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DAYTIME HABITAT SELECTION BY RESIDENT GOLDEN EAGLES (*AQUILA CHRYSAETOS*) IN SOUTHERN IDAHO, U.S.A.

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ABSTRACT.—Energy and other anthropogenic development are increasing throughout the range of Golden Eagles (*Aquila chrysaetos*) in western North America, and both private and government agencies have expressed concern about indirect and direct effects on Golden Eagles. To facilitate sustainable development and reduce risk to Golden Eagles, the U.S. Fish and Wildlife Service has established guidelines to assist developers in project planning and siting. A major component of environmental impact assessment is documenting Golden Eagle spatial use near a project site before development. Unbiased estimates of habitat selection (spatial use) in and near a proposed project area are possible with location data collected by Global Positioning System (GPS) transmitters attached to a sample of Golden Eagles in the area. During spring 2011, we identified occupied Golden Eagle territories within a study area in southern Idaho, and deployed four GPS and Argos tags on resident adult Golden Eagles. We developed seasonal resource selection functions (RSFs) for each monitored Golden Eagle, and estimated seasonal daytime habitat selection by the average Golden Eagle by averaging predictions from four RSFs. The final RSFs estimated that relative probability of selection by Golden Eagles was highest closer to nests and over moderately rugged terrain. Other predictor variables such as brightness (a measure of non-vegetated habitats) and slope were also seasonally important. Model validation indicated the models reliably predicted Golden Eagle use within the study area. This is the first study estimating Golden Eagle habitat selection based on a combination of GPS and nest locations. The process we developed may be used to improve our understanding of Golden Eagle habitat selection and to provide valuable information to help minimize risk to Golden Eagles from different land management practices.

KEY WORDS: *Golden Eagle*; Aquila chrysaetos; *energy development*; *GPS*; *habitat selection*; *habitat use*; *logistic regression*; *resource selection*; *risk*; *telemetry*; *territories.*

SELECCIÓN DE HÁBITAT DIURNO POR *AQUILA CHRYSAETOS* EN EL SUR DE IDAHO, EEUU

RESUMEN.—La obtención de energía y otras actividades de desarrollo antrópico se están extendiendo a lo largo de la distribución de *Aquila chrysaetos* en el oeste de América del Norte, y tanto las agencias privadas como las gubernamentales han expresado su preocupación acerca de los efectos directos e indirectos sobre esta especie. Para facilitar el desarrollo sostenible y reducir el riesgo para *A. chrysaetos*, el Servicio de Pesca y Vida Silvestre de Estados Unidos ha establecido lineamientos para ayudar a los promotores en la planificación y emplazamiento de proyectos. Un componente principal de la evaluación del impacto ambiental es documentar el uso del espacio que realiza *A. chrysaetos* en las inmediaciones de un lugar donde se emplazará un proyecto, antes de su desarrollo. Para ello, es posible obtener estimaciones no sesgadas de selección de hábitat (uso espacial) dentro o cerca de un área propuesta para un proyecto, con datos de posicionamiento obtenidos mediante transmisores GPS (Sistema de Posicionamiento Global) colocados a una muestra de *A. chrysaetos* en el área. Durante la primavera de 2011 identificamos territorios ocupados por individuos de *A. chrysaetos* dentro de un área de estudio en el sur de Idaho y colocamos cuatro transmisores de tipo GPS y Argos en individuos adultos residentes. Desarrollamos funciones de selección de recursos (FSRs) estacionales para cada individuo monitorizado y estimamos la selección de hábitat diurno estacional de un individuo tipo de *A. chrysaetos* promediando las predicciones de las cuatro FSRs. Las FSRs finales estimaron que la probabilidad relativa de selección de hábitat por parte de *A. chrysaetos* fue mayor cerca de los nidos y en terrenos moderadamente irregulares. Otras variables predictivas tales como el brillo (una medida de hábitats sin vegetación) y la pendiente también fueron importantes estacionalmente. La validación del modelo indicó que los modelos predijeron de manera confiable el uso del espacio por parte de *A. chrysaetos* en el área de estudio. Este es el primer estudio que estima el uso de hábitat de *A. chrysaetos* basado

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en una combinación de localizaciones GPS y lugares de cría. El proceso que desarrollamos puede ser utilizado para mejorar nuestro conocimiento sobre selección de hábitat por parte de *A. chrysaetos* y para proporcionar información valiosa que ayude a minimizar el riesgo de diferentes prácticas de manejo del suelo para esta especie.

[Traducción del equipo editorial]

Many types of human development have the potential to affect Golden Eagle (*Aquila chrysaetos*) population persistence at local and regional scales. Increasing energy demands, particularly for oil, gas, and renewable energies such as wind and solar, have prompted a nationwide investment in developing these resources within the range of Golden Eagles in the western U.S.A. These developments have been accompanied by growing concern about their potential effects on Golden Eagle population viability as the result of direct mortality and displacement from key habitats (Carrete et al. 2009, Martínez et al. 2010, Katzner et al. 2012, USFWS 2013). The direct and indirect effects on Golden Eagles from energy development are particularly problematic because Golden Eagles are protected by the Bald and Golden Eagle Protection Act (BGEPA 1940) and the Migratory Bird Treaty Act (MBTA 1918). The BGEPA prohibits ''take,'' which includes ''pursuing, shooting, poisoning, wounding, killing, capturing, trapping, collecting, destroying, molesting, or disturbing Golden Eagles.'' However, permits are available for ''incidental take'' under BGEPA (USFWS 2009). The MBTA also prohibits take of Golden Eagles and all native migratory birds with the exception of game birds.

Concerns over Golden Eagle population declines (Harlow and Bloom 1989, Kochert and Steenhof 2002, Kochert et al. 2002) and potential effects on population persistence prompted the United States Fish and Wildlife Service (USFWS) to set forth guidelines (e.g., Pagel et al. 2010, USFWS 2013) in an attempt to minimize risk to the species. The Golden Eagle Conservation Plan Guidance (ECP) was intended to assist parties in determining potential impacts and to avoid, minimize, and mitigate adverse effects on Bald and Golden eagles. The ECP calls for scientifically rigorous surveys, monitoring, assessment, and research designs proportionate to the risk of Golden Eagles (USFWS 2013). The surveys are intended to estimate Golden Eagle use relative to proposed developments and to provide information to assist in determining best management practices that limit the potential direct and indirect effects on Golden Eagles. In addition, these surveys provide support for an eagle take permit under the ECP by estimating a predicted level of Golden Eagle take.

