

A Survey of Golden Eagles (*Aquila chrysaetos*) in the Western U.S.: 2006–2015



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500 Golden Avenue SW, Room 11515
Albuquerque, New Mexico 87102

Prepared by:

Ryan M. Nielson, Guy T. DiDonato, and Lyman L. McDonald

Western EcoSystems Technology, Inc.
415 West 17th St., Suite 200, Cheyenne, WY 82001

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SUGGESTED CITATION

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ABSTRACT

We flew aerial line transect surveys using distance sampling and mark-recapture procedures to estimate Golden Eagle (*Aquila chrysaetos*) abundance in 4 Bird Conservation Regions (BCRs) in the western United States between 15 August and 15 September, 2015. The study area consisted of BCRs 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies). In 2015, we flew 220 transects totaling 17,586 km. We observed 144 Golden Eagle groups within 1,000 m of 72 transects for a total of 179 individuals: 31 juveniles, 28 sub-adults, 50 adults, 4 unknown immatures (not adults), and 66 unknown adults (not juveniles). We estimated that a total of 6,431 Golden Eagles (90% confidence interval: 4,206 to 9,351) were within the Great Basin (9) during the survey period, a total of 4,884 (90% confidence interval: 2,901 to 7,512) were within the Northern Rockies (10), a total of 2,535 (90% confidence interval: 1,224 to 3,242) were within the Southern Rockies / Colorado Plateau (16), and a total of 6,877 (90% confidence interval: 4,384 to 9,964) were within the Badlands and Prairies (17). These estimates do not include Golden Eagles that were occupying military lands, elevations above 3,048 m (10,000 ft), large water bodies, or large urban areas. We used a Bayesian hierarchical model to estimate trends in individual BCRs and the entire study area. We did not find evidence of trends in total eagle numbers in most individual BCRs or the entire study area during 2006–2015, but we did detect a statistically significant positive trend in the Great Basin (9) over the 10-year period. The total number of Golden Eagles classified as juveniles during the survey in individual BCRs and the entire study area did not show evidence of trends during 2006–2015.

INTRODUCTION

The Golden Eagle (*Aquila chrysaetos*) is one of North America's largest raptors and is currently protected under the Migratory Bird Treaty Act (16 United States Code 703–712) and the Bald and Golden Eagle Protection Act (16 United States Code 668–668d; hereafter Act). In 2009, the United States (U.S.) Fish and Wildlife Service (Service) issued regulations under the Act that established conditions under which the Service could permit lethal take and disturbance of Golden Eagles. The Act delegates to the Secretary of the Interior the ability to permit take of the eagle “necessary for the protection of other interests in any particular locality” if the take is “compatible with the preservation of the bald eagle or golden eagle,” which is defined as no net-decrease in the number of breeding pairs within regional geographic management units (Bird Conservation Regions; BCRs; U.S. Fish and Wildlife Service 2009). For more discussion on permitting take of Golden Eagles and the need for accurate population trend and size data for Golden Eagles, see Millsap et al. (2013).

Other than work conducted by researchers at the Snake River Birds of Prey Natural Area in Idaho (Steenhof et al. 1997, Kochert et al. 1999) and Denali National Park (McIntyre and Schmidt 2012), few long-term monitoring studies of Golden Eagle populations have been

conducted in the western U.S. (for examples see Leslie 1992, Bittner and Oakley 1999, McIntyre and Adams 1999, McIntyre 2001, McIntyre and Schmidt 2012), and those have been limited in geographic range. Thus, survey-based estimates of numbers of Golden Eagles in the western U.S. were unavailable until 2003, when we designed and conducted the first aerial line transect distance sampling (DS; Buckland et al. 2001) survey for Golden Eagles across 4 BCRs in the western U.S. (Good et al. 2007).

The goal of the 2003 survey was to develop and test methods for estimating population size and monitoring trends of Golden Eagles across the 4 BCRs. The survey was originally designed, and then adjusted after 2003, to allow detection of an average 3% decline per year in the eagle population over a 20-year period with statistical power ≥ 0.8 , using a 90% confidence interval (CI; equivalent to $\alpha = 0.1$). Based on results of the 2003 survey (Good et al. 2007), a new, systematic sample of transects was generated to increase sample sizes (number of transects and number of observations) to levels necessary to meet our goal. This new sample comprising about 17,500 km of transects was surveyed annually during 2006–2015 (Table 1; Figure 1), with exception of transects in BCR 17 (Badlands and Prairies), which were not surveyed in 2011 (Nielson et al. 2012). In addition to generating a new sample of transects after the 2003 survey, we modified the survey protocol to improve safety and standardize criteria for aging Golden Eagles, and we developed new statistical methods for estimating abundance and detecting trends (Nielson et al. 2014). Here we describe methods for surveys conducted during summer months (August and September) 2006–2015 and report findings from our analysis of abundance and trends of the Golden Eagle population.

STUDY AREA

The study area consisted of BCRs 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies) within the U.S. (Figure 1). These regions collectively covered about 80% of the range of the Golden Eagle in the coterminous western U.S. (U. S. Fish and Wildlife Service 2009). Habitat types across these BCRs ranged from low-elevation sagebrush and grassland basins to high-elevation coniferous forests and mountain meadows. Areas within these regions containing Department of Defense (DOD) lands, urban areas, large bodies of water greater than 30,000 ha, and terrain above 3,048 m (10,000 ft) were excluded from this study. These no-fly zones covered 6.7% of the total study area and were not surveyed for safety reasons, or in the case of DOD lands, because access was problematic. The total area in the sample frame for 2006–2010 and 2012–2015, containing all 4 BCRs, was 1,962,909 km² (Figure 1).

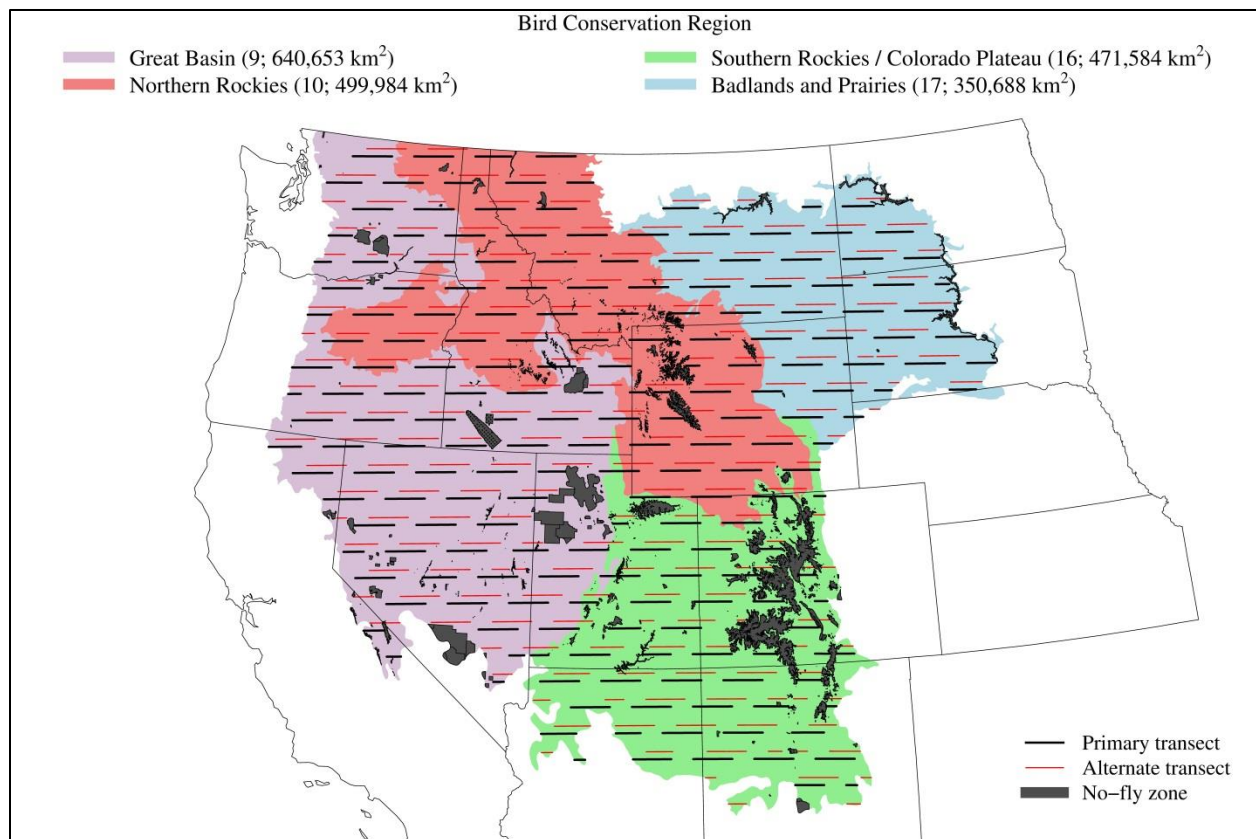


Figure 1. Study area and survey transects for the western-wide Golden Eagle survey.

