2017

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Wildlife Society Bulletin 41(2):212–223; 2017; DOI: 10.1002/wsb.770

Original Article

Assessment of Frequency and Duration of Point Counts When Surveying for Golden Eagle Presence

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ABSTRACT We assessed the utility of the recommended golden eagle (*Aquila chrysaetos*) survey methodology in the U.S. Fish and Wildlife Service 2013 Eagle Conservation Plan Guidance. We conducted 800-m radius, 1-hr point-count surveys broken into 20-min segments, during 2 sampling periods in 3 areas within the Intermountain West of the United States over 2 consecutive breeding seasons during 2012 and 2013. Our goal was to measure the influence of different survey time intervals and sampling periods on detectability and use estimates of golden eagles among different locations. Our results suggest that a less intensive effort (i.e., survey duration shorter than 1 hr and point-count survey radii smaller than 800 m) would likely be inadequate for rigorous documentation of golden eagle occurrence pre- or postconstruction of wind energy facilities. Results from a simulation analysis of detection probabilities and survey effort suggest that greater temporal and spatial effort could make point-count surveys more applicable for evaluating golden eagle occurrence in survey areas; however, increased effort would increase financial costs associated with additional person-hours and logistics (e.g., fuel, lodging). Future surveys can benefit from a pilot study and careful consideration of prior information about counts or densities of golden eagles in the survey area before developing a survey design. If information is lacking, survey planning may be best served by assuming low detection rates and increasing the temporal and spatial effort. Published 2017. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS *Aquila chrysaetos*, golden eagle, point count, survey frequency, survey protocol.

The U.S. Fish and Wildlife Service (USFWS) implements the Bald and Golden Eagle Protection Act (BGEPA), which prohibits take of eagles unless authorized by the USFWS. The goal of the BGEPA is to maintain stable or increasing populations of bald (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*; U.S. Fish and Wildlife Service 2009). However, an Eagle Permit Rule was issued by the USFWS to authorize permits for incidental take of bald and golden eagles, in part, because development of renewable energy sources is a national priority and wind energy facilities are increasing across much of the range of golden eagles (U.S. Fish and Wildlife Service 2009). Wind energy is a renewable, noncarbon-emitting source of energy, but it involves risks including direct mortality of birds and bats due to collision with turbine blades and potential disturbance and displacement during and following construction (Hunt 2002, Chamberlain et al. 2006, Pearce-Higgins et al. 2012). Golden eagles experience mortality through collision with wind turbines and, in some locations and circumstances, mortality rates are substantial (Hunt et al. 1999, Hunt 2002, Smallwood and Thelander 2008, Pagel et al. 2013).

Received: 27 December 2015; Accepted: 13 December 2016
Published: 15 June 2017

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Golden eagles are large, apex predatory birds that are broadly distributed, but typically occur at low densities throughout their range (Kochert et al. 2002). They exhibit characteristics of delayed maturity of several years, low reproductive rates, a long life span, and no natural predators; thus, anthropogenic-caused mortality and disturbance (e.g., risks associated with energy development) might have negative population-level effects. Consequently, a critical component of golden eagle management in the presence of intensifying wind energy development is an understanding of the species' distribution and status at 3 spatial scales: 1) the continental United States; 2) regional scales for which management plans can be implemented and; 3) wind-energy project scales at which specific management actions can be implemented (e.g., permitting, mitigation). In particular, data are needed to facilitate relationships among golden eagle use areas and proposed wind turbine locations within project areas and establish a basis for identifying areas to focus management and long-term population monitoring.

In 2013, the USFWS released the second version of the Eagle Conservation Plan Guidance (hereafter, "Guidance";

U.S. Fish and Wildlife Service 2013). Recommendations were provided within the Guidance for appropriate, scientifically rigorous survey designs for assessing area use by golden eagles. Specifically, these recommendations included a specified 800-m radius (~200 ha) for point-count surveys of eagles at proposed wind energy sites (Strickland et al. 2011).

To assess golden eagle occurrence and potential risk and disturbance at prospective wind project sites, reports commonly have been based on observations (eagle min/hr) with a map of areas where eagles were seen. This approach does not account for imperfect detection (i.e., false absences). Surveys that fail to address imperfect detection likely underestimate presence of eagles. In addition, comparison among project sites or periods may not be valid unless detection probabilities are known or can be estimated to account for differences among factors such as terrain, vegetation, weather conditions, seasonality, observers, breeding status of birds, bird age, and bird behavior.

Occupancy is the probability that ≥1 individual of a species of interest is present during a specified time period at a site (i.e., Conroy and Carroll 2009). Occupancy can be used as a state variable for monitoring wildlife populations and requires considerably less effort than estimating population abundance at broad scales (MacKenzie et al. 2006). When incorporating repeated surveys of the same area within a relatively short time frame, occupancy estimation and modeling can provide unbiased estimates of a species' presence and account for detection probability. Occupancy estimation and modeling can integrate data useful for assessing associations of observed eagles with various habitat attributes and characteristics of the landscape, including anthropogenic features that might pose risks to birds (MacKenzie et al. 2006). Moreover, the approach allows comparison of occupancy and detection among different spatial and temporal scales.

A critical assumption of occupancy modeling is that the occupancy status at each survey plot does not change over the survey period (MacKenzie et al. 2002). This assumption, often referred to as the closure assumption, may be violated if, for example, the home range of the study species is larger than the survey plot, and the species may therefore be temporarily absent from a survey plot. In cases where mobile animals may be temporarily absent from survey plot, the term "use" has been suggested as more appropriate than the term "occupancy" (Mackenzie and Royle 2005). Golden eagle home ranges are larger than our survey-plot size; therefore, we adopt this terminology throughout this manuscript. As such, we apply the terms "use modeling" and "probability of use" in lieu of the more traditional terms "occupancy modeling" and "occupancy probability," respectively. Additionally, we interpret detection probability as in the context of an animal being in the surveyed area and detected.

An issue often raised when developing survey and monitoring programs is the effectiveness of different levels of effort and costs. We conducted experimental surveys in 2012–2013 to assess survey recommendations among 3 geographically different regions of the Intermountain West, USA, but restricted our surveys to the brood-rearing and postfledging periods. We reasoned that the reproductive period would also correspond to the period of greatest activity for golden eagles. We therefore limited our surveys to this period to potentially maximize the number of eagles detected per unit time. Our goal was to facilitate development of a survey and monitoring strategy for obtaining information about golden eagles that can be applied by the USFWS. Our specific objectives were to 1) estimate eagle use in relation to landscape features and characteristics to better inform risk models applied to prospective wind energy projects; 2) evaluate survey design, including point-count survey duration, point-count survey radius, the number of survey plots, and the number of repeated visits to each survey plot to better inform survey design; and 3) model how different spatial and temporal allocations of effort affected the estimability and bias of use and detection probabilities.

