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CHARACTERISTICS OF THE LANDSCAPE SURROUNDING GOLDEN EAGLE NEST SITES IN DENALI NATIONAL PARK AND PRESERVE, ALASKA

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Abstract.—Descriptions of landscape characteristics of Golden Eagle (*Aquila chrysaetos*) nesting territories and foraging areas in Alaska are generally broad and qualitative. To provide a basis for future studies on relationships between landscape characteristics and reproductive success, we described landscape characteristics within a 3000-m radius surrounding the geographic center of 36 Golden Eagle nesting territories in Denali National Park and Preserve, Alaska. Within the 3000-m territory cores, we delineated 27 unique land-cover types based on 11 unique types of vegetation cover and structure within four terrestrial physiographic zones: Alpine, Upland, Lowland, and Riparian. Rugged terrain, alpine areas, and a mosaic of land-cover types including Alpine Low Shrub, Alpine Barren, Upland Low Shrub, Riparian Barren, and Riparian Shrub characterized most territory cores. Alpine was the most common physiographic zone, and low shrub was the most common land-cover type in territory cores ($\bar{x}$ = 68.5% area, 95% C.I. = 61.2–75.5%). Our results should be useful for monitoring responses of breeding Golden Eagles to future changes in this landscape.

Key Words: *Golden Eagle*; Aquila chrysaetos; *nesting habitat*; *Denali National Park*; *Alaska*.

CARAETERÍSTICAS DEL PAISAJE QUE CIRCUNDA LOS SITIOS DE NIDIFICACIÓN DE *AGUILA CHRYSAETOS* EN EL PARQUE Y RESERVA DENALI, ALASKA

Resumen.—Las descripciones del paisaje que circunda los territorios de nidificación y las áreas de forrajeo de *Aquila chrysaetos* en Alaska son generalmente someras y cualitativas. Con el objetivo de proveer una mejor base para estudios futuros sobre la relación entre características del paisaje y el éxito reproductivo, describimos las características del paisaje en un radio de 3000 m alrededor del centro geográfico de 36 territorios de nidificación de *A. chrysaetos* en el Parque Nacional y Reserva Denali, Alaska. Dentro de esta área, determinamos 27 tipos de cobertura de suelo distintos con base en 11 tipos únicos de cobertura y estructura de la vegetación, ubicados en cuatro zonas fisiográficas terrestres: alpina, de tierras altas, de tierras bajas y ribereña. La mayoría de las áreas núcleo de los territorios se caracterizaron por estar en terrenos rocosos, áreas alpinas y en un mosaico de tipos de cobertura del suelo que incluye arbustos bajos alpinos, terrenos alpinos desprovistos de vegetación, arbustos bajos de tierras altas, terrenos ribereños desprovistos de vegetación y arbustos ribereños. La alpina fue la zona fisiográfica más común y el arbustal bajo, la cobertura del suelo más común en las áreas núcleo de los territorios ($\bar{x}$ = 68.5% del área, IC del 95% = 61.2–75.5%). Nuestros resultados deberían ser útiles para monitorear las respuestas de los individuos reproductivos a cambios futuros en este paisaje.

[Traducción del equipo editorial]

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Breeding Golden Eagles (*Aquila chrysaetos*) are central-place foragers, with much of their activity centered on their occupied nest (Watson 1997, Kochert et al. 2002). Golden Eagles often select nesting sites based on proximity to suitable hunting terrain (Watson 1997). Land-cover provides food, shelter, and breeding sites for prey and may reflect the amount of potential prey habitat (Ferrer and Donazar 1996, Knick and Dyer 1997, Kochert et al. 1999), potential foraging habitat (Janes 1984, Marzluff et al. 1997), and potential prey availability (Carter and Jones 1999) surrounding nest sites. Land-cover, particularly vegetation structure and canopy, may influence prey availability and foraging success of Golden Eagles and other large raptors (Bechard 1982, Tjernberg 1983, Marzluff et al. 1997, McGrady et al. 1997). Specifically, establishing a breeding season home range in open landscapes may favor detection of prey and potentially enhance hunting success of Golden Eagles (Carrete et al. 2000).