METHODS

Surveys

We conducted DS surveys from 15 August to 15 September each year, after all juvenile Golden Eagles were expected to have fledged and before most Golden Eagles had begun their fall migration (Fuller et al. 2001). We established transects by randomly overlaying the study area with 2 systematic sets of 100-km long, east-west transects (systematic sample with a random start). The first systematic set contained the primary transects. The second set contained alternate transects surveyed to recoup lost primary transect lengths in the event that a nearby primary transect could not be flown (e.g., due to a forest fire or localized weather event). After removing portions of transects extending outside the study area or over no-fly zones, each systematic set comprised about 17,500 km of transects. We attempted to survey all primary transects each year using 2 crews in Cessna 205 and 206 fixed-wing aircraft. In 2013, one of our aircraft experienced major mechanical difficulties and we were forced to continue the survey with a Cessna 185, which has a smaller back seat than a 205/206 but windows of the same size, thus visibility was consistent with past years. In 2015, we used one Cessna 206 and one Kodiak fixed-wing aircraft. Both planes and their crews flew a series of training transects prior to the survey's start to examine potential issues affecting eagle observations from these two planes.

Surveys began at sunrise and were terminated by 1330 hours. Early morning transects were flown from east to west to provide the best possible lighting for detecting Golden Eagles. Surveys were flown at about 160 km/hr. We flew at 107 m above ground level (AGL) over open, level to rolling terrain, and at 150 m AGL over forested, rugged, or mountainous terrain. The general survey sequence for flying transects was consistent during 2006–2010, and 2012–2015.

Relatively low precision (relative CI half-width > 55%; Nielson et al. 2012) of estimates of Golden Eagle densities in BCR 16 during 2006–2010 prompted us to double our survey effort in that BCR in 2011 compared to previous years to provide insight into the relationship between survey effort and precision. To double our survey effort in BCR 16 in 2011, without increasing project costs, we did not survey transects in BCR 17 – the BCR with historically the largest and most precise density estimates. We surveyed newly added transects in BCR 16 in 2011 solely to assess the value of increasing survey effort in that region and did not include the data in the analyses presented here to maintain consistency in data sources across years and our study of trends in abundance.

We verified the species, number, and age classes of each group (≥ 1 individual) of flying and perched Golden Eagles sighted and measured perpendicular distances from the transect line to each group by flying off transect and recording the group's location via global positioning system (GPS). We also used GPS to record the location of flying Golden Eagles where they were first observed. GPS coordinates, including aircraft flight paths, were recorded in a laptop computer using Garmin's nRoute software (Garmin International, Inc., 1200 E. 151st St., Olathe, KS 66062). We tried to visually track flying eagles to avoid double-counting along the same transect. Random movement of eagles between transects, though unlikely due to long distances between transects (> 57 km) and our rate of travel during the survey, should not have affected our density estimates (Buckland et al. 2001). We used plumage characteristics (Clark 2001, Clark and Wheeler 2001, Bloom and Clark 2002) to assign 1 of 6 age classes to each Golden Eagle observed. Each crew consisted of 3 observers – 2 seated side-by-side in the back seat and the third in the front-right seat of the aircraft – and all observers on each crew used a decision matrix (Figure 2) to reach a consensus on age classification of each Golden Eagle detected.

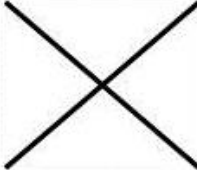
Tawny bar	?	Unknown immature	Adult	Unknown
	No	Juvenile		Juvenile
	Yes	Sub-adult	Adult	Unknown adult
Aging		Yes	No	?
		White on tail or wings		

Figure 2. Golden Eagle age classification decision matrix used during surveys conducted 2006–2015.

Line transect DS methods require knowing or estimating the probability of detection at some distance from the transect line (Buckland et al. 2001). We used mark-recapture (double-observer; Pollock and Kendall 1987, Manly et al. 1996, McDonald et al. 1999, Seber 2002) DS methods to estimate the probability of detection as a function of the distance from the transect line and observer position (front vs. rear seats). During mark-recapture sampling, we recorded Golden Eagles that were detected by the front-right observer but not detected by the back-right observer, eagles detected by the back-right observer and missed by the front-right observer, and eagles detected independently by both right-side observers. Observers rotated seats daily to allow for estimating the average probability of detection, regardless of observer, from the front and rear seats of the aircraft. We recorded survey data that allowed us to evaluate probability of detection as a function of the observer's position in the aircraft, AGL, the bird's behavior (flying or perched), and distance from the transect line.

We conducted mark-recapture trials on the right side of the aircraft during all surveys, with the exception of 68 transects flown in 2008 (Nielson et al. 2010). Transects surveyed by only 2 observers in 2008 were surveyed from the front-right and back-left positions. Mark-

recapture trials required observers on the aircraft's right side to search for and detect Golden Eagles independently of one another, so we installed a cardboard wall as a visual barrier between the 2 observers. In addition, when a Golden Eagle group was detected by an observer on the right side, several seconds were allowed to pass before the observation was communicated to the other observers. This allowed time for both observers to independently detect or not detect each group.

Statistical Analysis

Estimating abundance. Our approach to estimating Golden Eagle abundance generally followed the mark-recapture DS procedure described by Borchers et al. (2006) and consisted of 4 steps: 1) estimating the shape of the detection function, 2) using the mark-recapture data to properly scale the detection function, 3) integrating the scaled detection function to estimate the average probability of detection within the search width, and 4) applying standard DS methods to inflate the number of Golden Eagles observed by the average probability of detection and to estimate Golden Eagle density for each BCR each year (Buckland et al. 2001).

Lower detection probabilities at the nearest available sighting distance compared to longer distances farther from the transect line have been documented for surveys from fast moving aircraft (Becker and Quang 2009). Given the speed at which the aircraft moves, objects closer to the transect line can be in an observer's field of view for less time, and thus, more difficult to detect. Indeed, some detection functions estimated from survey data collected during 2006–2015 had a substantial peak around 300 m from the transect line. For this reason, we used a non-monotonic, non-parametric, Gaussian kernel estimator (Wand and Jones 1995) to model shapes of detection functions (step 1; Chen 1999, 2000) as a function of distance from the transect line, rather than the less flexible detection functions available in the program Distance (v6.0; Thomas et al. 2006). The kernel density estimator used was of the form

$$\hat{f}(x) = (nh)^{-1} \sum_{i=1}^n K\left(\frac{x - x_i}{h}\right), \quad [1]$$

where x was a random perpendicular distance within the range of observed distances, x_i was one of the n observed distances, h was a smoothing parameter (bandwidth), and K was a kernel function satisfying the condition $\int K(x)dx = 1$. Estimation of the smoothing parameter (h) followed the “plug-in” procedure described by Sheather and Jones (1991). Based on theoretical considerations and recommendations in Park and Marron (1992), we used 2 iterations (l) of functional estimation for our analysis.

Perpendicular distances have a boundary at the minimum available sighting distance. The kernel density estimator does not perform well near discontinuities such as sharp boundaries (Wand and Jones 1995), so we reflected the observed distances to both sides of 0 along the number line for density estimation (Chen 1996, 1999, 2000) after subtracting the minimum sighting distance (W_1) from the observed distances. Following kernel estimation, we only used the portion of the detection function to the right of 0. Analyses of historic data beginning in 2006 has not indicated that shapes of detection functions differ between front and back seat observers,

so all observations from the 3 observer positions in the aircraft were used to estimate detection functions using equation [1].