STUDY AREA

We conducted this study in north-central New Mexico, USA, and southwestern Idaho, USA, during 2012 and 2013, and in southwestern Wyoming, USA, during 2013 only (Fig. 1). We selected these locations based on 1) a desire to sample across a range of latitude and phenology; and 2) existing knowledge that each locale contained populations of nesting golden eagles. The New Mexico study area (hereafter, NM) was near Chama and Dulce, NM, and located within the Southern Rockies ecoregion (Wilken et al.

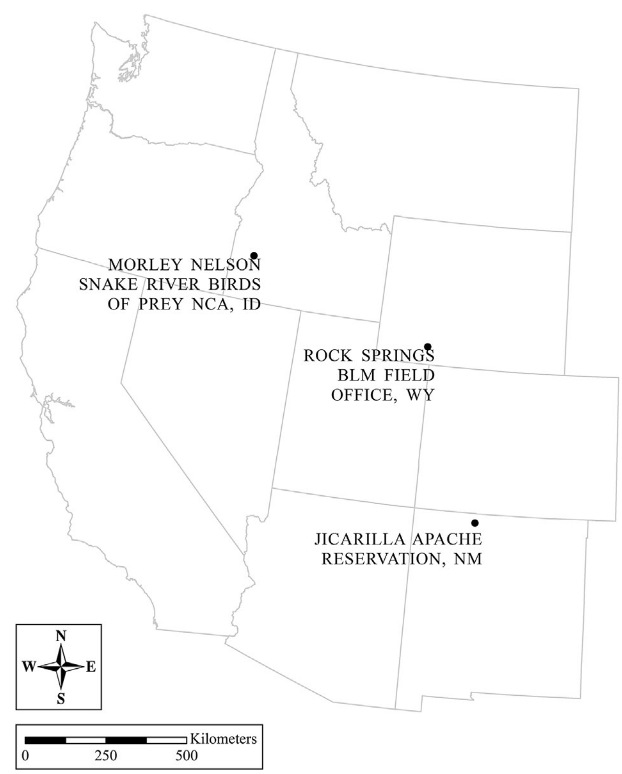

Figure 1. Locations of study areas in northern New Mexico, southwestern Wyoming, and southwestern Idaho in the western United States, where we surveyed for golden eagles over 2 consecutive breeding seasons during 2012 and 2013.

2011). Topography within the NM study area was varied, with steep mountainous terrain interspersed with rolling shrublands, mesic meadows, and riparian areas. Coniferous forests dominated the higher elevations, while sagebrush (*Artemisia* spp.) characterized shrublands, and mesic meadows and riparian areas were characterized by numerous grass species and sparse aspen (*Populus tremuloides*) and cottonwood (*Populus* spp.) stands. The Idaho study area (hereafter, ID) was located within the Snake River ecoregion between Kuna and Mountain Home, ID (Wilken et al. 2011). The area was generally flat to gently sloping and interspersed with buttes and low hills. The Snake River Canyon formed the southern border of the study area. Historically, the area was dominated by sagebrush; however, invasion of the area by cheatgrass (*Bromus tectorum*) shortened the fire periodicity and resulted in a marked decline in sagebrush cover (Whisenant 1990). The Wyoming study area (hereafter, WY) was located in the Wyoming Basin ecoregion southeast of Rock Springs, WY (Wilken et al. 2011). Topographically, this area included buttes and mesas, isolated mountains, plains, and dry valleys. Shrubs, particularly sagebrush, were the dominant vegetative feature throughout the study area.

Survey Plot Selection

We identified 60–75 candidate survey plots along existing roads in each study area. Although the Guidance does not specify that survey point must be placed along existing roads, our goal was to anticipate how methodologies within the Guidance might be applied to actual surveys for golden eagles; we believe our use of the existing road network was therefore appropriate. We randomly placed candidate sites along the road network using a Geographic Information System (GIS) and centers of all survey plots were constrained from being within 2 km of one another to minimize potential of counting the same eagle from adjacent plots (ArcMap 10.0; ESRI, Redlands, CA, USA). During on-site visits to each study area, we used 2 criteria to reduce the number of candidate survey plots to 50/study area. Our first criterion was that these 50 survey plots approximate a uniform distribution about the study area. Second, we selected plots that had the greatest, unobstructed viewshed to 800 m from the survey-plot center. We acknowledge that our decision to force survey plots to have a complete (or nearly so) viewshed to 800 m may have affected the detectability of some eagles, especially if eagles were drawn to pronounced topographic features (e.g., cliff sides, pinnacles). However, we believe that the additional viewable area gained by excluding pronounced topographic features within the survey plot offset any advantages of including those features.

Survey Protocol

We conducted 1-hr point-count surveys at each survey plot, with each plot visited 3 times during each of 2 predefined periods of the breeding season: the brood-rearing period (May and early Jun) and postfledging period (Jul). During each point-count survey, we systematically scanned the 3-dimensional space within the 800-m plot for all raptors, ravens (*Corvus* spp.), and turkey vultures (*Cathartes aura*). Although our attention focused on the 800-m survey plot, we recorded eagles and other focal birds detected beyond 800 m. When observers detected an eagle or focal bird, they recorded the time, estimated horizontal and vertical distances at the time first detected, behavior (e.g., perched or flying), flight path if in flight, age class (i.e., juvenile, subadult, and adult), and total time in the area. To help estimate distances, we used laser range finders, U.S. Geological Survey 1:24,000 topographic maps, and photocopies of aerial images of each survey plot. We attempted to control for temporal heterogeneity in use of golden eagles by stratifying visits among daylight hours. At least 1 of the 3 visits to each survey plot was required to be within 2 hr of sunrise or sunset with the remaining visits between. For each season we began work in NM first, then proceeded to WY (2013 only), and then to ID to accommodate potential latitudinal variations in breeding phenology.

We used a Kestrel weather meter (model 4000; Nielsen-Kellerman, Boothwyn, PA, USA) to record temperature (° C), wind speed (m/s; 30-s average), and wind direction at the beginning (Minute 0), midpoint (Minute 30), and end (Minute 60) of each point-count survey. The exception was for the 2012 brood-rearing period in NM, for which we used meteorological data from the National Oceanic and Atmospheric Administration weather station located in Dulce, NM. We did not use wind speeds from this station because the region's rugged terrain can result in substantial differences in wind speed among nearby locations.