Landscape characteristics of Golden Eagle nesting territories in Alaska are generally limited to qualitative descriptions (Kochert et al. 2002). Few studies have been conducted on this species at the northern latitudes of North America (Watson 1997, Kochert et al. 2002), and no studies have provided quantitative measurements of nesting territory characteristics in this region. The goal of our study was to provide quantitative descriptions of landscape characteristics immediately surrounding nest sites of Golden Eagles in Denali National Park and Preserve (Denali).

Methods

Study Area. The 2100-km^2 study area, centered at 63°35.8′N, 149°38.2′W, was in the northern foothills of the Alaska Range in northeastern Denali in central Alaska. Elevations in the study area ranged from 427–2590 m; elevations of foothill summits ranged from 607–1372 m. The study area was characterized by steep-sided mountains, large swift-running glacial rivers, broad glacially-carved valleys, and extensive gravel bars. Water, wind, and glaciers shaped the terrain in the study area. The study area contains the highest reported nesting density of Golden Eagles in North America (Kochert et al. 2002). Nests are built exclusively on cliffs and rock outcroppings in the study area.

Calculating Nesting Centroids and Territory Cores. We calculated the nesting centroid as the mean latitude and longitude of all known nests within each nesting territory using methodology described by McGrady et al. (1997) and Kochert et al. (1999). We did not know home-range size or shape; therefore, we measured landscape characteristics within a 3000-m radius (or 1/2 the nearest neighbor distance of known nesting territories) surrounding the nesting centroid and refer to that sampling area as the territory core. We acknowledge that this approach does not reflect actual size and shape of home ranges; however, we lacked empirical data to delineate individual Golden Eagle home ranges in Denali. Further, although techniques for predicting home range of Golden Eagles are used in other areas (McLeod et al. 2002), these predictive models were based on empirical data on home-range size in those specific areas and are not directly transferable to Denali.

Creating the Land-cover Map. We created a land-cover map for this project because no high-resolution land-cover map was available. We used the most recent color infrared aerial (CIR) photographs (August 1981; 1:63 360 scale) and field verification of CIR photographs to develop the land-cover map (Kidd and Stickney 2000) for 36 randomly-selected nesting territories. No large ecological disturbances, such as fire, or any significant change in land-cover occurred in the mapping area between 1981 and 1997 (C. Roland, Plant Ecologist, Denali National Park pers. comm.).

We used a mirror stereoscope to delineate boundaries of land-cover types on acetates overlaying CIR photographs. We created digital land-cover maps by digitizing mapped areas on acetate overlays using ArcView© Geographic Information System version 3.2 (GIS) software (Environmental Systems Research Institute [ESRI], Redlands, CA U.S.A.; Kidd and Stickney 2000). We mapped land-cover at a minimum resolution of 0.5 ha, but mapped distinct landscape features such as lakes, ponds, and barren rock outcroppings at their actual size. Estimated accuracy of land-cover delineations using the Alaska Vegetation Classification (AVC; Viereck et al. 1992) Level III was 85%.

Landscape Characteristics. Plant communities are the basic elements of the hierarchical five-level AVC (Viereck et al. 1992); each AVC level contains more formations and describes vegetation cover with an increasing degree of complexity. We originally mapped at AVC Level IV, resulting in 77 unique land-cover classes in the study area (Kidd and Stickney 2000). We used the variables physiographic zone, vegetation structure, and canopy cover to create a modified AVC Level III (Table 1) as a balance between coarse descriptions of AVC levels I–III and complex descriptions of AVC level IV.

We used a U.S. Geological Survey (USGS) Digital Elevation Model (DEM) and the digital land-cover maps to generate triangular irregular networks (TINS) using ARC/INFO© version 8.2 GIS (ESRI, Redlands, CA U.S.A.) to estimate surface area of land-cover types within territory cores. We calculated a terrain ruggedness index (TRI) for each territory core using the ratio between surface area and planar area. Higher TRI values indicate a larger difference between surface area and planar area and represent greater terrain ruggedness.