Instead of assuming probability of detection was known at some distance from the transect line (Buckland et al. 2001), we used the mark-recapture trials to estimate probability of detection at the distance from the transect line where probability of detection was highest, assuming point independence at that distance (Borchers et al. 2006). At the distance where detection rates were highest, we assumed that the kernel distance function should equal the mark-recapture detection probability, and so we scaled the kernel function appropriately (step 2; Borchers et al. 2006).

Analysis of the mark-recapture data involved estimating the conditional probability of detection by the front seat observer (observer 1) given detection by the back seat observer (observer 2) at distance x_i (labeled $p_{1|2}(x_i)$), and the probability of detection by observer 2, given detection by observer 1 (labeled $p_{2|1}(x_i)$). We used logistic regression (McCullagh and Nelder 1989) to model the conditional probability of detection for observer j ($j=1,2$) using equations

$$p_{j|3-j}(x_i) = \frac{\exp(\beta_{j|3-j} X_i)}{1 + \exp(\beta_{j|3-j} X_i)}, \quad [2]$$

where $\beta_{j|3-j}$ was the vector of coefficients to be estimated for observer j given detection by observer $3-j$, and X_i was a matrix of distance covariates. We considered 3 logistic regression models where probability of mark-recapture success was (1) constant at all distances (i.e., intercept term only), or related to a (2) linear or (3) quadratic function of distance from the transect line. For each observer position, we chose the model with the lowest value of the second-order variant of Akaike's Information Criterion (AICc; Burnham and Anderson 2002). Since mark-recapture trials were only conducted on the right side of the aircraft, we assumed probability of detection by the back-left observer (observer 3) was same as $p_{2|1}$ because both back seat positions had the same visibility, and we regularly rotated observers among different positions in the aircraft.

Although observers behaved independently within the aircraft, observers on the right side shared the same sighting platform, and thus, groups of Golden Eagles that were more likely to be detected by observer 1 were also more likely to be detected by observer 2. To properly scale the detection function (equation [1]), we needed to assume that the unconditional probability of detection $p_j(x_i)$ equaled the conditional probability of detection $p_{j|3-j}(x_i)$ at some distance from the transect line. The conditional probability is related to the unconditional probability as $p_{j|3-j}(x_i) = p_j(x_i)\delta(x_i)$, where $\delta(x_i)$ can be thought of as a bias factor (Borchers et al. 2006). Because $\delta(x_i)$ cannot be estimated from mark-recapture data (Borchers et al. 2006), we chose the distance from the transect line at which most observations occurred as the most likely candidate for offering a scenario where $\delta(x_i) = 1$, which allowed us to use the conditional estimates of probability of detection (equation [2]) to scale the detection functions. We identified where the largest number of observations by the front and back seat observers occurred based on

the location of the maximum value of the estimated kernel detection functions (Borchers et al. 2006). Observations at this distance were least likely to depend on unmeasured factors that might have affected the detection process, and most likely to provide point independence. We then scaled the detection function (equation [1]) so that the maximum height of the function was equal to mark-recapture probability (equation [2]) at the distance where the maximum occurred. For example, if the maximum of the kernel detection function for the back-left observer was at a distance of $x_{\max[\hat{f}(x)]} = 200$ m, and the mark-recapture probability of detection at 200 m for the back seat observer was estimated as $\hat{p}_{2|1}(200) = 0.8$, then the kernel function (equation [1]) would be scaled such that $\hat{f}(200) = 0.8$. When only 2 observers were in the aircraft, we scaled the detection function for the front-right observer such that $\hat{f}(x_{\max[\hat{f}(x)]}) = \hat{p}_{1|2}(x_{\max[\hat{f}(x)]})$. We calculated the conditional probability of detection on the right side of the aircraft at distance x_i by at least 1 observer when both observers were present was calculated as (Borchers et al. 2006)

$$\hat{p}^c(x_i) = \hat{p}_{1|2}(x_i) + \hat{p}_{2|1}(x_i) - \hat{p}_{1|2}(x_i)\hat{p}_{2|1}(x_i), \quad [3]$$

and the detection function for observations on the right side of the aircraft when both right side observers were present was scaled such that $\hat{f}(x_{\max[\hat{f}(x)]}) = \hat{p}^c(x_{\max[\hat{f}(x)]})$.

We estimated separate detection functions and average group sizes for groups of Golden Eagles observed flying, observed perched from 107 m AGL, and observed perched from 150 m AGL. One difference among these 3 observation types was the minimum observable perpendicular distance to Golden Eagle groups from the transect line. Golden Eagles in flight might be detected when directly on or near the transect line, but might not be seen if perched directly below the aircraft. When flying at 107 m AGL over level to rolling, open habitats, a 50-m wide swath beneath the aircraft (i.e., 25 m on either side) could not be viewed (Good et al. 2007). When flying at 150 m AGL over other habitat types, the invisible swath was 80-m wide. Thus, the minimum available sighting distance (W_1) was set to 25 m and 40 m for perched birds observed when surveying from 107 m and 150 m AGL, respectively. New flight helmets were used by observers beginning in 2015 that reduced the visible search area. For 2015, the minimum available sighting distance (W_1) was set to 39 m and 55m for perched birds observed when surveying from 107 m and 150 m AGL, respectively. Observers recorded all Golden Eagle observations regardless of distance from the transect line, though the average probability of detection was estimated out to 1,000 m (W_2).

Analysis of the survey data from 2006–2015 did not show evidence that detection rates are trending (e.g., that observers are improving). Given consistent survey methods since 2006, we pooled all data during 2006–2015 to estimate the shapes of the detection functions (step 1; equation [1]) and to scale those detection functions (step 2; equations [2] – [3]). Pooling data across years reduced year-to-year variability in detection functions due to small sample sizes within a given survey period. We updated past estimates upon inclusion of 2015 survey data for estimation of average probabilities of detection.

We calculated density estimates for all Golden Eagles, including juveniles and other non-breeding individuals, using a standard distance formula (Buckland et al. 2001),

$$\hat{D} = \frac{\sum_{i=1}^n s_i}{2(W_2 - W_1)L\bar{P}}, \quad [4]$$

where n was the number of observed Golden Eagle groups; s_i was the size of the i^{th} group; W_1 and W_2 were the minimum and maximum sighting distances, respectively; L was the total length of transects flown (thus, $2[W_2 - W_1]L$ was the total area searched); and $\bar{P}$ was the estimated average probability of detection within the area searched ($\hat{P}_a$ in Buckland et al. 2001:53).

We first calculated the total area searched for perched birds across all transects based on the AGL flown and estimated the density of perched birds ($\hat{D}_p$). Then, we estimated the density of flying Golden Eagles ($\hat{D}_f$) using $W_1 = 0$. Finally, we estimated total density for a BCR as $\hat{D}_p + \hat{D}_f$. We calculated the estimated density for the entire study area as an area-weighted average of BCR densities (Buckland et al. 2001).

More large groups of individuals may be detected from a transect line compared to smaller groups or individuals (Buckland et al. 2001). If so, average group size could be overestimated (Buckland et al. 2001) and introduce bias in equation [3]. We used Pearson's correlation analysis to investigate the relationship between group size and distance from the transect line. If the 90% CI for the estimated correlation coefficient did not include 0.0, indicating a statistically significant relationship, we used the truncation method (Buckland et al. 2001) to estimate average group size. Otherwise, we used the original group sizes.

We bootstrapped (Manly 2006) individual transects flown 2006–2015 to estimate 90% CIs for projected Golden Eagle abundance within each BCR and the entire study area. This process involved taking 10,000 random samples with replacement and re-running the analysis steps 1–4 to produce new estimates of Golden Eagle abundance. We calculated CIs based on the central 90% of the bootstrap distribution (the percentile method). We used the R language and environment for statistical computing (v3.2.2; R Development Core Team 2015) to estimate yearly densities and population totals in each BCR and the entire study area.