It is now current practice to conduct a variety of surveys to estimate Golden Eagle use near proposed energy developments. These surveys often include aerial nest and territory surveys, as well as intensive ground observational surveys documenting Golden Eagle use. The aerial nest surveys provide valuable information for identifying occupied Golden Eagle nests and territories that may be affected by proposed development. However, the ability to accurately estimate and predict Golden Eagle use from ground-based observational studies is limited. First, ground-based surveys collect Golden Eagle use data under spatial and logistical constraints that may over- or underestimate Golden Eagle habitat use in certain areas. Second, ground-based surveys are subject to imprecision associated with documenting Golden Eagle locations and sampling biases caused by weather, time of day, access, and observer bias. Because of these limitations, some studies have been designed to collect more precise and detailed Golden Eagle location information through the use of solar-powered, backpack platform transmitter terminal (PTT) global positioning systems (GPS) telemetry units sized for deployment on Golden Eagles (hereafter referred to as GPS PTT units). In addition, the Argos satellite uplink transmitter available for some PTTs allows for real-time data collection on locations of instrumented Golden Eagles. With this technology, researchers are able to collect precise information on locations, movements, and habitat selection patterns from instrumented individuals (Meyburg and Meyburg 2002) without the need to recapture the animal for GPS PTT retrieval. As with observational data, there is inherent bias in telemetry data. Inference about a population or individuals within a study area is usually based on small sample sizes and may not represent the average individual. However, this technology has been used to document migration distances and timing (McIntyre et al. 2008), juvenile dispersal (Soutullo et al. 2006b, McIntyre and Collopy 2006, Urios et al. 2007), juvenile survival (McIntyre et al. 2006, McIntyre et al. 2008), and daily movements of juvenile Golden Eagles (Soutullo et al. 2006a).

More recently, Katzner et al. 2012 used data collected by GPS technology to describe Golden Eagle flight behavior and to assess risks relative to wind energy developments during migration cycles. However, this technology and subsequent Golden Eagle use data have not been used to generate resource selection functions (RSFs) to predict Golden Eagle habitat selection across a landscape.

We analyzed Golden Eagle GPS data in conjunction with known nesting locations to estimate habitat selection within our study area. Our method uses standard habitat selection modeling (Manly et al. 2002, McDonald 2013), and focuses on Golden Eagle use during daylight hours when the solar-powered PTT units provided the highest GPS fix-rate success.

In our study, we investigated two-dimensional third-order daytime habitat selection (Johnson 1980, McDonald 2013) by resident Golden Eagles in southern Idaho, U.S.A., during three seasons: spring, summer, and fall. Our objectives were to: (1) inventory Golden Eagle nests and territories within the study area; (2) generate robust RSFs to predict Golden Eagle habitat selection across the study area; and (3) demonstrate how predictions of Golden Eagle habitat selection may be used to delineate high-use areas or areas of potentially higher risk in land management planning.

Study Area

Our study area was in southern Idaho and northern Nevada near the town of Jackpot, Nevada. The study area consisted of approximately 213 180 ha (2132 km^2) that encompassed known Golden Eagle nesting territories and was centered on the large geographic features of China Mountain, Browns Bench, and Salmon Falls Creek Reservoir. Elevation within the study area ranged from 1274 to 2683 m. The landscape at lower elevations was composed mainly of sagebrush (*Artemisia tridentata*) flats with some interspersed pasture/hay agriculture. The landscape at higher elevations comprised rolling sagebrush hills, aspen (*Populus tremuloides*) stands, and coniferous stands. Numerous drainages lined with rocky outcroppings and cliff faces existed within the study area, including the largest drainages: Cottonwood Creek and Salmon Falls Creek. In addition, Salmon Falls Reservoir was in the central portion of the study area. Average annual monthly temperatures ranged from 0.2 to 15.8°C. Average annual precipitation and snowfall was 25.1 cm and 73.4 cm, respectively (WRCC 2005).

Methods

Raptor Nest Survey. We identified occupied/maintained Golden Eagle nests within the study area using a helicopter from 18 April through 26 April 2011, when Golden Eagles were expected to be incubating eggs or brooding nestlings. We recorded the locations of all occupied and unoccupied Golden Eagle nests identified during the survey and tentatively assigned territory status. We conducted a follow-up survey on 18 May 2011 to confirm status of each identified territory and associated nest(s). A Golden Eagle nesting territory was defined as ''an area that contained, or historically contained, one or more nests (or scrapes) within the home range of a mated pair… a confined area where nests are found, usually in successive years, and where no more than one pair is known to have bred at one time'' (Steenhof and Newton 2007). A territory was designated as occupied if the area encompassed a nest or nests or potential nest sites and was defended by a mated pair of Golden Eagles. Each nest within a territory was designated as: (1) occupied if we observed an adult eagle in an incubating position, eggs or young, a pair of eagles at or near the nest, newly constructed or refurbished stick nest, freshly molted feathers, or current year's whitewash (Pagel et al. 2010, Steenhof and Newton 2007) or (2) unoccupied if we did not observe any of these.

Capturing Golden Eagles. We deployed GPS PTT units on four resident Golden Eagles within the study area in late winter/early spring 2011. We targeted Golden Eagles in four territories where individuals had laid eggs in previous years because captures occurred prior to establishment of nests and prior to the 2011 aerial survey. Two nests were along the primary China Mountain ridge near the center of the study area. One nest was in a small canyon on the western slope of China Mountain, and the fourth nest was in the southeastern portion of the study area along Cottonwood Creek. Distances between each targeted nest ranged from 9.6 km to 23.0 km. We targeted one adult resident breeding Golden Eagle from each territory.