We used a GIS to construct 2–3 covariates specific to each survey plot in each of our 3 study areas. First, we used one-third arc-second digital elevation models (DEMs) to construct an index of topographic roughness within each of the 800-m-radius survey plots. We calculated topographic roughness as the standard deviation of elevation within the survey plot (Zhang et al. 1999). Second, we calculated the distances from the center of each survey plot to the nearest steep slope by creating a slope surface from DEMs for each of the 3 study areas, extracting the locations of slopes $\geq 40^{\circ}$, and measuring the distance between survey-plot centers and the nearest steep slope. Third, we created 1-m resolution maps of prominent vegetation thought to influence occurrence of golden eagles; these were forest cover in NM and sagebrush cover in ID. We did not create a vegetative cover map for WY because of the uniform coverage of shrubs (sagebrush and juniper [*Juniperus* spp.]) within the study area. For the vegetation maps, we obtained 1-m resolution natural-color orthoimagery of study areas from the Interactive Numeric and Spatial Information Data Engine for ID (www.cloud.insideidaho.org) and U.S. Department of Agriculture's (USDA) Geospatial Data Gateway for WY (www.datagateway.nrcs.usda.gov). Both imagery data sets were from the USDA's National Agriculture Imagery Program and captured in 2011. Within ArcGIS, we used the maximum-likelihood classification tool to perform a supervised classification on the imagery for each study area. In the ID study area, we classified images into 1 of 3 categories: grass, bare ground, or shrubs. In NM, we classified images as forest or nonforest. For each study area, we attempted to have a minimum of 5,000 pixels sampled for each category.

Percent sagebrush and forest cover within each survey plot were used as covariates for probability of use for ID and NM data, respectively.

Statistical Analysis

We present raw counts of golden eagles detected during our point-count surveys and number of survey plots in which eagles were detected. For the raw counts, we included all observations even if an observer indicated that the same eagle may have been observed twice during a single point-count survey. We separated observations by point-count survey radius (≤250 m, ≤500 m, ≤800 m, and unlimited radius) and point-count survey duration (≤20 min, ≤40 min, and ≤60 min) to examine raw numbers of eagles that were detected. We estimated the average time (±SE), rounded to the nearest minute, spent by eagles detected while flying, perched, and both, within the 800-m point-count survey radius.

Use modeling.—We used single-season, single-species occupancy models (MacKenzie et al. 2006) to estimate detection probability (p) and probability of use (ψ) within Program PRESENCE (Hines 2006*a*, v. 6.4). We used Akaike's Information Criterion corrected for small sample sizes (AIC_c) values to rank competing models in model sets following the recommendations of Burnham and Anderson (2002) and report parameter estimates and standard errors from the most supported models. For each model set, the effective sample size was set to the number of golden eagle detections in the model data. For all use modeling, we excluded all eagles detected beyond the 800-m point-count survey radius.

Model development.—Although we assumed *a priori* that detection probability and probability of use would differ across study areas, sampling periods, and years, we tested for this assumption by combining all data except postfledging periods of ID in 2012 and 2013 and the postfledging period of NM in 2013 because of few detections of eagles (Tables 1 and 2). Candidate models for this model set examined the effects of study area, year, sampling periods, and combined effects of these 3 covariates on detection probability and probability of use.

Following modeling at the larger scale, we then modeled detection probability and probability of use for each study area, sampling periods, and year separately, again excluding the postfledging periods from ID in 2012 and ID and NM in 2013 because of few eagle detections. For each data set, we created a candidate model set for detection probability and probability of use. Covariates examined for their effect on detection probability included observer identity, visit number, temperature, time of day, a quadratic effect of time of day, and wind speed and direction as described above. For probability of use, we considered the effects of topographic ruggedness, distance to steep cliffs, percent shrub cover (ID only), and percent forest cover (NM only). In some cases, we were unable to include all candidate covariates because of lack of model convergence or data idiosyncrasies (e.g., "observer" covariate was dropped from 2013 ID brood-rearing period because all eagle detections were by a single observer). We did not attempt to model detection probability and probability of use concurrently because of sparse data.

Lastly, with the WY data set, for which we had only 2013 data, we modeled detection probabilities and probability of use as functions of survey radius (250 m, 500 m, and 800 m) and survey duration (20 min, 40 min, or 60 min). This was done by creating multiple but limited data sets (i.e., detections only out to 500 m or detections only within 20 or 40 min) from the original data set. We treated each of these data sets as a separate group within the modeling framework and modeled use using single-season occupancy models (MacKenzie et al. 2006). We were not able to do this analysis for the NM and ID study areas because of sparse detections of eagles.

Simulation analysis.—Following the methodology of Lee et al. (2012), we used Program GENPRES (Hines 2006*b*, v. 130329.1132) to test how different spatial and temporal allocations of effort (and hence, cost) affected the estimability and bias of detection probability and probability of use. We simulated detection probability and probability of use of single-season, single-species models with parameter values derived from our data. To examine how spatial allocation of effort affects estimability and bias, we varied the number of simulated survey plots from 25 to 50 to 75. To

Table 1. Model selection results from data pooled across years (2012 and 2013), seasons (brood-rearing and postfledging), and study areas (Idaho, New Mexico, and Wyoming, USA) for golden eagle occupancy (Ψ) and detection (p) probabilities.

Model	AIC_c[a]	ΔAIC_c[b]	$AIC_c\ w$[c]	Model likelihood	K[d]	Deviance[e]
Ψ (Study area), p (.)	594.45	0.00	0.51	1.00	5	583.72
Ψ (.), p (Study area)	597.01	2.56	0.14	0.28	5	586.28
Ψ (.), p (Year)	597.58	3.13	0.11	0.21	4	589.10
Ψ (Year), p (.)	598.23	3.78	0.08	0.15	4	589.75
Ψ (Season), p (.)	598.51	4.06	0.07	0.13	4	590.03
Ψ (.), p (Season)	598.62	4.17	0.06	0.12	4	590.14
Ψ (Year + Study area + Season), p (.)	599.94	5.49	0.03	0.06	9	579.63
Ψ (.), p (Year + Study area + Season)	603.58	9.13	0.01	0.01	9	583.27

[a] Akaike Information Criterion corrected for small sample sizes.
[b] ΔAIC_c is the difference between a given models AIC_c score and the lowest AIC_c score.
[c] $AIC_c\ w$ is the relative weight of evidence for a particular model.
[d] No. of parameters in a model.
[e] Null model deviance = 590.17.

Table 2. Model selection results for probabilities of detection (p) of golden eagles in the Morley Nelson Snake River Birds of Prey National Conservation Area, Idaho, USA, during the brood-rearing periods of 2012 and 2013. For all models, occupancy probability (ψ) was held constant across all survey plots and (.) denotes constant probability for a parameter.