Estimating trends. We estimated trends (average rate of population change) in the numbers of Golden Eagles along transects during surveys from 2006–2015 using the methods described by Millsap et al. (2013). We first fit a log-linear hierarchical model (Gelman and Hill 2007) fit using Markov chain Monte Carlo (MCMC) methods. We then calculated annual density ($\#/\text{km}^2$) of Golden Eagles in each BCR as a function of the model, and finally we calculated trends by BCR and for all BCRs combined as the average population change from 2006 to 2015 based on the index described by Sauer and Link (2011).

The structure of the log-linear hierarchical model was

$$\log(\lambda_{i,j,a,b,c,t}) = \log(A_{j,a,b,c}) + \log(P_{a,b,c}) + S_{i,c} + \beta_{i,c}T_t^* + \gamma_{i,c,t} + \omega_{j,c} + \varepsilon_{i,j,a,b,c,t} \quad [5]$$

where we assumed that the density of Golden Eagles along each section of transect was from an overdispersed Poisson distribution with an expected value λ that was specific for each BCR (i),

transect (j), detection class (a , b , and c), and year (t). In this model, A represented the area sampled for each detection class along transects and P represented the detection probability. Area sampled was based on W_1 and W_2 , and the length of transect j flown at each AGL. The indices a , b , and c were associated with detection classes. Detection probabilities for perched Golden Eagles were different over gentle terrain flown at 107 m versus rugged terrain flown at 150 m (indexed by a). Detection probabilities also varied according to the side of the aircraft (indexed by b) and behavior (flying vs. perching birds; indexed by c). The S and β represent BCR-specific intercept and slope parameters for underlying trends over the time series, and we centered years on the median value (i.e., $T_t^* = t - \text{median year}$). Separate estimates of trend (β) and random (ε) effects were estimated for perched and flying birds, and we included random BCR-year random effects (γ) and transect random effects (ω).

We incorporated uncertainty associated with the detection probabilities by sampling probabilities, P , from normal distributions with means and variances estimated from the data collected 2006–2015. We specified vague prior distributions (Link et al. 2002) to begin the MCMC sampling. Parameters for BCR effects and the time trend at the study-area level were assigned relatively flat normal distributions with mean of 0.0 and variance of 100. Parameters at the BCR level were assigned normal distributions with means equal to the study-area parameters and standard deviations (SD) $\sim \text{Uniform}(0, 100)$. Random year by BCR effects, transect effects, and overdispersed Poisson errors were assigned mean 0.0 normal distributions with SD $\sim \text{Uniform}(0, 100)$. We determined the appropriate burn-in and chain length (Link et al. 2002) by visual inspection of trace plots using 4 chains and 50,000 iterations. Final models were fit using 4 chains containing 30,000 iterations following a 50,000-iteration burn-in. The model was fit using WinBUGS (Lunn et al. 2000, Spiegelhalter et al. 2003) to estimate posterior distributions of the unknown parameters.

We calculated annual density ($\#/\text{km}^2$) estimates of Golden Eagles in each BCR as a function of the model (equation [5]) parameters using (Millsap et al. 2013)

$$n_{i,t,c} = \exp(S_{i,c} + \beta_{i,c}T_t^* + \gamma_{i,t,c} + 0.5\sigma_{w_c}^2 + 0.5\sigma_{\varepsilon_c}^2), \quad [6]$$

where $\sigma_{w_c}^2$ and $\sigma_{\varepsilon_c}^2$ represented estimated variances for the transect effects and random effects, respectively. Note that perched birds were indexed as $c = 1$ and flying birds as $c = 2$, and we summed these 2 densities to estimate a total density in each BCR for each year.

We calculated trends by BCR (B_i) as the average population change from 2006 to 2015 based on the index described by Sauer and Link (2011):

$$B_i = \left(\frac{N_{i,2006}}{N_{i,2015}} \right)^{1/(2015-2006)} \quad [7]$$

where N is the total estimated population size for both flying and perched birds. We also calculated trend for all BCRs combined using the same method. Ninety-percent credible intervals (CRIs; Bayesian confidence intervals) were used to determine if the average rates of change in abundance were statistically significant at the $\alpha = 0.1$ level. If a 90% CRI for time trend at a BCR or study area level contained 1.0, we concluded that the observed trend was not strong enough to statistically conclude it was real. We applied the trend analysis to the total counts of Golden

Eagles observed along each transect and also to the counts of Golden Eagles classified as juveniles.

We did not include the additional transects flown in BCR 16 in 2011 in the trend analysis in order to maintain consistency to other years (i.e., 2006–2010, 2012–2015). Including counts from the additional transects would add little information to the trend analysis, since those transects were only surveyed in one year. Since BCR 17 was not surveyed in 2011, it contributed less information to the MCMC process and estimates of trend for the entire study area. Similarly, alternate transects flown on an irregular basis contribute less to estimates of BCR effects and trends.

RESULTS

Abundance

The two aircraft and their crews flew six common training transects (usually within 30 to 60 minutes of each other) prior to surveys. During these training flights, the crew in the Kodiak observed more eagles (1.9 perched eagles/transect) on the common transects (compared to 0.7 perched eagles/transect), after removing those eagles flushed by the first survey plane. After the survey began, the crew in the Kodiak plane flew transects primarily in BCRs 9 and 16, while the crew in the Cessna 206 flew transects in BCRs 9, 10, and 17.

In 2015, we flew 220 (partial and complete) transects totaling 17,586 km in the study area (Tables 1 and 2). We observed 144 Golden Eagle groups within 1,000 m of the transect line along 72 transects (Figure 3) for a total of 179 individuals (Figure 4): 31 juveniles, 28 sub-adults, 50 adults, 4 unknown immatures, 59 unknown adults, and 7 of unknown age (Figure 5). Average Golden Eagle group size did not increase with perpendicular distance from the aircraft for observed Golden Eagle groups within 1,000 m of the transect line in 2006–2015. Mean group size across years was 1.21 ($SE = 0.01$).

Table 1. Total length (km) of transects flown in each Bird Conservation Region for summer surveys conducted 2006–2015.

Year	Great Basin (9)	Northern Rockies (10)	Southern Rockies / Colorado Plateau (16)	Badlands and Prairies (17)	Total
2006	6,016	4,606	3,966	3,143	17,731
2007	5,861	4,572	3,998	3,245	17,676
2008	5,773	4,563	3,958	3,124	17,418
2009	5,934	4,728	3,807	3,147	17,616
2010	5,911	4,557	3,939	3,201	17,608
2011	5,820	4,585	3,880	— ^a	14,285
2012	5,868	4,531	3,919	3,169	17,487
2013	6,001	4,587	3,898	3,164	17,650
2014	5,893	4,527	3,956	3,177	17,553
2015	5,898	4,515	4,014	3,159	17,586

^aBCR 17 was not surveyed in 2011.

Table 2. Number of primary (Prm.) and alternate (Alt.) transects surveyed in each Bird Conservation Region during each summer survey conducted 2006–2015.

Year	Great Basin (9)		Northern Rockies (10)		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)	
	Prm.	Alt.	Prm.	Alt.	Prm.	Alt.	Prm.	Alt.
2006	71	10	58	9	54	4	39	1
2007	72	3	59	5	52	3	39	1
2008	76	2	63	5	58	3	38	0
2009	79	2	64	4	56	5	39	0
2010	79	1	65	2	58	4	38	1
2011	78	1	63	1	57	2	— ^a	— ^a
2012	78	3	62	4	59	3	39	0
2013	76	4	64	2	59	2	38	0
2014	79	0	64	1	59	3	37	1
2015	78	4	64	6	59	4	39	0

^aBCR 17 was not surveyed in 2011.