Capture efforts were timed to take place before egg-laying to minimize the influence on reproductive success. A USFWS-permitted biologist with a capture permit issued by the U.S. Geological Survey (USGS) Bird Banding Lab, as well as relevant state scientific collection permits, captured all Golden Eagles. We used a padded leg-hold trapping technique for all captures (Bloom 1987), with fresh, natural prey items, including mule deer (*Odocoileus* *hemionus*) carcasses, as bait. We placed trap sets close to the four target nests in locations that we could monitor from long distances via binoculars. Upon capture, each Golden Eagle was hooded, placed into an *aba* to prevent struggling, and banded with USGS size 9 rivet leg band. We recorded mass, wing chord length, toe-pad length, and hallux length of each captured Golden Eagle. Nontargeted individuals (e.g., nonbreeders) were banded, measured, and released at the point of capture.

Captured adult Golden Eagles were fitted with GPS PTT-100 transmitters weighing 86 grams (Microwave Telemetry, Columbia, Maryland, U.S.A.). Transmitters were equipped with a solar recharger, auxiliary battery, and UHF transmitter. We attached transmitters using a backpack-style harness constructed of 0.84 cm Teflon ribbon (Bally Ribbon Mills, Bally, Pennsylvania, U.S.A.). The estimated precision of the location data collected via these units was 18 m for horizontal GPS positions (Microwave Telemetry pers. comm.). We programmed the GPS units to obtain one location per hour (the maximum fix rate for the devices) from at least one hour before sunrise to at least one hour after sunset. Data from each backpack were automatically downloaded every two days via the Argos satellite data collection relay system (CLS America, Largo, Maryland, U.S.A.).

Model Covariates. We used a geographical information system (GIS) and 30-m × 30-m pixel level resolution digital elevation model to obtain measures of covariates associated with recorded Golden Eagle locations and a sample of random locations including: *elevation, rugged,* and *slope*. Terrain ruggedness (*rugged*) measured the variation in slope and aspect across the landscape on a scale of 0 to 1 (1 being most rugged) and was calculated using the ''Vector Ruggedness Measure'' tool in ArcMap 10.1 (Hobson 1972, Sappington et al. 2007, ESRI 2011). Solar *radiation* accounted for atmospheric effects, elevation, slope, aspect, sun angle, and shadows cast by surrounding topography as measured by the Area Solar Radiation tool (ESRI 2011). We also considered distance from a location to the China Mountain ridge line (*rim edge*) as a potential RSF covariate because this was a prominent ridge line within the study area and was used by Golden Eagles for perching, nesting, and exploitation of thermals/updrafts (C. LeBeau unpubl. data).

Vegetation covariates at Golden Eagle locations were based on Landsat Thematic Mapper satellite images (USGS 2012). We used images that represented the vegetation present during each season (spring–fall; e.g., 27 May 2009, 20 July 2011, and 22 September 2011, respectively) and had the highest quality (e.g., lowest percentage of cloud cover). To evaluate aboveground biomass using ArcMap 10.1, we used the Normalized Difference Vegetation Index, NDVI:

$$NDVI = \frac{(band\ 4 - band\ 3)}{(band\ 4 + band\ 3)}$$

(Deering 1978, Vogelmann et al. 2001, Chander et al. 2009) and the Soil Adjusted Vegetation index, SAVI:

$$SAVI = \frac{(1+L) * (band\ 4 - band\ 3)}{(band\ 4 + band\ 3 + L)}$$

where $L = 0.5$ and is a soil brightness correction factor (Huete 1988, Vogelmann et al. 2001, Chander et al. 2009). Measures of *NDVI*, represented the amount of visible light absorbed by plants as well as the amount of near-infrared light plants reflected (Deering 1978). *SAVI* is similar to *NDVI*, but attempts to accommodate for some of the limitations of *NDVI* by using a soil adjustment factor, which reconciles the influence of soil in spectral features by the percentage of green cover (Huete 1988). *NDVI* and *SAVI* values ranged from −1 to 1 with larger values measuring areas of greater vegetation vigor or biomass. We also applied Tasseled Cap Transformations to the Landsat images to calculate *greenness*, *wetness*, and *brightness* vegetation indices to indicate vegetation canopy, moisture, and bare soil, respectively (Kauth and Thomas 1976, Crist 1985). Values for *greenness*, *wetness*, and *brightness* ranged from −1 to 1 where higher values related to increased presence of vegetation and a greater magnitude of moisture and soil reflectance, respectively.

We obtained occupied Greater Sage-Grouse (*Centrocercus urophasianus*) lek locations from Idaho Fish and Game and Nevada Department of Wildlife to characterize potential Golden Eagle prey habitat. We calculated the distance to nearest lek (*lek*) from Golden Eagle and random locations to identify areas of sage-grouse concentrations during spring lekking. In addition, we used proportion of shrub cover within a 1-km^2 area (*shrub*) surrounding each eagle and random location generated from LANDFIRE (Landscape Fire and Resource Management Planning Tools) landcover dataset, to describe the potential black-tailed jackrabbit (*Lepus californicus*) habitat

Table 1. Explanatory covariates measured at each used and available location for modeling Golden Eagle seasonal habitat selection in southern Idaho, U.S.A., 2011. All data layers were represented at a 30-m resolution and included quadratic terms where indicated.

Covariate Name	Description
Landscape features	
elevation	Elevation (m)
elevation_mean	Mean elevation within a 1-km^2 moving window (m)
slope[a]	Slope (degrees; 0 to 90)
slope_mean[a]	Mean slope within a 1-km^2 moving window (degrees)
rugged[a]	Terrain ruggedness (0 to 1; high values = high terrain variation)
rugged_mean[a]	Mean rugged within a 1-km^2 moving window
radiation	Mean solar radiation within a 1-km^2 moving window
rim_edge	Distance to the China Mountain ridge line (km)
nestness[a]	Minimum distance to Golden Eagle nests (km)
lek	Distance to nearest occupied sage-grouse lek (km)
Vegetation	
NDVI	Mean NDVI within a 1-km^2 moving window
SAVI	Mean SAVI within a 1-km^2 moving window
wetness[a]	Mean wetness within a 1-km^2 moving window
brightness[a]	Mean brightness within a 1-km^2 moving window
greenness	Mean greenness within a 1-km^2 moving window
shrub	Proportion of shrub cover within a 1-km^2 moving window

[a] Quadratic and linear terms were both considered during model development.

