] Extreme egg dates.

[b] Estimated by adding a 42-day incubation period (Katzner and others, 2020b) to reported laying dates.

[c] Earliest laying is the presumed "incubating" reported for March 6 and latest is coarsely estimated by subtracting 30 days from observation of "half-grown young" on July 3.

[d] Southeastern Utah, southwestern Colorado, northeastern Arizona, and northwestern New Mexico.

[e] Estimated by subtracting a 42-day incubation period (Katzner and others, 2020b) from reported hatching dates.

[f] Based on back-dating from mid-May through June marking of nestlings at 52 days of age.

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