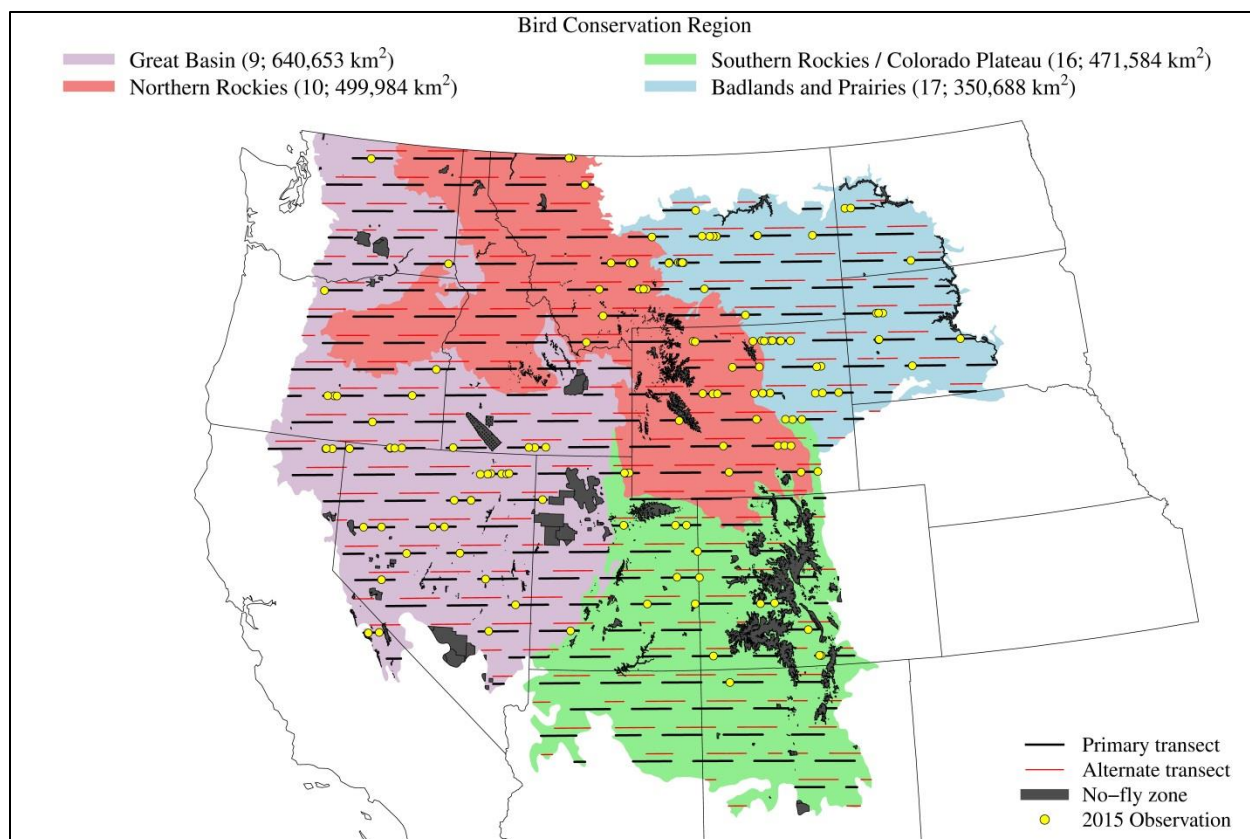


Figure 3. Study area for the annual Golden Eagle survey, with observations of Golden Eagle groups observed during the 2015 summer survey.

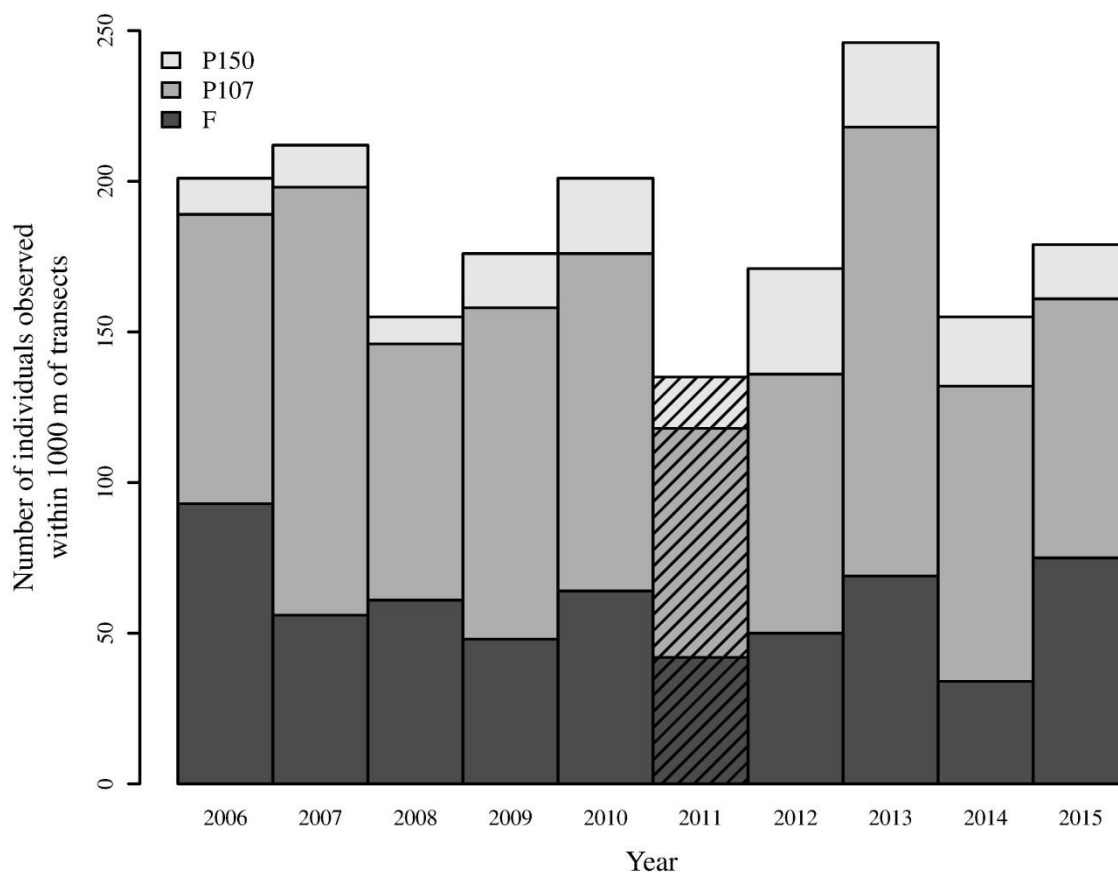


Figure 4. Number of Golden Eagles observed within 1,000 m of transect lines during summer surveys conducted 2006–2015. Observation types (detection classes) are perched and observed from 150 m AGL (P150), perched and observed from 107 m AGL (P107), and flying (F). BCR 17 was not surveyed in 2011, as indicated by the cross-hatched bar.