We calculated amount of surface area, TRI, percent cover of physiographic zone, and percent of land-cover type for each territory core. We described landscape characteristics using mean ($\bar{x}$), standard deviation (SD), standard error (SE), and 95% confidence intervals (95% C.I.).

Data Analysis. We used paired *t*-tests to compare differences in surface and planimetric estimates of each

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Table 1. Attributes of land-cover types in Golden Eagle territory cores, Denali National Park and Preserve, Alaska (Kidd and Stickney 2000).

Classification Variable	Description
Physiographic zones	
Alpine	Areas ≥800 m above sea level (ASL).
Upland	Well-drained slopes, ridges, and inactive flood plains <800 m ASL level.
Lowland	Poorly drained areas in valley bottoms and on lower slopes of hillsides and other low-lying floodplain areas.
Riparian	Active flood plain, annual seasonal inundated areas, and river bars.
Rivers/Streams	Permanent rivers and streams.
Lakes/Ponds	Permanent lakes and ponds.
Vegetation type, height, and canopy-cover class	
Barren	Vegetation cover is <10%.
Barren partially-vegetated	Vegetation cover is 10–25%.
Shrub	Vegetation is ≤3 m tall.
Forest	Trees >3 m tall and equal ≥10% of area.
Dwarf	Vegetation is <0.2 m tall.
Low	Vegetation is ≥0.2 m and ≤1.5 m tall.
Tall	Vegetation is >1.5 m tall.
Open	Canopy cover is 25–60%.
Closed	Canopy cover is >60%.

physiographic zone. We used linear regression to examine relationships between number of land-cover types and TRI and amount of Alpine area (ha) and elevation of nesting centroids. We used square-root transformation for all count data, but report means as untransformed values for clarity. We conducted all statistical analyses using S-Plus Version 6.0 statistical software (Insightful 2001) and evaluated significance at $P = 0.05$.

Results

The amount of surface area within territory cores ranged from 3285–4873 ha ($\bar{x} = 4069$, SE = 57.8, 95% C.I. = 3955–4186). TRI values ranged from 1.17–1.73 ($\bar{x} = 1.45$, SE = 0.02, 95% C.I. = 1.40–1.49). Elevation of nesting centroids ranged from 701–1402 m ($\bar{x} = 1108$ m, SE = 27.41, 95% C.I. = 1052–1163); 88.9% of all nesting centroids were ≥800 m in the Alpine zone.

Territory cores contained three to six physiographic zones (median = 4), but Alpine and Upland zones made up most of the core area (Table 2). The proportion of a territory core within the Alpine zone increased with elevation of the nesting centroid ($r^2 = 0.38$, $P < 0.001$). All territory cores contained Riparian and Streams/Rivers zones (Table 2). The Lowland and Lakes/Ponds zones did not occur at high frequency or make up a substantial portion of any territory core (Table 2). We found significant differences between surface and planimetric area estimates for Alpine, Upland, Riparian, and Streams/Rivers physiographic zones (Table 3).

Overall, we delineated 27 unique land-cover types (Table 4) and 8–19 land-cover types within individual territory cores ($\bar{x} = 13.44$, SE = 0.50, 95% C.I. = 12.42–14.46). Number of land-cover types was

Table 2. Composition of 36 Golden Eagle territory cores by six physiographic zones, Denali National Park and Preserve, Alaska.

Physiographic Zone	Percent of Territories	Composition (%)		
		Mean	SE	95% C.I.[a]
Alpine	100	68.23	3.83	60.44–76.02
Upland	89	25.94	3.85	18.12–33.76
Lowland	31	0.53	0.38	0.00–1.30
Riparian	100	4.69	0.56	3.55–5.83
River/ Streams	100	0.41	0.06	0.27–0.54
Lakes/Ponds	33	0.01	0.01	0.00–0.01

[a] 95% Confidence Interval.

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Table 3. Planimetric and surface areas estimates of mean hectares (SE) of six physiographic zones in Golden Eagle territory cores, Denali National Park and Preserve, Alaska.