(Steenhof et al. 1997, LANDFIRE 2012). Lastly, distance from a Golden Eagle and random location to the associated individual's nest (*nest*) was considered for the final RSF because it is an important feature in occupied Golden Eagle habitats (McGrady et al. 2002, McLeod et al. 2002), and can account for some of the spatial correlation in habitat selection (i.e., locations farther away have a lower probability of use).

Model Development. Due to low GPS fix success (71%) attributable to limitations of the backpacks' solar charging system as a result of topography, we used only locations obtained from 2 hr after sunrise to 2 hr before sunset, when Golden Eagles were most active and when GPS fix success was highest (98%; Soutullo et al. 2006a). We defined GPS fix success as the ratio of regular GPS fix attempts and the actual GPS fixes. We defined available habitat for each individual as a minimum convex polygon (MCP) around all observed GPS locations for that individual within the boundary of the study area because landscape-level habitat availability should be based on the distribution of radio-collared animals (McClean et al. 1998). We excluded 8% of all locations that were located outside of the study area from the analysis because we did not have habitat covariate data associated with these locations. We generated sets of available locations by taking simple random samples of locations within each individual's MCP. The number of available locations selected from each home range was two times the number of used locations for each Golden Eagle.

Golden Eagles are a landscape-level species (Kochert et al. 2002, Katzner et al. 2012) and it is important to consider multiple scales when estimating Golden Eagle habitat selection. Thus, we calculated the average value of each terrain covariate and vegetation indices within 1 km of each used and available location (e.g., *slope_mean*; Table 1). Covariate values for *elevation*, *slope*, and *rugged* were obtained from the 30-m $\times$ 30-m grid cell that encompassed each used and available location (Table 1). Many of the habitat features within the study area consisted of small rocky outcrops or steep canyons that may have been suitable perch locations. Use of these features by Golden Eagles would not be detectable on a larger scale (e.g., 1 km), so we included the value at the smallest extent possible, believing any errors in the underlying grid and the Golden Eagle GPS locations would be random and negligible. Along with linear terms for *slope*, *rugged*, *brightness*, and *wetness*, we considered quadratic terms for these covariates based on hypotheses that Golden Eagles may have preferred locations with moderate, rather than extreme, covariate values.

We incorporated the covariates into a binary logistic regression equation in a use–availability framework with a maximized likelihood to estimate an exponential RSF (Manly et al. 2002, Johnson et al. 2006, McDonald 2013) that predicted the relative probability of Golden Eagle habitat selection. We focused on the time of year when Golden Eagles breed and raise their young and assumed habitat selection patterns could differ across this time period. Therefore, we developed separate models during three different biologically meaningful seasons in 2011: spring: late February to early March–30 June); summer (1 July–15 September); and fall (16 September–1 November). In addition, the covariates related to Golden Eagle habitat selection used in the analysis had different distributions within the three seasons. For example, *brightness* values ranged from 0.314 to 0.375 during spring, 0.204 to 0.447 during summer, and 0.234 to 0.460 during fall.

Our evaluation of Golden Eagle habitat selection within the study area consisted of a multistep process, where we: (1) developed RSFs for each individual within the individual's home range during each season, (2) reestimated individual RSFs using a combined dataset (used and available) with locations from all monitored Golden Eagles, (3) predicted a model-averaged (Burnham and Anderson 2002) relative probability of Golden Eagle habitat selection within the study area during each season, and finally (4) validated the predictive ability of each RSF estimated in Step (3) using a leave-one-out technique (Johnson et al. 2006). For example, we developed a unique RSF (i.e., different combinations of covariates; Step 1) for each Golden Eagle resulting in four unique RSFs for each season. We considered each RSF to be equally plausible at predicting habitat selection for the average individual Golden Eagle within the study area, and so reestimated each individual's RSF using the used and available locations from all four Golden Eagles resulting in 12 total RSFs, three for each season (Step 2). In Step 3, we averaged the predictions across seasonal RSFs estimated in Step 2. Finally, we validated the resulting RSFs by testing their predictive ability in a leave-one-out approach in Step 4.

The lack of published, landscape-level Golden Eagle habitat selection studies precluded identification of a list of *a priori* models for model estimation and comparison. Thus, we first developed a habitat selection model for each individual using forward, stepwise selection (Neter et al. 1996) and the Bayesian information criterion (BIC; Burnham and Anderson 2002). Models with smaller BIC values had more support in the data and were considered parsimonious (Burnham and Anderson 2002). We built models using forward variable selection via improvements in BIC values using R language for statistical computing (R Development Core Team 2012). For example, the covariate selected first resulted in the lowest BIC score among other univariate models. We added remaining covariates to the first selected covariate and reevaluated the model to see if the BIC score could be lowered. If the model BIC was further reduced, then the model-building process continued looking forward (adding covariates) until the BIC value could not be further reduced or until the model reached a maximum of five covariates resulting in a RSF for each Golden Eagle. We limited each RSF to five covariates to maintain simplicity and consistency among the four individuals, although we acknowledge that we may have missed some relationships.

Correlations among covariates may result in erroneous inferences (Neter et al. 1996). Prior to model building, we conducted a pairwise correlation analysis to identify potential colinearities between covariates. Based on results of the correlation analysis, we did not allow any mutually correlated variables in any one model. For example, if two covariates were correlated based on Pearson's correlation coefficient ($|r|$) being >0.6, we dropped that covariate that was chosen later in the model selection process. In addition, we calculated variance-inflation factors (Fox and Monette 1992) to test for multicollinearity between covariates in the final individual models. Based on convention, we only considered quadratic versions of covariates in conjunction with their linear counterparts.

During development of individual RSFs (Step 1), we sought covariates that were related to habitat selection within an individual's home range. Step 2 of our modeling process consisted of using those identified covariates within individual models to predict the relative probability of selection by the average individual Golden Eagle within the study area. This was done to account for the variability in habitat selection patterns among the four individuals. For example, the habitat selection analysis for one Golden Eagle might indicate that a particular covariate (e.g., *slope*) was an important predictor of habitat selection by that Golden Eagle; however, this covariate may have had little relationship to the selection patterns for other Golden Eagles, which suggests some level of variability among the individuals monitored. We accounted for this variability in habitat selection by treating the individual as the experimental, or primary, sampling unit (Thomas and Taylor 2006), and applying each individual model to a combined dataset that included all Golden Eagles' used and available data.