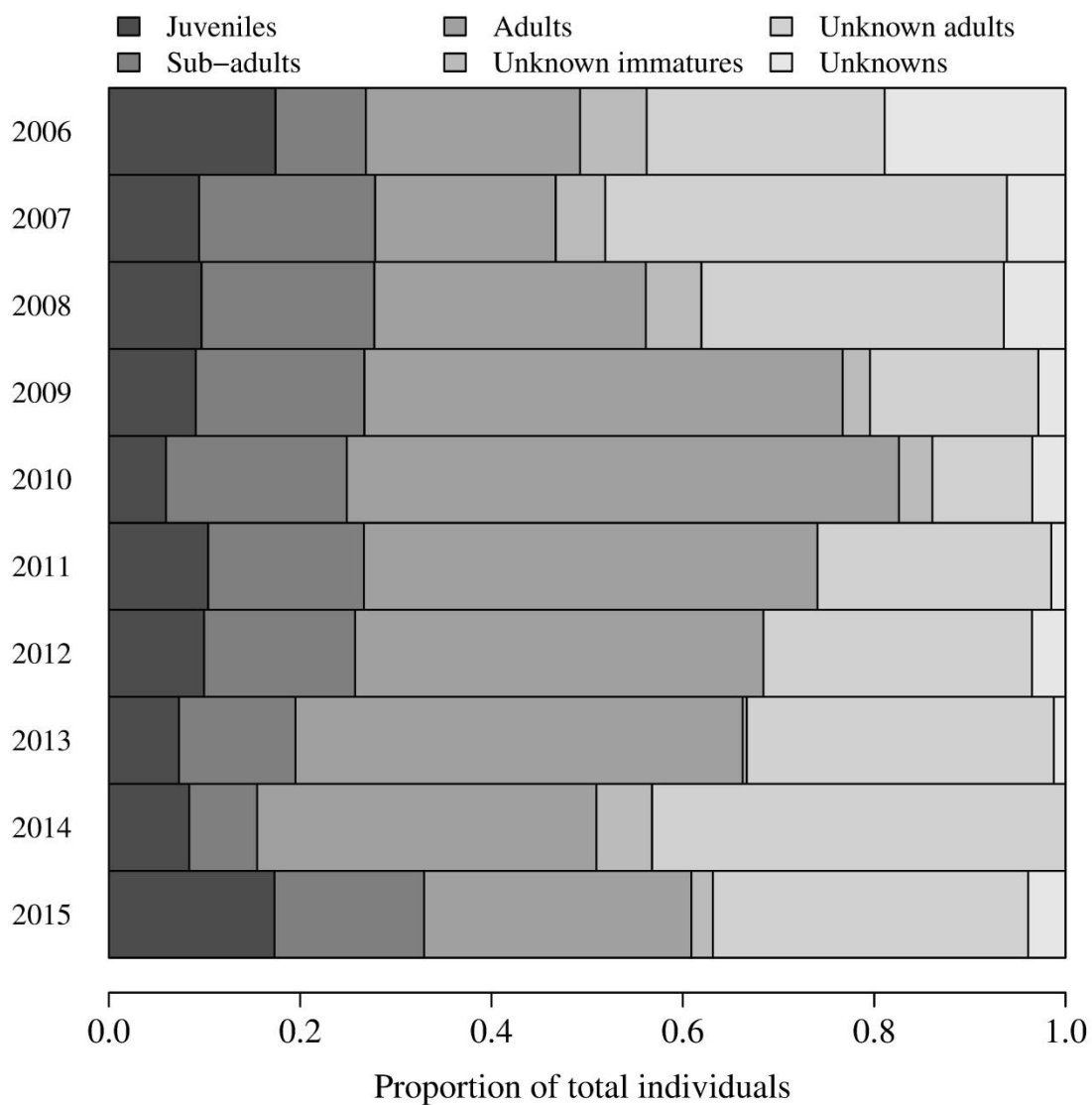


Figure 5. Age classifications of all Golden Eagles observed within 1,000 m of transect lines during summer surveys conducted 2006–2015.

The total number of observations of perched Golden Eagle groups when the aircraft was 107 m AGL, perched groups when the aircraft was 150 m AGL, and flying groups are shown in Table 3. Scaled detections functions, along with estimated average probabilities of detection ($\bar{P}$), are shown in Figure 6.

Table 3. Numbers of Golden Eagle groups observed within 1,000 m of survey transects during summer surveys conducted 2006–2015 categorized by observation type: perched and observed from 107 m above ground level (AGL), perched and observed from 150 m AGL, and flying.

Year	Observed perched from 107 m AGL	Observed perched from 150 m AGL	Observed flying	Total
2006	74	9	74	157
2007	115	11	46	172
2008	73	8	52	133
2009	90	15	43	148
2010	97	21	50	168
2011 ^a	67	17	33	117
2012	74	25	42	141
2013	123	22	62	207
2014	81	19	31	131
2015	67	15	62	144
Total	861	162	495	1,518

^aBCR 17 was not surveyed in 2011.

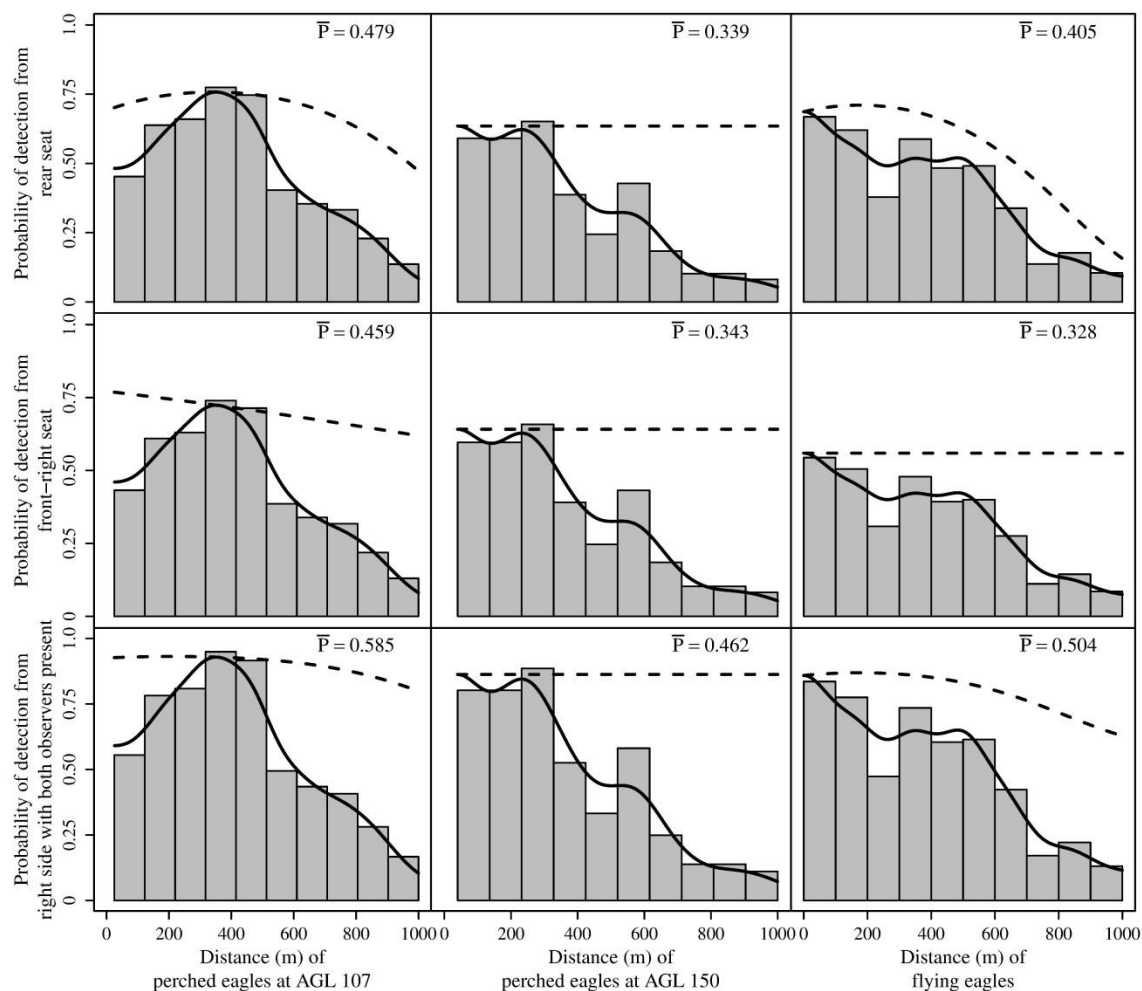


Figure 6. Probability of detection of perched Golden Eagle groups from 107 and 150 m AGL and probability of detection of flying Golden Eagle groups during summer surveys conducted 2006–2015. Dashed lines represent probabilities of detection estimated from mark-recapture sampling. Solid lines represent scaled detection functions that were integrated and divided by the search width to estimate the average probability of detection ($\bar{P}$) within 1,000 m of the transect line. Histograms show the relative numbers of observations in each distance interval.

Based on estimated densities of Golden Eagles within each BCR (Table 4), during late summer of 2015 we projected a total of 6,431 Golden Eagles (90% CI: 4,206–9,351) in BCR 9, 4,884 (90% CI: 2,901–7,512) in BCR 10, 2,535 (90% CI: 1,224–3,242) in BCR 16, and 6,877 (4,384–9,964) in BCR 17 (excluding military lands, elevations above 3,048 m [10,000 ft], large water bodies, and large urban areas) (Table 5, Figure 7).

Table 4. Estimated mean densities of Golden Eagles (#/km²) of all ages in each Bird Conservation Region (excluding no-fly zones) in the late summer of 2003 and 2006–2015^a. Upper and lower limits for 90% confidence intervals are to the right of each estimate.