Physiographic Zone	Planimetric Area	Surface Area	t^a	P
Alpine	1813 (107)	2788 (164)	2.93	0.006
Upland	794 (109)	1046 (156)	−4.90	0.001
Lowland	19 (13)	20 (14)	−1.25	0.217
Riparian	170 (21)	189 (22)	−8.04	0.001
Rivers/Streams	12 (2)	17 (3)	−7.29	0.001
Lakes/Ponds	2 (1)	2 (1)	−1.29	0.203

[a] Paired *t*-test.

not related to TRI (r^2 = 0.007, P = 0.62). The proportion of an individual territory core made up of a single land-cover type ranged from 0.16–0.78 ($\bar{x}$ = 0.39, SE = 0.02, 95% C.I. = 0.34–0.44). A single land-cover type made up ≥50% of the area in 10 territory cores. We detected a bimodal distribution in frequency of occurrence of land-cover types in territory cores. Twelve land-cover types occurred in ≤25% of territory cores (Table 4) and totaled ≤3% of the area within these territory cores. The remaining 15 land-cover types occurred in ≥56% of the territory cores (Table 4).

Shrub and Barren were the most common land-cover types in territory cores (Table 4). Shrub land-cover types comprised a mean of 68.5% (SE = 3.4; 95% C.I. = 61.2–75.5%) of the area within territory cores. Common plants in the Shrub category were birches (*Betula glandulosa* and *B. nana*) and willows (*Salix* spp.). A mean of 27.6% (SE = 3.6, 95% C.I. = 20.3–34.9%) of the area within territory cores was the Barren cover type. Talus slopes, rock outcroppings, cliffs, and river bars were the common features of the Barren cover type. Forested land-

Table 4. Modified Alaska Vegetation Classification Level (AVC) III land-cover types in Golden Eagle territory cores, Denali National Park and Preserve, Alaska. Land-cover types in bold type occur in >50% of the territory cores.

Modified AVC III Land-cover Type	N^a	Composition (%)		
		Mean	SE	95% C.I.
Alpine Barren	34	19.92	3.51	12.79–27.05
Alpine Barren Partially-Vegetated	35	4.48	0.76	2.94–6.02
Alpine Dwarf Shrub	26	3.30	0.91	1.45–5.14
Alpine Low Shrub	30	4.41	1.39	1.60–7.23
Alpine Open Low Shrub	36	10.87	1.38	8.08–13.66
Alpine Closed Low Shrub	35	24.97	2.92	19.04–30.91
Alpine Open Tall Shrub	2	0.01	0.01	0.00–0.03
Alpine Closed Tall Shrub	6	0.27	0.14	0.00–0.56
Lowland Low Shrub	3	0.15	0.13	0.00–0.42
Lowland Open Low Shrub	9	0.34	0.21	0.00–0.78
Lowland Closed Low Shrub	1	0.04	0.04	0.00–0.12
Riparian Barren	31	2.17	0.43	1.29–3.04
Riparian Barren Partially-Vegetated	21	0.79	0.23	0.34–1.25
Riparian Closed Low Shrub	2	0.02	0.02	0.00–0.06
Riparian Open Tall Shrub	33	0.96	0.15	0.65–1.27
Riparian Closed Tall Shrub	30	0.75	0.14	0.47–1.04
Riparian Open Broadleaf Forest	1	0.00	0.00	0.00–0.01
Upland Barren	5	0.09	0.07	0.00–0.23
Upland Barren Partially-Vegetated	8	0.16	0.09	0.00–0.35
Upland Low Shrub	26	3.47	0.62	2.20–4.73
Upland Open Low Shrub	23	3.40	0.97	1.44–5.37
Upland Closed Low Shrub	30	8.29	1.28	5.69–10.88
Upland Open Tall Shrub	6	0.10	0.05	0.00–0.21
Upland Closed Tall Shrub	25	7.18	1.81	3.50–10.86
Upland Open Needleleaf Forest	20	3.04	0.95	1.12–4.95
Upland Closed Needleleaf Forest	2	0.03	0.02	0.00–0.08
Upland Open Broadleaf Forest	4	0.19	0.16	0.13–0.51

[a] Number from a total of 36 territory cores that contained the land-cover type.