We estimated final RSFs from the reapplication of each individual model to the combined dataset (Step 2). We estimated confidence intervals for each coefficient in each of the final 12 RSFs using bootstrapping, where the individual Golden Eagles were randomly sampled with replacement and the final model was refit to the new sample of used locations and available locations (Manly 2007). We used 200 bootstrap iterations to calculate standard errors of model coefficients (estimated as SDs of the bootstrap distribution of estimates). We calculated lower and upper confidence limits for each estimate from the SEs using the estimate $+/-$ 1.645(SE). Coefficient estimates with 90% confidence intervals (CIs) not containing 0 were considered statistically significant at the alpha = 0.10 level. We calculated odds ratios $[(\exp(\beta_0)-1)*100]$ from coefficients in the final RSF models and used them to interpret the relationship between each covariate and Golden Eagle habitat selection (McDonald et al. 2006). Odds ratios describe the estimated percent change in relative probability of selection for a 1-unit change in a predictor variable. We did not calculate odds ratios for covariates with both linear and quadratic effects. We created marginal effects plots using the estimated parameters and their associated CIs from the top model in each season and study area to show the marginal effect of selected variables (McDonald et al. 2006).

We used the resulting 12 final RSFs (Step 2) to estimate the relative probability of selection by the average Golden Eagle within the study area (Step 3). We used a model averaging process to account for the variability of selection among individuals. Model averaging is commonly used to address model uncertainty among a set of models estimating habitat selection (e.g., Arnold 2010). This approach minimizes the effect of uninformative parameters among individual models, particularly if covariates are included in one model and not in another (Burnham and Anderson 2002). This is particularly important when using multiple RSFs to make an overall prediction of the relative probability of use by the average Golden Eagle within the study area. To make an overall prediction of use within the study area, we placed a 100-m $\times$ 100-m grid over the study area and extracted covariate values for each cell. Using these values we predicted the relative probability of selection using each individual final RSF. When we made predictions across the study area, we used the distance to the nearest known occupied nest observed during the aerial nesting inventory survey (i.e., it was not limited to the four monitored Golden Eagles). The average predictions from the four Golden Eagle RSFs were classified into five equal-area bins (low, medium-low, medium, medium-high, and high use) using percentiles.

Following model estimation and creation of a predictive map for the study area, the model estimation and prediction processes were evaluated (Step 4), which is an important part of determining the quality of a RSF (Johnson et al. 2006, McDonald et al. 2006). We sequentially left one individual out of the model estimation and prediction mapping process (Steps 2–3) and investigated the ability of the data from the other three Golden Eagles to predict use for the individual that was held out. Predictions for the used and available locations for the individual not included in developing predictions were binned into 20 equal area classes – i.e., the same number of sampled locations (available and/or used) were assigned to each class based on percentiles of the predicted values. We then calculated Spearman's rank correlation coefficient to estimate the strength of the relationship between prediction class (1–20, with 20 being ''best''), and the number of used locations within each bin. Higher correlations indicate the data and process used to create the final predictive map were robust for among-animal variability in habitat use.

Results

Nesting Inventory. We identified 32 occupied Golden Eagle territories (0.10 occupied territories per km^2) during the nest surveys conducted from 18 April to 18 May 2011. Three of the 32 occupied territories had nests classified as unoccupied because no adults were observed near the nests during aerial nesting surveys, but GPS/Argos data showed adult use around these nest locations indicating an occupied territory. Eagle 1 was the only monitored eagle that had an occupied nest; however, this nest was unsuccessful. Some nesting attempts may have been undetected due to the timing of the aerial survey. Overall, occupied territories appeared evenly distributed throughout the study area with an average inter-nest distance of 4.71 km during 2011 (Fig. 1).

Captures. Capture efforts occurred over 11 d within four different territories between 17 February