Year	Great Basin (9)		Northern Rockies (10)		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)	
2003	0.0170	0.0240 0.0120	0.0090	0.0170 0.0040	0.0100	0.0140 0.0060	0.0180	0.0250 0.0130
2006	0.0066	0.0097 0.0041	0.0117	0.0182 0.0068	0.0086	0.0125 0.0057	0.0263	0.0372 0.0181
2007	0.0090	0.0124 0.0064	0.0136	0.0217 0.0077	0.0056	0.0083 0.0030	0.0244	0.0335 0.0172
2008	0.0065	0.0094 0.0043	0.0138	0.0199 0.0091	0.0031	0.0049 0.0016	0.0170	0.0241 0.0115
2009	0.0072	0.0100 0.0051	0.0135	0.0210 0.0082	0.0052	0.0083 0.0023	0.0165	0.0243 0.0101
2010	0.0084	0.0126 0.0053	0.0144	0.0209 0.0086	0.0050	0.0062 0.0022	0.0227	0.0325 0.0148
2011	0.0095	0.0127 0.0068	0.0133	0.0188 0.0092	0.0060	0.0081 0.0039	— ^b	— ^b — ^b
2012	0.0092	0.0135 0.0060	0.0123	0.0179 0.0080	0.0078	0.0109 0.0043	0.0137	0.0195 0.0093
2013	0.0112	0.0154 0.0081	0.0163	0.0246 0.0094	0.0086	0.0134 0.0046	0.0255	0.0347 0.0182
2014	0.0090	0.0128 0.0059	0.0065	0.0100 0.0038	0.0061	0.0085 0.0035	0.0173	0.0255 0.0112
2015	0.0100	0.0146 0.0066	0.0098	0.0150 0.0058	0.0054	0.0069 0.0026	0.0196	0.0284 0.0125

^aEstimates for 2006–2015 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006–2014 have been updated and are slightly different than those presented in previous reports.

^bBCR 17 was not surveyed in 2011.

Table 5. Estimated numbers of Golden Eagles of all ages in each Bird Conservation Region and across the entire study area (excluding no-fly zones) in the late summer of 2003 and 2006–2015^a. Upper and lower limits for 90% confidence intervals are to the right of each estimate.

Year	Great Basin (9)		Northern Rockies (10)		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)		Total	
2003	10,939	15,754 7,522	4,831	8,580 2,262	4,998	7,275 3,199	6,624	9,207 4,611	27,392	35,369 21,556
2006	4,219	6,242 2,610	5,845	9,108 3,386	4,056	5,894 2,696	9,223	13,040 6,343	23,342	30,267 18,440
2007	5,766	7,941 4,078	6,811	10,872 3,825	2,653	3,908 1,416	8,540	11,756 6,035	23,770	30,267 18,832
2008	4,165	6,041 2,736	6,915	9,944 4,557	1,477	2,322 769	5,967	8,450 4,022	18,523	23,650 14,819
2009	4,598	6,386 3,237	6,762	10,497 4,100	2,439	3,904 1,097	5,779	8,533 3,534	19,579	25,141 15,406
2010	5,378	8,063 3,415	7,206	10,460 4,277	2,340	2,944 1,045	7,961	11,395 5,181	22,885	28,239 17,722
2011	6,107	8,132 4,387	6,665	9,378 4,576	2,836	3,840 1,820	— ^b	— ^b — ^b	— ^b	— ^b — ^b
2012	5,866	8,617 3,815	6,131	8,971 4,000	3,689	5,139 2,044	4,792	6,854 3,260	20,479	25,370 16,480
2013	7,180	9,892 5,186	8,160	12,277 4,708	4,048	6,317 2,178	8,944	12,159 6,397	28,332	35,437 22,728
2014	5,754	8,222 3,762	3,255	4,995 1,896	2,892	4,024 1,662	6,066	8,930 3,926	17,967	22,635 14,196
2015	6,431	9,351 4,206	4,884	7,512 2,901	2,535	3,242 1,224	6,877	9,964 4,384	20,727	26,164 16,126

^aEstimates for 2006–2015 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006–2014 have been updated and are slightly different than those presented in previous reports.

^bBCR 17 was not surveyed in 2011.

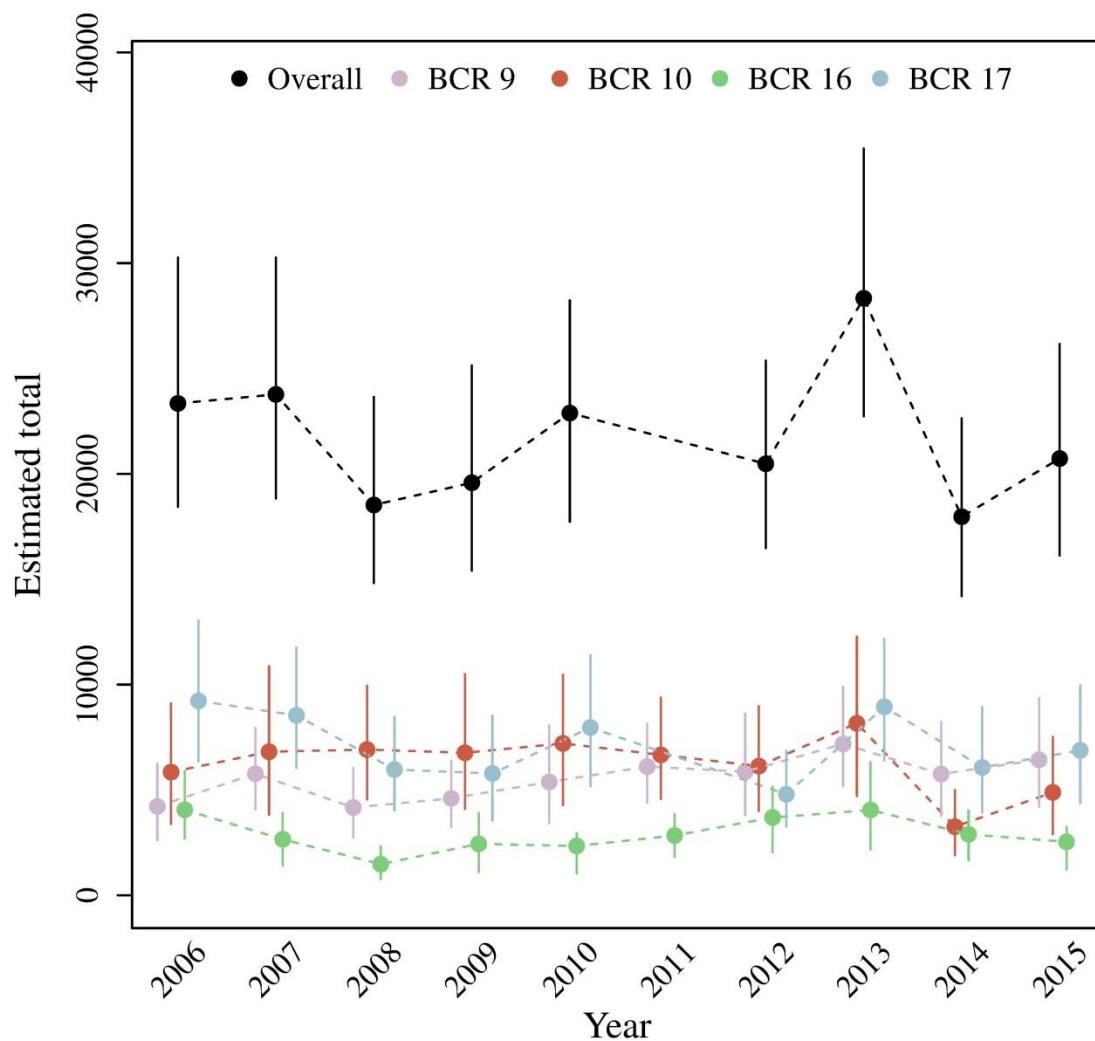


Figure 7. Estimates with 90% confidence intervals (vertical lines) of the total number of Golden Eagles (all ages) within each Bird Conservation Region (BCR) and across the entire study area (excluding no-fly zones) in late summer (15 August–15 September) 2006–2015. The BCRs are: 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies). BCR 17 was not surveyed in 2011, so estimates for BCR 17 and the entire study area (“Overall”) are not presented for that year.