Model	AIC_c[a]	ΔAIC_c[b]	$AIC_c\ w$[c]	Model likelihood	K[d]	Deviance
Brood-rearing—2012						
ψ (.), p (.)	64.42	0.00	0.64	1.00	2	58.02
ψ (.), p (Wind speed)	66.73	2.31	0.20	0.32	3	54.73
ψ (.), p (Observer)	69.29	4.87	0.06	0.09	3	57.29
ψ (.), p (Temperature)	69.38	4.96	0.05	0.08	3	57.38
ψ (.), p (Time of day)	69.75	5.33	0.04	0.07	3	57.75
ψ (.), p (Survey round)	79.00	14.58	0.00	0.00	4	57.67
Brood-rearing—2013						
ψ (.), p (Temperature)	63.77	0.00	0.53	1.00	3	51.77
ψ (.), p (.)	64.42	0.65	0.38	0.72	2	58.02
ψ (.), p (Time of day)	68.24	4.47	0.06	0.11	3	56.24
ψ (.), p (Wind speed)	69.91	6.14	0.02	0.05	3	57.91
ψ (.), p (Time of day^2)	74.14	10.37	0.00	0.01	4	52.81
ψ (.), p (Survey round)	76.66	12.89	0.00	0.00	4	55.33

[a] Akaike Information Criterion corrected for small sample sizes.
[b] ΔAIC_c is the difference between a given models AIC_c score and the lowest AIC_c score.
[c] $AIC_c\ w$ is the relative weight of evidence for a particular model.
[d] No. of parameters in a model.

examine how temporal allocation affects estimability and bias, we varied the number of visits to each survey plot (2, 3, 4, 5, or 6 visits). We set detection probabilities to 0.1, 0.3, or 0.5, and probabilities of use to 0.2, 0.35, or 0.5, and simulated 1,000 data sets for each combination of spatial and temporal effort and combinations of detection probability and probability of use and analyzed each with a model of constant detection probability and probability of use (p(.) ψ(.)). Following Lee et al. (2012), we termed each combination of parameter values and spatial and temporal effort as a "simulation set." We considered models with a parameter estimates of 0 for ≥1 parameters as failures of estimability and all other models as successes of estimability. Failures were not considered in further analysis. We report model success for each simulation set as the number of successes of estimability/1,000. We report the absolute bias of p and ψ as the average difference between the input parameter estimates used to generate the simulation and the estimate produce by the simulation.

RESULTS

Raw Counts and Detections

Survey year.—We conducted 1,500 hr of point-count surveys: 600 hr each in NM and ID and 300 hr in WY. Each sampling period (brood-rearing and postfledging) was surveyed for 150 hr. Surveyors recorded 329 golden eagle detections throughout the study, with 45% ($n = 148$) within and 55% ($n = 181$) beyond the 800-m survey-plot perimeter. Raw detection rates within the survey-plot perimeter were similar between years, with detections of 0.09 and 0.10 golden eagles/hr in 2012 and 2013, respectively. Detection rates within the unlimited survey-plot radius were also similar between years; 0.21 and 0.23 golden eagles/hr in 2012 and 2013, respectively. Excluding data from the WY study area, which was sampled only in 2013, raw detection rates were greater in 2012 (≤800 m, 0.09 golden eagles/hr; unlimited, 0.21 golden eagles/hr) compared with 2013 (≤800 m, 0.07 golden eagles/hr; unlimited, 0.14 golden eagle/hr).

Survey areas.—Detections of golden eagles were not equitably distributed among study areas in either year. When only considering the NM and ID study areas, there was little difference in detection rates between years: 70% and 78% of detections at ≤800 m, and 65% and 77% of detections at the unlimited survey-plot radius were in NM in 2012 and 2013, respectively (Table S1, available online in Supporting Information). However, including 2013 data available for WY, more detections were made in WY (56%) compared with NM (34%), and ID (10%) at ≤800 m. Similarly, detections at the unlimited survey-plot radius were greatest at WY (60%), intermediate at NM (31%), and least at ID (9%) in 2013 (Table S2, Supporting Information).

Sampling period.—In general, surveyors detected more golden eagles during the brood-rearing periods than post-fledging periods regardless of survey-plot radius. For NM and ID, detections at ≤800 m declined by an average of 78% (range = 54–100%) from the brood-rearing period to the postfledging period in both 2012 and 2013. At the unlimited survey-plot radius, detections dropped by an average of 67% (range = 57–81%) from the brood-rearing to the postfledging period (Tables S1 and S2). This pattern held for the WY study area within the <800-m survey radius, but more eagles were detected at the unlimited survey-plot radius in the postfledging period than the brood-rearing period (Table S2).

Survey radius and survey duration.—As survey-plot radius and area surveyed increased, the number of eagles detected also increased (Tables S1 and S2, Supporting Information). The pattern remained consistent across years, study areas, and sampling periods. Similarly, increasing point-count survey duration also had the general effect of increasing eagle detections (Tables S3 and S4, Supporting Information). Broadly, this pattern was consistent across years, study areas, sampling periods, and both ≤800 m and unlimited survey-plot radii. Notable exceptions were postfledging periods in

ID during 2012 and 2013 and postfledging period in NM in 2013 where increasing survey duration did not appear to substantively increase detections of eagles. Ultimately, when data among areas and years were pooled, an increase from 20 min to 40 min during the brood-rearing period resulted in a 127% (±25 SE) increase in detections; an increase from 40 min to 60 min resulted in an additional 47% (±8 SE) increase in detections. This pattern was reduced for the postfledging period with a 46% (±21 SE) and 14% (±5 SE) increase in detections with each additional 20 min of observation following the first 20 min. There was no evidence that the number of eagle detections reached, or was approaching, an asymptotic limit over the time periods we examined.

Eagle behavior and duration of presence.—Eagles were detected more frequently in flight (84%) than perched (16%) within the 800-m radius survey plots. The longest an eagle in flight remained within a survey plot was 11 min; the average observed flight time within the plots was 2.7 min (±0.3 SE). In contrast, perched eagles remained within survey plots for an average of 21.6 min (±3.2 SE), with the longest recorded presence being a full 60-min observation period. Golden eagles were observed within the 800-m survey plots for only 703 min (0.8%) of the total 90,000 min of observation. We never observed a situation in which an eagle was detected in the survey plot but exited prior to initiation of a survey.

Plot Use

Survey radius and survey duration.—The number of survey plots where golden eagles were detected varied with survey radius in 2012 (Table S5, Supporting Information) and 2013 (Table S6, Supporting Information). This pattern held for all study areas and sampling periods. Though present, the trend of increasing use of survey plots was inconsistent in its strength across seasons and study areas. The increase in survey-plot use for the ID study area was weaker than that in the NM study area for both years and seasons. Without exception, each successively larger survey area resulted in a greater number of survey plots identified as used in the brood-rearing period than in the postfledging period.

Similar to increasing the survey radius, increasing the survey duration from 20 min to 40 min to 60 min generally resulted in a greater number of survey plots identified as used both in the ≤800 m and unlimited survey radius (Tables S7 and S8, Supporting Information, respectively), but only for the brood-rearing period. During the postfledging period, increased survey duration resulted in only modest increases in the number of used survey plots. The brood-rearing period generally had more used survey plots than the postfledging period in NM and ID for a given survey duration, but the converse was true in WY (Tables S7, S8, S9, and S10, Supporting Information).