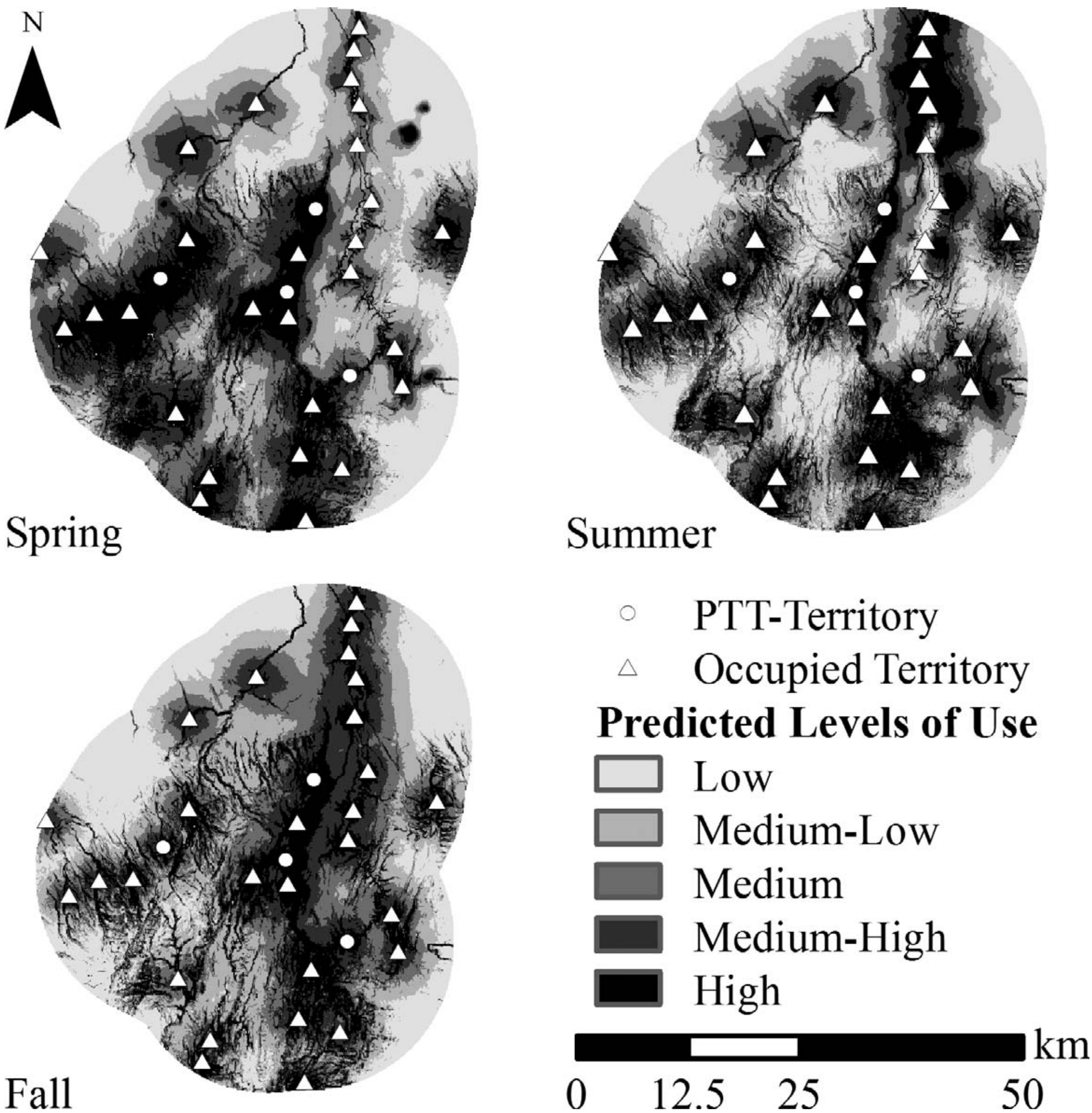

Figure 1. Predicted Golden Eagle habitat use (low–high) during spring, summer, and fall and occupied territories observed within the study area, southern Idaho and northern Nevada, U.S.A., 2011.

and 16 March 2011. We captured and banded five Golden Eagles. Two adult (defined by plumage characteristics; Bloom 2001, Kochert et al. 2002) males and two adult females were fitted with backpack satellite telemetry packages via a harness system. One of the captured Golden Eagles was determined to be 2 yr old based on plumage (Bloom 2001). Although this subadult was banded and measured, it was released without a GPS backpack. Most Golden Eagle captures occurred where mule deer carcasses were bait.

Habitat Selection. We estimated daytime habitat selection between 0800–1900 H during spring and summer and 0900–1700 H during fall. The total number of locations recorded during each season varied for each individual because we excluded locations recorded outside of the study area from the analysis (Table 2). The size of each individual's MCP varied among the three seasons, but the smallest MCPs were estimated during spring, ranging from 6771 ha (Golden Eagle 2) to 32 818 ha (Golden Eagle 3; Table 2).

Table 2. Size of minimum convex polygon (MCP) in ha for each individual Golden Eagle during each season in southern Idaho, U.S.A., 2011.

GOLDEN EAGLE ID	SEX	SEASON	NO. OF LOCATIONS	SIZE OF MCP (ha)
Golden Eagle 1	Female	Spring	981	20 229
		Summer	548	28 434
		Fall	183	59 015
Golden Eagle 2	Male	Spring	1207	6771
		Summer	725	64 786
		Fall	439	55 661
Golden Eagle 3	Female	Spring	1127	32 818
		Summer	690	48 520
		Fall	392	104 862
Golden Eagle 4	Male	Spring	1108	11 341
		Summer	790	54 427
		Fall	556	56 351

The final seasonal RSFs for each individual contained numerous covariates; however, *nest*, *slope*, *rugged*, and *brightness* were identified repeatedly as important predictors of Golden Eagle habitat selection. The variable *nest* was in all final RSFs, except for Golden Eagle 1, where *nest* was only included in the spring model. *Rugged* was included in many of the seasonal RSFs, and both the linear and quadratic terms occurred in all spring models and in the fall model for Golden Eagle 1 (Tables 3–5), indicating a moderate level of *rugged* (0.025–0.030) was generally selected. *Brightness* and *slope* also were common in the Golden Eagle models (Tables 3–5), and marginal plots indicated that habitats with moderate to higher levels of *brightness* and *slope* were commonly selected. Selection for other covariates was less consistent (Tables 3–5). Unique covariates selected for the final spring, summer, and fall RSFs ranged from 8 (summer and fall) to 10 (spring; Tables 3–5). *Slope* measured at the pixel level occurred in each summer RSF except for Golden Eagle 1, where the average *slope_mean* measured within 1 km of each used and available location was selected first during model building. *Wetness*, *radiation*, and *greenness* were included in multiple final RSFs (Tables 3–5), but their relationships with habitat selection were variable across seasons and individuals.

Estimated coefficients for covariates found in >1 individual RSF within a season were generally consistent among individuals, indicating similar habitat preferences (Tables 3–5). During spring, the odds ratio for *nest* indicated that the relative probability

Table 3. Final resource selection functions for resident Golden Eagle daytime habitat selection during the spring of 2011 in southern Idaho, U.S.A.

GOLDEN EAGLE ID	FINAL RESOURCE SELECTION FUNCTIONS
Golden Eagle 1	$w(x) = \exp\left\{ \begin{array}{l} (283.600 \times brit)^a - (441.895 \times brit^2)^a + \\ (3.717 \times elevation\_mean)^a - (0.381 \times nest)^a - \\ (0.115 \times radiation) + (236.034 \times rugged)^a - \\ (4354.400 \times rugged^2)^a \end{array} \right\}$
Golden Eagle 2	$w(x) = \exp\left\{ \begin{array}{l} (-0.404 \times nest)^a - (109.367 \times rugged)^a - \\ (1759.370 \times rugged^2)^a - (0.913 \times shrub) + \\ (0.150 \times slope)^a - (0.002 \times slope^2) \end{array} \right\}$
Golden Eagle 3	$w(x) = \exp\left\{ \begin{array}{l} (-0.450 \times nest)^a + (0.177 \times lek) + \\ (352.454 \times brit)^a - (530.179 \times brit^2)^a + \\ (275.831 \times rugged)^a - (5127.05 \times rugged^2)^a \end{array} \right\}$
Golden Eagle 4	$w(x) = \exp\left\{ \begin{array}{l} (-0.488 \times nest)^a + (257.082 \times rugged)^a - \\ (4801.47 \times rugged^2)^a + (16.609 \times savi)^a - \\ (530.179 \times wet) \end{array} \right\}$

[a] Parameter estimate is statistically significant at an alpha = 0.10.