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scapes were not common in territory cores; a mean of 3.3% (SE = 1.0, 95% C.I. = 1.2–5.4%) of the area within territory cores was Forest. White spruce (*Picea glauca*) was the only tree species in the Needleleaf Forest land-cover type. Broadleaf Forests contained paper birch (*Betula papyrifera*) and balsam poplar (*Populus balsamifera*).

Discussion

Rugged terrain and dwarf or low-shrub vegetation were the most common features in most Golden Eagle territories cores in our mountainous study area. Establishing nesting sites and presumable nearby foraging areas in open landscapes may be advantageous for detecting prey and enhancing hunting success (Tjernberg 1983, Marzluff et al. 1997, McGrady et al. 1997, Carrete et al. 2000). We did not measure prey availability or prey abundance in this study; however, 21 of the 27 land-cover types identified in this study support primary prey species of breeding Golden Eagles in Denali including snowshoe hare (*Lepus americanus*), Willow Ptarmigan (*Lagopus lagopus*), and arctic ground squirrel (*Spermophilus parryii*; C. McIntyre unpubl. data).

Although many raptors nest in mountainous or rugged terrain, few raptor studies include measurements of topography or terrain ruggedness (but see Janes 1984, Donazar et al. 1993, Whitfield et al. 2001, Boal et al. 2003). Topography is an important component of the landscape and may influence distribution and abundance of land-cover types (Forman 1995) within nesting territories. Further, wind direction and speed may interact with terrain to influence how Golden Eagles use their home range (McGrady et al. 1997, McLeod et al. 2002). Despite the influence of terrain, habitat studies rarely use surface area estimates of land-cover and often present landscapes as flat, regardless of topographic relief. Planimetric measurements of land-cover can grossly underestimate actual amounts of those land-cover types, particularly in mountainous regions. Ignoring the effects of topography on habitat quality or habitat descriptions may lead to a misunderstanding of the ecology of animals that live in mountainous terrain (Powell and Mitchell 1998, Rolando et al. 2000) and could potentially lead to mismanagement of their habitat. We suggest that future habitat studies incorporate descriptions of topography, terrain, and surface area when possible.

Lack of an accurate high-resolution land-cover map and information on ranging behavior of Golden Eagles in Denali limited our analyses to a relatively small area around nesting centroids. Our initial description of the landscape surrounding territory cores of Golden Eagles in the late 20th century, however, provides a quantitative baseline on which to measure future change. The advent of new high-resolution GIS data layers for Denali will streamline future mapping and analyses efforts. Accurate high-resolution land-cover maps also will allow us to determine if Golden Eagles select areas with the characteristics we described and avoided other parts of the landscape.

Throughout much of their Holarctic range, Golden Eagles live in landscapes where human activities directly modify their habitats (Watson 1997, Kochert et al. 2002). Studies by Kochert et al. (1999) and Steenhof et al. (1999) emphasize the importance of measuring landscape attributes on the nesting grounds and responses of nesting raptors as these attributes change. Our study area was in a large remote national park, mostly within a federally protected wilderness area, and we do not expect landscapes within Golden Eagle territory cores in Denali to change due to direct modification by humans. Rather, we expect that large-scale perturbations, including global climate change, will shape the future landscapes in Denali. Global climate change most certainly will cause regional changes in vegetation patterns (Rupp et al. 2000, Sturm et al. 2001) that could affect prey abundance and foraging success of Golden Eagles in Denali. Advancing tree line and increased shrub growth (Sturm et al. 2001) may provide more habitats for some Golden Eagle prey species in Denali; however, more closed-canopy vegetation may influence the hunting efficiency of eagles in this region (Watson 1997). In combination with information on reproductive success and productivity, results of our study should be valuable for measuring habitat change and quantifying how Golden Eagles respond to these likely future changes in Denali.

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