Use Modeling

Combined data.—The most strongly supported model included the effect of study area on probability of use with detection probability being constant across all study areas, sampling periods, and years (Table 1). Probability of use estimates from this model were 0.48 (SE = 0.11), 0.46 (SE = 0.10), and 0.24 (SE = 0.07) for WY, NM, and ID, respectively, with a detection probability of 0.20 (SE = 0.04).

Study areas.—Despite 1,500 hr of point-count surveys, the small number of eagle detections across all study areas, sampling periods, and years (Table S11, Supporting Information), necessitated that we model detection probability and probability of use separately and not consider any interactions between covariates to avoid model overparameterization. We obtained insufficient data during the postfledging sampling periods of both years in ID and in the 2013 postfledging period in NM to assess either detection probabilities or probabilities of use (Table S11, Supporting Information).

Support for covariates of detection probability was low among study areas and between sampling periods and years (Tables 2–4). In the brood-rearing periods of ID and WY during 2013, models including the effect of temperature on detection probability received the most support. However, there was considerable model-selection uncertainty between the top model and the second-ranked model, which, in both cases, was a model with constant detection probability. Further, there was inconsistency in the direction of temperature on detection probability between the brood-rearing periods of ID and WY in 2013. In ID, the effect of increasing temperature was negative ($\beta = -1.97$, 95% CI = −3.60 to −0.34), while in WY, the effect of increasing temperature was positive ($\beta = 1.15$, 95% CI = −0.22–2.52). For all other model sets, the model with constant detection probability received the most support with little model selection uncertainty (Tables 2–4), with the exception of the postfledging period of WY in 2013 where the effect of wind speed on detection probability received nearly as much support as the model of constant detection probability. In this model, the effect of wind speed on detection probability was slight and positive, but the 95% confidence intervals overlapping 0 ($\beta = 0.97$, 95% CI = −0.19–2.13), indicating a spurious effect.

Models with constant probability of use received more support than models including covariates in 6 of the 7 model sets (Table 5). The exception was the brood-rearing period of 2013 in ID where the model including the effect of percent shrub cover received the most support. The relationship between probability of use for golden eagle and percent shrub cover within the survey radius was positive; however, the standard error of the beta coefficient was large ($\beta = 1.44$, 95% CI = −0.11–2.99). For all other model sets, models including an effect on probability of use were ranked a distant second to models with constant use probability.

Effects of survey duration and radius.—We only had sufficient data from WY 2013 to assess influence of survey duration and survey radius on detection probability and probability of use (Tables S12 and S13, Supporting Information). In the brood-rearing period, there was support for the effect of longer survey durations on both the detection probability and probability of use (Table S12). Point estimates of detection probability increased monotonically; a 20-min survey produced a detection probability of 0.057 (SE = 0.034), while the 40-min and 60-min efforts produced estimates of 0.179 (SE = 0.080) and 0.235 (SE = 0.083),

Table 3. Model selection results for probabilities of detection (p) of golden eagles in the Jicarilla Apache Reservation, New Mexico, USA, during the brood-rearing periods of 2012 and 2013 and postfledging period of 2012. For all models, occupancy probability (ψ) was held constant across all survey plots and (.) denotes constant probability for a parameter.

Model	AIC_c[a]	ΔAIC_c[b]	AIC_c w[c]	Model likelihood	K[d]	Deviance
Brood-rearing—2012						
ψ (.), p (.)	110.87	0.00	0.66	1.00	2	106.01
ψ (.), p (Observer)	113.77	2.90	0.16	0.23	3	105.92
ψ (.), p (Time of day)	113.81	2.94	0.15	0.23	3	105.96
ψ (.), p (Survey round)	117.20	6.33	0.03	0.04	4	105.87
Postfledging—2012						
ψ (.), p (.)	68.12	0.00	0.62	1.00	4	61.72
ψ (.), p (Temperature)	69.87	1.75	0.26	0.42	3	57.87
ψ (.), p (Wind speed)	72.92	4.80	0.06	0.09	2	60.92
ψ (.), p (Time of day)	73.05	4.93	0.05	0.09	4	61.05
ψ (.), p (Survey round)	75.93	7.81	0.01	0.02	3	54.60
ψ (.), p (Observer)	80.18	12.06	0.00	0.00	3	58.85
ψ (.), p (Time of day^2)	82.13	14.01	0.00	0.00	4	60.80
Brood-rearing—2013						
ψ (.), p (.)	102.69	0.00	0.50	1.00	2	97.77
ψ (.), p (Temperature)	105.66	2.97	0.11	0.23	3	97.66
ψ (.), p (Wind speed)	105.70	3.01	0.11	0.22	3	97.70
ψ (.), p (Time of day)	105.71	3.02	0.11	0.22	3	97.71
ψ (.), p (Observer)	105.84	3.15	0.10	0.21	4	94.20
ψ (.), p (Time of day^2)	107.88	5.19	0.04	0.07	4	96.24
ψ (.), p (Survey round)	108.21	5.52	0.03	0.06	4	96.57

[a] Akaike Information Criterion corrected for small sample sizes.
[b] ΔAIC_c is the difference between a given models AIC_c score and the lowest AIC_c score.
[c] AIC_c w is the relative weight of evidence for a particular model.
[d] No. of parameters in a model.

respectively. However, the 95% confidence intervals on estimates overlapped one another in all cases. Probability-of-use point estimates from the brood-rearing period were similar to those of detection probability for the same period. Estimates from the brood-rearing period were 0.168 (SE = 0.092), 0.377 (SE = 0.153), and 0.587 (SE = 0.208) for a 20-min, 40-min, and 60-min survey, respectively. However, as with the effect of survey duration on detection probability, the 95% confidence intervals for these point estimates overlapped one another in all cases. For the postfledging period, however, there was no support for the effect of survey duration on detection probability or probability of use (Table S13).

There was considerable support for the effect of survey radius on both detection probability and probability of use in both the brood-rearing and postfledging periods of WY in 2013 (Table

Table 4. Model selection results for probabilities of detection (p) of golden eagles in southwestern Wyoming, USA, during the brood-rearing and postfledging periods of 2013. For all models, occupancy probability (ψ) was held constant across all survey plots and (.) denotes constant probability for a parameter.

Model	AIC_c[a]	ΔAIC_c[b]	AIC_c w[c]	Model likelihood	K[d]	Deviance
Brood-rearing—2013						
ψ (.), p (Temperature)	100.29	0.00	0.26	1.00	3	92.11
ψ (.), p (.)	100.52	0.23	0.24	0.89	2	95.52
ψ (.), p (Time of day^2)	100.81	0.52	0.20	0.77	4	88.81
ψ (.), p (Observer)	101.37	1.08	0.15	0.58	4	89.37
ψ (.), p (Time of day)	102.80	2.51	0.08	0.29	3	94.62
ψ (.), p (Wind speed)	103.19	2.90	0.06	0.23	3	95.01
ψ (.), p (Survey round)	107.52	7.23	0.01	0.03	4	95.52
Postfledging—2013						
ψ (.), p (.)	102.69	0.00	0.38	1.00	2	97.77
ψ (.), p (Wind speed)	102.98	0.29	0.33	0.87	3	94.98
ψ (.), p (Temperature)	105.16	2.47	0.11	0.29	3	97.16
ψ (.), p (Time of day)	105.67	2.98	0.09	0.23	3	97.67
ψ (.), p (Survey round)	106.70	4.01	0.05	0.13	4	95.06
ψ (.), p (Observer)	108.85	6.16	0.02	0.05	4	97.21
ψ (.), p (Time of day^2)	109.23	6.54	0.01	0.04	4	97.59

[a] Akaike Information Criterion corrected for small sample sizes.
[b] ΔAIC_c is the difference between a given models AIC_c score and the lowest AIC_c score.
[c] AIC_c w is the relative weight of evidence for a particular model.
[d] No. of parameters in a model.