Table 4. Final resource selection functions for resident Golden Eagle daytime habitat selection during the summer of 2011 in southern Idaho, U.S.A.

GOLDEN EAGLE ID	FINAL RESOURCE SELECTION FUNCTIONS
Golden Eagle 1	$w(x) = \exp\left\{ \begin{array}{l} (0.273 \times slope\_mean)^a + (63.077 \times rugged)^a - \\ (415.813 \times wet)^a - (1155.340 \times wet^2)^a \end{array} \right\}$
Golden Eagle 2	$w(x) = \exp\left\{ \begin{array}{l} (-0.613 \times nest)^a + (29.784 \times brit)^a + \\ (3.544 \times green) - (0.134 \times radiation) + \\ (0.212 \times slope)^a - (0.004 \times slope^2) \end{array} \right\}$
Golden Eagle 3	$w(x) = \exp\left\{ \begin{array}{l} (-0.613 \times nest)^a + (25.213 \times brit)^a - \\ (0.134 \times radiation) - (82.832 \times rugged\_mean) + \\ (0.121 \times slope)^a \end{array} \right\}$
Golden Eagle 4	$w(x) = \exp\left\{ \begin{array}{l} (-0.615 \times nest)^a - (13.333 \times brit) + \\ (0.216 \times slope)^a - (0.003 \times slope^2)^a - \\ (19.039 \times wet) \end{array} \right\}$

[a] Parameter estimate is statistically significant at an alpha = 0.10.

of a Golden Eagle selecting habitat within the study area decreased by an average of 35.0% (range = 31.7–38.6%) for every 1 km increase in *nest* (Tables 3–5). The final models for two of the individuals (Golden Eagles 1 and 3) contained linear and quadratic effects for *brightness* in the spring, and estimates predicted that on average, relative probability of selection increased up to ≈0.327 *brightness* units, then declined (range = 0.321–0.332; Table 3). The linear and quadratic terms for *rugged* were included in each Golden Eagle's final RSF and the relative probability of selection increased on average up to 0.280 *rugged* units, then declined (n = 4; range = 0.269–0.311; Table 3).

During summer, the relative probability of selection decreased on average by 45.9% for every 1 km increase in *nest* (n = 3; range = 45.83–45.94%). Selection increased on average by 31.6% for every one unit increase in *brightness* (n = 2; range = 28.7–34.7%; Table 4). The final models for two of the individuals (Golden Eagles 2 and 4) contained linear and quadratic effects for *slope*, and estimates predicted that on average, relative probability of selection increased up to 31.3° of *slope*, then declined (n = 2; range = 26.5–36.0; Table 4). Although the linear term for *slope* was in the final model for Golden Eagle 3, the quadratic term was not selected during model building. Based on the final model for Golden Eagle 3, the relative probability of selection increased by 12.9% for every 1° increase in *slope* (Table 4).

During fall, the relative probability of selection decreased on average by 30.9% for every 1 km increase in *nest* (n = 3; range = 30.6–31.1%; Table 5). As in summer, selection increased by 12.360% for every 1° increase in *slope* for Golden Eagle 3 (Table 5). The linear and quadratic term for *slope* was included in

Table 5. Final resource selection functions for resident Golden Eagle daytime habitat selection during the fall of 2011 in southern Idaho, U.S.A.

GOLDEN EAGLE ID	FINAL RESOURCE SELECTION FUNCTIONS
Golden Eagle 1	$w(x) = \exp\left\{ \begin{array}{l} (-0.061 \times elevation\_mean) - (0.113 \times rim\_edge) + \\ (254.503 \times rugged)^a - (5607.760 \times rugged^2)^a \end{array} \right\}$
Golden Eagle 2	$w(x) = \exp\left\{ \begin{array}{l} (-0.373 \times nest)^a - (87.173 \times rugged\_mean) + \\ (8813.050 \times rugged\_mean^a) + (0.116 \times slope)^a - \\ (0.001 \times slope^2) \end{array} \right\}$
Golden Eagle 3	$w(x) = \exp\left\{ \begin{array}{l} (-0.365 \times nest)^a - (0.835 \times shrub) + \\ (0.116 \times slope)^a \end{array} \right\}$
Golden Eagle 4	$w(x) = \exp\left\{ \begin{array}{l} (-0.369 \times nest)^a - (1.810 \times elevation) + \\ (0.055 \times radiation) + (0.147 \times slope)^a - \\ (0.002 \times slope^2)^a \end{array} \right\}$

[a] Parameter estimate is statistically significant at an alpha = 0.10.

Table 6. Spearman's rank correlation coefficients estimated during validation of final resource selection functions. For example, 0.929 is the correlation between observed use for Golden Eagle 1 in the Spring of 2011 and use predicted by averaging predictions from the final spring RSFs for Golden Eagles 2, 3, and 4.

GOLDEN EAGLE ID	SPRING	SUMMER	FALL
Golden Eagle 1	0.929	0.822	0.787
Golden Eagle 2	0.989	0.846	0.863
Golden Eagle 3	0.879	0.926	0.896
Golden Eagle 4	0.947	0.971	0.946

the final RSF for Golden Eagle 4 and selection increased up to 36.0°, then declined (Table 5).

Validation of the four seasonal models from each Golden Eagle indicated the final RSFs had strong predictive abilities when estimated by pooling data from three of the four individuals. Correlations between observed use and the 20 prediction classes ranged from 0.879 to 0.989 during spring, 0.822 to 0.971 during summer, and 0.787 to 0.946 during fall (Table 6).

The relative probability of selection was highest around all identified nests within the survey area. Selection also appeared to be highest around the steep canyons and cliff faces during all three seasons (Fig. 1).

DISCUSSION

To our knowledge, this is the first study to report seasonal habitat selection models for Golden Eagles using GPS data. Using a leave-one-out technique and pooling data across Golden Eagles for estimation of predictive RSFs proved useful for identifying important Golden Eagle habitat within the study area. Many of the covariates we considered were important predictors of Golden Eagle habitat selection, but distance to the nest was the most influential and was included in 10 of the 12 individual RSFs.