Table 5. Model selection results for occupancy probability (Ψ) of golden eagles in Idaho, New Mexico, and Wyoming, USA, during the brood-rearing and postfledging periods of 2012 and 2013. Probability of detection (p) was held constant across all survey plots for all models. (.) denotes constant probability for a parameter.

Model	AIC_c[a]	ΔAIC_c[b]	AIC_c w[c]	Model likelihood	K[d]	Deviance
Brood-rearing—2012 (Idaho)						
ψ (.), p (.)	64.42	0.00	0.82	1.00	2	58.02
ψ (TRI[e]), p (.)	69.47	5.05	0.07	0.08	3	57.47
ψ (% Shrub cover), p (.)	69.69	5.27	0.06	0.07	3	57.69
ψ (Slope[f]), p (.)	70.02	5.60	0.05	0.06	3	58.02
Brood-rearing—2013 (Idaho)						
ψ (% Shrub cover), p (.)	63.37	0.00	0.61	1.00	3	51.37
ψ (.), p (.)	64.42	1.05	0.36	0.59	2	58.02
ψ (TRI[e]), p (.)	69.97	6.60	0.02	0.04	3	57.97
Brood-rearing—2012 (New Mexico)						
ψ (.), p (.)	110.87	0.00	0.67	1.00	2	106.01
ψ (TRI[e]), p (.)	113.52	2.65	0.18	0.27	3	105.67
ψ (Slope[f]), p (.)	113.86	2.99	0.15	0.22	3	106.01
Postfledging—2012 (New Mexico)						
ψ (.), p (.)	68.12	0.00	0.65	1.00	2	61.72
ψ (TRI[e]), p (.)	70.26	2.14	0.22	0.34	3	58.26
ψ (% Forest cover), p (.)	72.7	4.58	0.07	0.10	3	60.70
ψ (Slope[f]), p (.)	72.84	4.72	0.06	0.09	3	60.84
Brood-rearing—2013 (New Mexico)						
ψ (.), p (.)	102.69	0.00	0.51	1.00	2	97.77
ψ (TRI[e]), p (.)	104.49	1.80	0.51	0.41	3	96.49
ψ (% Forest cover), p (.)	104.77	2.08	0.18	0.35	3	96.77
ψ (Slope[f]), p (.)	105.77	3.08	0.11	0.21	3	97.77
Brood-rearing—2013 (Wyoming)						
ψ (.), p (.)	100.52	0.00	0.68	1.00	2	95.52
ψ (Slope[f]), p (.)	103.25	2.73	0.17	0.26	3	95.07
ψ (TRI[e]), p (.)	103.66	3.14	0.14	0.21	3	95.48
Postfledging—2013 (Wyoming)						
ψ (.), p (.)	102.69	0.00	0.64	1.00	2	97.77
ψ (TRI[e]), p (.)	105.17	2.48	0.18	0.29	3	97.17
ψ (Slope[f]), p (.)	105.21	2.52	0.18	0.28	3	97.21

[a] Akaike Information Criterion.
[b] Difference between the model's AIC sore and the lowest AIC score in the model set.
[c] Relative weight of evidence for the model.
[d] No. of parameters in the model.
[e] TRI = Topographic Ruggedness Index calculated as the standard deviation of elevation within the 800-m survey radius.
[f] Slope = Distance (m) to slopes of $\geq 40°$.

S13, Supporting Information). Estimates of detection probability from the brood-rearing period were 0.031 (SE = 0.022), 0.112 (SE = 0.056), and 0.175 (0.081) for the ≤250-m, ≤500-m, and ≤800-m survey radii, respectively. For the postfledging period, estimates were 0.000 (SE = 0.000), 0.143 (SE = 0.084), and 0.321 (SE = 0.100) for the ≤250-m, ≤500-m, and ≤800-m survey radii, respectively. Estimates of probability of use were greater from the brood-rearing period (≤250, ψ = 0.170 [SE = 0.115]; ≤500 m, ψ = 0.567 [SE = 0.269]; ≤800 m, ψ = 0.793 [SE = 0.352]) than those from the postfledging period (≤250 m, ψ = 0.000 [SE = 0.000]; ≤500 m, ψ = 0.121 [SE = 0.063]; ≤800 m, ψ = 0.363 [SE = 0.121]).

Simulation results.—Our simulations revealed that both the number of survey plots and the number of visits to each plot had large effects on failure rate and the bias of parameters. Failure rates declined as the number of visits to each plot increased and number of survey plots increased (Table 6). For example, within the low detection probability ($p = 0.10$) and low probability of use (ψ = 0.20) simulation set, the lowest-effort scenario (25 survey plots, with 2 visits) had a failure rate of 97.4%, whereas the highest-effort scenario in this simulation set (75 survey plots, with 6 visits) had a failure rate of 15.9%. This pattern was consistent through all simulation sets (all levels of p and ψ) with, not surprisingly, failure rates declining as survey effort increased. However, our simulations also revealed that there were diminishing returns on failure reduction with increased effort at certain levels of ψ and p. For example, failure rates were <10% when $p = 0.30$ and ψ = 0.20 in the scenario with 25 survey plots visited 5 times each and in the scenario with 50 survey plots with 4 visits (Table 6). Considering only time spent conducting point-count surveys, 1-hr point-count surveys in each of the previous 2 scenarios would require 125 person-hours for the former and 200 person-hours for the latter. Similar to failure rates, biases (p and ψ) generally declined with increasing effort (Figs. S1–S6, Supporting Information). Bias of the parameter ψ was small and within ±0.05 of 0 for the majority of simulations, except when p was set to 0.10 and plots were visited 2 or 3 times (Figs. S4–S6, Supporting Information). For detection probability, increasing survey effort, both spatially and temporally, resulted in a reduction in detection probability bias (Figs. S1–S3, Supporting Information). However, with low detection probability, bias remained large even at high-effort simulations.