The resident Golden Eagles in this study exhibited high site fidelity to areas around their nest sites within their territory during spring, summer, and fall. The nest location or territory is the focal point of each individual's home range (McGrady et al. 2002, McLeod et al. 2002). However, nest locations themselves may not be driving Golden Eagle use of the landscape outside the breeding season (or in the breeding season when the nest is not occupied), but may rather be acting as a proxy for important foraging areas that played a role in nest-site selection (Orians and Pearson 1979). These foraging areas can be more difficult to identify than nests; thus, results from our study indicate that identifying nest locations across the landscape is critical when predicting Golden Eagle habitat selection during spring, summer, and fall. The nest survey and subsequent follow-up survey identified nests and territories within the study area, but the nest survey may have missed Golden Eagle territories occupied by pairs that did not lay eggs that year. The presence of these Golden Eagles may have constrained space use and possibly habitat selection by monitored Golden Eagles, which could have influenced our predictions of habitat selection of the average individual Golden Eagle within the study area. Golden Eagle selection patterns can vary depending on reproductive success (Marzluff et al. 1997); however, none of the monitored Golden Eagles were successful in their nesting attempts; thus, habitat selection patterns were characteristic of eagles with failed nesting attempts or without nesting attempts, which may be different from Golden Eagles with successful reproduction.

Slope, *rugged*, and *brightness* were also important covariates of daytime Golden Eagle habitat selection. All three covariates could characterize rocky, non-vegetated, steep habitats within the study area. Golden Eagles use three main strategies to search for prey: soaring, still-hunting from a perch, and low contouring flight (Edwards 1969, Dunstan et al. 1978, Dekker 1985, Palmer 1988). Perch hunting was most common in southwest Idaho where habitat was open and perches (power lines, canyon rims, and rock outcrops) were abundant (Dunstan et al. 1978). In addition, most daylight hours for male (78%) and female (85%) Golden Eagles are spent perched (Collopy and Edwards 1989). Perching habitat usually consists of a substrate where eagles have an expansive view and many are characteristic of steep, rocky cliff faces or outcrops. Similarly, nesting substrate within the study area consisted of rocky cliff faces and outcrops. These landscape features are represented in the *slope*, *terrain ruggedness*, and *brightness* covariates.

The other vegetation indices (including *shrub*, *greenness*, *wetness*, *NDVI*, and *SAVI*) showed variability among individuals; only *SAVI* and *wetness* were statistically significant at an alpha level of 0.10. Prey variables such as distance to Greater Sage-Grouse lek and shrub cover were not included in the top models or were not considered significant at an alpha level of 0.10. Greater Sage-Grouse are likely not an important prey species of Golden Eagles in the study area and, although the amount of shrub cover may be associated with jackrabbit abundance, it may not reflect availability of jackrabbits to Golden Eagles. Our analysis suggested that Golden Eagles selected habitats with higher *brightness* values, which could increase the vulnerability of prey species, including jackrabbits and Greater Sage-Grouse, in the region.

The scale at which we assessed some of the covariates was also important. Selection was higher in areas of increasing *slope* and *rugged* at the smallest scale (pixel level), suggesting the steep canyons and cliffs were important Golden Eagle habitat features. In addition, our models included quadratic effects of the *slope* and *rugged* covariates, suggesting Golden Eagles preferred a specific range of these habitats and were not selecting for habitats in the lower and upper extremes. All covariates were measured from remotely sensed data and have inherent inaccuracies; thus, some of the results may be a product of this error; however, we used the best available landscape data.

Golden Eagles use multiple habitat types and varying degrees of spatial use throughout their annual cycle (Marzluff et al. 1997, Kochert et al. 2002, Katzner et al. 2012). We predicted spring habitat selection to be higher around habitats characteristic of rugged, steep, terrain and in close proximity to nest locations; however, use along the northeast canyon that runs north and south within the study area appeared to be low. This canyon runs through a low-lying sagebrush basin and the only rugged and steep terrain that exists is located within the narrow canyon where the nests are located. Habitat selection shifts slightly from the rugged, steep terrain in spring to a more shrub- and vegetation-dominated landscape during summer and fall, which likely results from Golden Eagles expanding their foraging areas. Because nest locations are the focal point of habitat selection by individual Golden Eagles during spring, summer, and fall, it is important to target a random sample of nests when capturing Golden Eagles from a larger study area. We developed our RSFs for areas with nesting pairs. The four Golden Eagle territories targeted in this study area were evenly distributed and represented a range of landscape characteristics. Further investigation is needed to determine whether the RSFs and predictive maps adequately identify habitat selection by nonresident or transient individuals. To apply these models to other similar mountain/canyon/sagebrush landscapes under minimal assumptions, occupied Golden Eagle nests would need to be identified within and around the study area of interest.

Future research should include measurement of habitat selection relative to perch and flying locations if they can be correctly identified, which would provide land managers a more detailed assessment of habitat use associated with different behaviors. In addition, estimating habitat selection patterns for nonresident Golden Eagles would be important for fully describing Golden Eagle habitat selection. The 12 different models we developed and the covariates selected in each final model can be used to develop a list of *a priori* models in future research.

Identifying Golden Eagle territories and important Golden Eagle habitats on a landscape prior to land management or development decisions is critical for assessing potential effects on resident Golden Eagles. Until recently, delineation of these areas has been limited to observational studies. However, this study demonstrates the effectiveness of using GPS technology and aerial nest surveys for predicting Golden Eagle habitat selection across a landscape. The development of the final RSFs and predictive maps included a multistep process in which we identified a suite of covariates that best described habitat selection by the Golden Eagles monitored, and we used those covariates to predict the average relative probability of use within the study area by the average resident Golden Eagle. The methods we employed considered a thorough list of covariates and accounted for the variation in selection patterns among individuals.

The RSFs prediction methods described in this study may be used to inform land managers and project proponents of potential conflict areas with resident Golden Eagles, and to provide managers the ability to quantitatively measure risk and potential effects associated with habitat changes, specifically in a pre- and post-development scenario (McDonald and McDonald 2002). Additional research, impact analyses and development of best management practices, such as micrositing practices, should minimize potential negative effects of human development on Golden Eagles.

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