Table 6. Proportion of simulated data set resulting in failure of estimability of detection and occupancy probabilities under different scenarios of detection ($p = 0.10, 0.30, 0.50$) and occupancy probability ($\psi = 0.20, 0.35, 0.50$) in context of temporal (2–6 visits) and spatial (25, 50, and 75 survey plots) effort based on golden eagle data collected in Idaho, New Mexico, and Wyoming, USA, during 2012 and 2013. Each cell is the resulting probability of failure based on 1,000 simulation data sets for each set of parameters constituting the cell. Cell colors allow visualization of probability of estimation failure increasing from green to red.

		No. survey plots								
		$\psi = 0.20$			$\psi = 0.35$			$\psi = 0.50$		
Detection scenario	No. visits	25	50	75	25	50	75	25	50	75
$P = 0.10$	2	0.97	0.92	0.87	0.95	0.85	0.77	0.89	0.77	0.69
	3	0.85	0.75	0.66	0.78	0.66	0.47	0.70	0.52	0.37
	4	0.80	0.57	0.46	0.61	0.39	0.28	0.51	0.32	0.24
	5	0.67	0.44	0.31	0.51	0.25	0.16	0.38	0.24	0.18
	6	0.55	0.32	0.16	0.35	0.15	0.08	0.26	0.13	0.10
$P = 0.30$	2	0.67	0.40	0.26	0.49	0.18	0.10	0.36	0.18	0.12
	3	0.35	0.11	0.03	0.17	0.04	0.02	0.13	0.04	0.01
	4	0.16	0.03	0.00	0.05	0.00	0.00	0.04	0.01	0.00
	5	0.08	0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.00
	6	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
$P = 0.50$	2	0.33	0.07	0.03	0.12	0.01	0.01	0.10	0.03	0.01
	3	0.06	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
	4	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISCUSSION

The Eagle Conservation Plan Guidance (U.S. Fish and Wildlife Service 2013) specifically recommends 800-m radius (~200 ha) point-count surveys be conducted over a minimum period of 2 years to assess the use and distribution of golden eagles for a proposed wind-energy project area. Our data support the multiyear aspect of these recommendations because the raw detections of eagles varied annually. For preconstruction surveys, our data suggest results from single-year surveys are likely to be unreliable because of variance of the environmental and ecological conditions that influence eagle use, distribution, and activity patterns in a study area. Even multiple years of monitoring might not accurately provide a range of variance in eagle presence if those years are similar and consist of either ecologically favorable or unfavorable conditions such as weather and prey availability (Steenhof et al. 1997). Regional and local information about historical ecological conditions and golden eagle annual reproduction would be useful for deciding the minimum number of years necessary to estimate probability of use that is subject to varying environmental conditions.

Our survey plots were randomly placed along passible roads, so this convenience sampling might result in a biased estimation of eagle use in our study areas and inadequately have sampled areas for our selected covariates (e.g., topographic ruggedness and forest cover; Anderson 2001). To be clear, the Guidance does not specify that sample point be placed along roads (U.S. Fish and Wildlife Service 2013). However, our intent was to learn the effectiveness for the stated goal of determining eagle use when the recommended survey guidelines were applied (U.S. Fish and Wildlife Service 2013). To that end, we believe our design reflects a realistic situation and our findings are informative for revising recommendations and future survey design.

We observed substantive differences in detections between the brood-rearing and postfledging periods of our surveys. For NM and ID, we obtained more eagle detections during the brood-rearing period than the corresponding postfledging period, but not in WY. This difference in patterns of detection is confusing. It may be partially explained by greater foraging activity of adult eagles to provision their nestlings during the brood-rearing period. Alternatively, it could be expected that greater detections would occur during the postfledging period when juveniles would be out of the nest and moving about (albeit, remaining closer to nests). Thus, the difference in detections may be related to the density of the local breeding population in each study area and the proximity of survey points to eagle nests. Other possible explanations may relate to environmental conditions. The seasonally higher daytime temperatures observed during the postfledging period may have made eagles more sedentary as seen in red-tailed hawks (*Buteo jamaicensis*; Ballam 1984), made detection of eagles more difficult via heat haze, or have resulted in eagles engaging in thermal soaring at altitudes that decreased detectability. Regardless of the cause of this seasonal disparity, it suggests preconstruction surveys limited to narrow temporal periods might result in misleading interpretations as to the use of eagles within an area. The factors influencing activity patterns of adult eagles and the resulting potential for detecting their presence during different study periods (i.e., brood-rearing vs. postfledging) and the breeding season compared with non-breeding warrants further investigation (Marzluff et al. 1997).

The apparent increase of eagle detections with increasing survey-plot radius is intuitive and expected. Mechanistically, this may be due to an increase in sampled area *per se*, but also because the larger sampled area might contain a more varied landscape, including features that are attractive to eagles such as perches or more prey. Additionally, if golden eagles kept a minimum distance away from observers, small-radius survey plots may have inherently resulted in fewer eagle detections. Consistent with this, we found the number of eagle detections increased from the 800-m survey-plot radius to the unlimited survey-plot radius; however, data from the unlimited survey-plot radius subset must be viewed cautiously for several reasons. First, correct identification of eagles at great distances (i.e., >800 m) may be problematic, especially where the range of golden eagles overlaps with that of other large soaring birds (e.g., turkey vultures, ferruginous hawks [*Buteo regalis*]). Second, it is unlikely that as the survey-plot radius increases, all of the survey-plot area will be visible. Exceptionally large survey radii are likely to contain areas not visible to an observer at the center of a plot. Third, with larger survey-plot radii, it is likely that observers' ability to more thoroughly survey the entire 3-dimensional space is reduced, which might reduce detectability.

As with raw detections, the number of survey plots in which eagles were detected also increased with larger survey radii. However, there was not a 1:1 correspondence in these increases; the number of detections increased more rapidly than the number of survey plots considered used. We suspect that the discordance between the number of detections and the number of used plots was primarily due to double-counting of individuals during successive visits to a given survey plot.

The number of survey plots identified as used increased with increasing survey duration, but the strength of these increases varied among study areas and between sampling periods. For example, prolonging surveys from 20 min to 60 min during the brood-rearing periods in ID in 2012 and 2013 resulted in 2 and 3 additional survey plots where eagles were detected, respectively. However, in NM during the same sampling period and years, prolonging surveys from 20 min to 60 min resulted in an additional 9 and 5 survey plots, respectively, where eagles were detected. Increasing survey duration from 20 min to 60 min in WY resulted in a similar pattern as observed in NM, with eagles being detected within 10 additional survey plots. However, the pattern did not hold during the postfledging period, which resulted in only minimal increases to the number of plots estimated to be used. Taken together, the seasonal differences may suggest changes in activity patterns, with eagles in the brood-rearing period being more active than eagles in the postfledging period. Regardless, it appears that during our study period and sampling areas, prolonging surveys in the brood-rearing period was beneficial whereas doing so during the postfledging period was not as efficacious.

Use Modeling

Study areas.—Many of the covariates we examined have been used as indicators of likelihood of golden eagle use of areas. For example, eagles are known to largely avoid areas of dense, contiguous forest (Whitfield et al. 2001, Sandgren et al. 2014). Given the species' tendency to frequent and nest on cliffs (Kochert et al. 2002), an association with more rugged topography might be expected. We failed to find any consistent, strong relationship between these or any other covariates regardless of year, sampling period, or study area. Indeed, even the constant models of detection probability and probability of use (i.e., ψ (.) p (.)) were associated with large standard errors and a large degree of model uncertainty. We do not attribute this lack of effect to an absence of biological relationships, but rather to the relatively small number of detections among our survey plots. Despite the survey effort of 1,500 hr, the majority of plots where eagles were detected consisted of a single detection from the 3 visits. As a result of the paucity of eagle detections, relating frequency of detections to landscape features (e.g., forest cover) or covariates of individual surveys (e.g., temperature) was problematic. Such relationships among covariates and eagle detections can be valuable for determining the spatial and temporal use of an area by golden eagles prior to and following construction of wind energy facilities. Our results do not indicate consistent associations among detectability and environmental factors such as wind, temperature, or landscape features; therefore, we cannot offer guidance for improving detectability. Presently, survey design in environments such as our study areas requires greater effort to produce more detections, which are necessary for maximizing the utility of use modeling. Ultimately, our results illustrate the difficulty in detecting and estimating probability of use by golden eagles.

Survey duration and radius.—We obtained sufficient data only from WY to examine how detection probability and probability of use varied with survey duration and survey-plot radius. As expected, lengthening survey duration and increasing the survey-plot radius resulted in increases of the point estimates of these parameters. However, reducing the data set from the 800-m, 1-hr surveys to the smaller subsets resulted in increases to standard errors and hence, a decrease in precision. Although it is clear that estimates of these parameters will vary with the effort put forth, it is also clear that there is a minimum threshold below which survey efforts are inadequate for understanding the limits of detectability and estimating probability of use. It appears that threshold is relatively high for golden eagles in our study areas. For example, raw detections within 800-m-radius plots were ≤ 0.10. This suggests that even with an assumed 50% occupancy rate, 6 surveys of 75 plots would result in a failure of estimability 10% of the time.

Simulation.—An approach to identifying such thresholds for adequacy of golden eagle surveys in areas such as our study sites is data simulation. Our results confirm that detection probability and probability of use vary among study areas. Therefore, as recommended by MacKenzie and Royle (2005), surveys likely will be improved when tailored to the environmental circumstances of the study locale. Low detection probabilities (i.e., $p = 0.10$) appear to have a pronounced, deleterious effect on failure rate, ψ bias, and p bias—especially when survey effort is low to moderate. In areas where golden eagle detection probabilities are known or likely to be low, meaningful results will be contingent on greater survey efforts to counter such effects. Generally, increasing the number of survey plots, survey time, or distance to which golden eagles are detected will increase the number of detections obtained, but there are diminishing returns to survey efforts. When detection probabilities were set to 0.3 or 0.5, our simulations demonstrate that different combinations of spatial and temporal effort have similar failure rates and biases of ψ and p. In such cases, it may be possible to tailor survey methodology to better fit specific needs (i.e., broad spatial coverage vs. greater temporal coverage) or logistical constraints. Data from our simulations suggest that surveys with only 2 visits to each survey plot in a temporal period of interest can produce data with unacceptable bias and high probability of estimability failure except when detection probability and probability of use are relatively high. Within the parameters of our simulation, our results suggest that the appropriate number of repeat visits to survey plots would range from 3 to 5. Fewer visits could be made if detection probability was thought to be moderate to high (e.g., $\geq$0.30), probability of use is thought to be high (e.g., $\geq$0.35), or the number of survey plots is increased. More repeat visits likely would be needed when detection probability and probability of use are thought to be low or when few survey plots are used. Regardless, once a survey design is developed and implemented, resulting data can be used to confirm or update parameters used in the initial simulation and subsequently revise the survey design based on the new information.

The potential for using plot surveys and occupancy modeling is indicated by results of surveys for territorial pairs of golden eagles in a large (516,844 ha) California, USA, study area in a region with relatively high eagle density (Hunt and Hunt 2013, Wiens et al. 2015). Wiens et al. (2015) searched 133 sample plots (1,385 ha) on 4 occasions and recorded 899 detections of golden eagles, and consequently observed 98 territorial pairs of golden eagles at 87 sample plots. Occupancy modeling of these survey data indicated that the probability of detecting breeding golden eagles and their young during surveys was $<$1 and declined, as we found, with progression of the breeding season, further emphasizing the need to account for detectability. Use of historical information about golden eagles facilitated the Wiens et al. (2015) study design, as was the case for surveys of nesting golden eagles in Alaska, USA, by Martin et al. (2009), who analyzed results with occupancy modeling to address issues of golden eagle management. Historical data or data from pilot studies can be combined with simulations to estimate the effort required and maximize survey design. In both of the above studies, the limitations we experienced utilizing occupancy analysis were overcome by matching the survey scale to the biological scale at which the species operates (i.e., home range). The need for biologically relevant sampling units has recently been further highlighted by Hayes and Monfils (2015), who showed that a discordance between home range size and sample plot size resulted in large biases in occupancy estimates.

ACKNOWLEDGMENTS

Many individuals in the U.S. Geological Survey and U.S. Fish and Wildlife Service have contributed to our formulation of objectives in the context of research needs for developing a Golden Eagle Management Plan. We have had discussions with many members of the Eagle Technical Assistance Team, which has been convened by the U.S. Fish and Wildlife Service. We especially want to thank B. Millsap and J. Nichols for their advice during study planning. Additionally, many individuals assisted with data collection in the field, data entry, and quality control, and we thank them for their efforts. We thank the people of the Jicarilla Apache Nation for allowing access to their lands and assisting with logistical planning in New Mexico. Additionally we thank L. Keith of the U.S. Bureau of Land Management Rock Springs, Wyoming Field Office; J. Holderman of the Morley Nelson Snake River Birds of Prey National Conservation Area, Idaho; and D. Stahlecker of Eagle Environmental, Inc., for their assistance with logistics and planning. C. Gulick, R. Perkins, and A. Teague assisted with data collection. We thank M. Kochert, D. Weins, R. Murphy, an anonymous reviewer, and Associate Editor S. Ellis-Felege for providing comments and suggestions that improved the manuscript. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Associate Editor: Ellis-Felege.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.

Tables S1–S13 include data summaries for estimates of detection and occupancy of golden eagles given different survey radii, survey period lengths, breeding period (brood-rearing or postfledging), year (2012 or 2013), and location (Idaho, New Mexico, Wyoming, USA).

Figures S1–S6 include estimates of bias in parameters of detection (*p*) and use (Psi) when *p* and Psi set at different levels in context of different numbers of survey plots (25, 50, or 75) and different numbers of visits to each plot (2–6).