Based on the ratio of Golden Eagles classified as juveniles to the total number of Golden Eagles of all ages observed (including those of unknown age) at any distance from the transect line, we projected that a total 459 Golden Eagles would have been classified as juveniles in BCR 9 (90% CI: 116–943), 1,039 in BCR 10 (90% CI: 423–1,804), 483 in BCR 16 (90% CI: 80–770), and 1,397 in BCR 17 (90% CI: 770–2,185) during the late summer of 2015 (excluding military lands, elevations above 3,048 m [10,000 ft], large water bodies, and large urban areas) (Table 6, Figure 8).

Table 6. Estimated numbers of juvenile Golden Eagles in each Bird Conservation Region and across the entire study area (excluding no-fly zones), in the late summer of 2003 and 2006–2015^a. Upper and lower limits for 90% confidence intervals are to the right of each estimate.

Year	Great Basin (9)		Northern Rockies (10)		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)		Total	
2003	1,190	2,605 544	1,286	2,634 628	498	1,216 204	2,072	3,312 1,296	5,046	6,839 3,723
2006	785	1,367 304	1,461	2,487 691	634	1,248 141	1,333	2,361 557	4,224	6,043 2,844
2007	497	917 175	1,039	2,181 154	0	^b ^b	813	1,445 305	2,356	3,747 1,308
2008	505	1,139 96	943	1,473 504	246	567 2*	234	688 2*	1,944	2,939 1,159
2009	214	517 2*	1,057	1,907 409	122	355 1*	428	761 124	1,839	2,884 1,039
2010	448	982 4*	546	1,206 5*	130	408 1*	204	478 2*	1,308	2,232 545
2011	654	1,225 212	1,000	1,793 360	0	^b ^b	^c ^c	^c ^c	^c ^c	^c ^c
2012	1,195	2,410 331	227	661 2*	137	443 1*	327	664 3*	1,945	3,314 928
2013	109	336 1*	636	1,179 210	405	858 107	832	1,480 363	1,969	3,000 1,173
2014	1,046	1,708 522	0	^b ^b	231	547 2*	225	526 2*	1,534	2,369 889
2015	459	943 116	1,039	1,804 423	483	770 80	1,397	2,185 770	3,418	4,651 2,238

^aEstimates for 2006–2015 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006–2014 have been updated and are slightly different than those presented in previous reports.

^bNo juveniles were observed in BCR 16 in 2007 or 2011 or in BCR 10 in 2014.

^cBCR 17 was not surveyed in 2011.

*Lower limit adjusted up to number observed during survey.

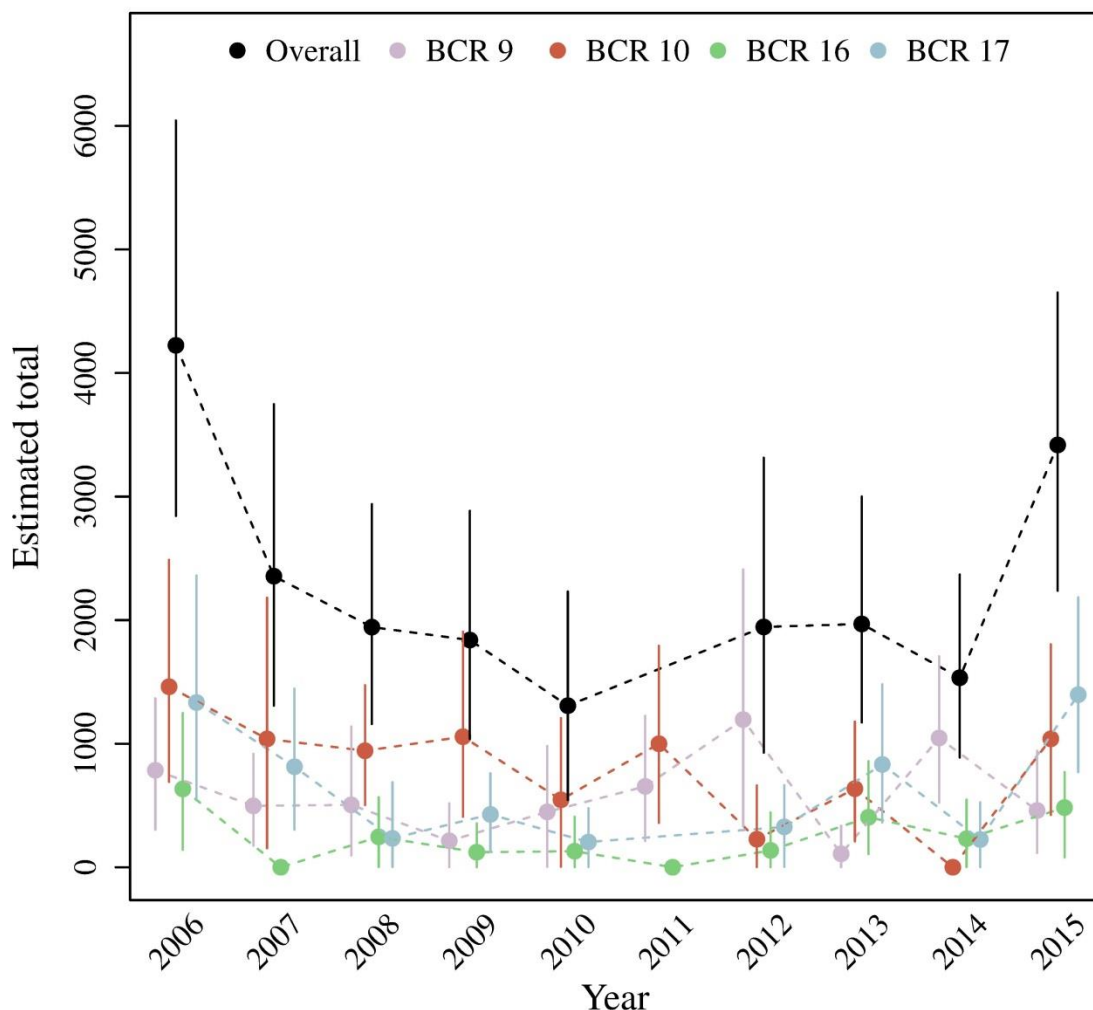


Figure 8. Estimates with 90% confidence intervals (vertical lines) of the total number of juvenile Golden Eagles within each Bird Conservation Region (BCR) and across the entire study area (excluding no-fly zones) in late summer (15 August–15 September) 2006–2015, based on the number of Golden Eagles classified as juveniles along sampled survey transects. The BCRs are: 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies). No juveniles were observed in BCR 16 in 2007 or 2011, so confidence intervals are not presented for those years. BCR 17 was not surveyed in 2011, so estimates for BCR 17 and the entire study area (“Overall”) are not presented for that year.

Trends in Abundance

We detected a significant positive trend (i.e., 90% CRI > 1.0) in the total number of Golden Eagles observed in BCR 9, which indicated an average increase of 3.7% ($[1.037 - 1] \times 100\% = 3.7\%$). We did not detect significant trends (i.e., 90% CRIs for average rates of change encompassed 1.0) in the total numbers of Golden Eagles observed in any other BCRs or across the entire study area during 2006–2015 (Table 7).

Table 7. Estimates of average rates of change from the trend analysis for all Golden Eagles (all ages) detected along each transect in 2006–2015, with 90% credible intervals (CRI).

Region	Trend (90% CRI)
Great Basin (9)	1.037 (1.001, 1.076)*
Northern Rockies (10)	0.977 (0.941, 1.015)
Southern Rockies / Colorado Plateau (16)	1.001 (0.948, 1.052)
Badlands and Prairies (17) ^a	0.974 (0.934, 1.013)
Overall study area	0.992 (0.971, 1.014)

^aBCR 17 was not surveyed in 2011.

*Significant positive trend at $\alpha = 0.1$

We did not detect significant trends (i.e., 90% CRIs contained 1.0) in the total number of Golden Eagles classified as juveniles in any individual BCRs or in the overall study area (Table 8).

Table 8. Estimates of average rates of change from the trend analysis for Golden Eagles detected and classified as juveniles along each transect in 2006–2015, with 90% credible intervals (CRI).

Region	Trend (90% CRI)
Great Basin (9)	1.02 (0.92, 1.14)
Northern Rockies (10)	0.93 (0.85, 1.01)
Southern Rockies / Colorado Plateau (16)	1.00 (0.86, 1.16)
Badlands and Prairies (17) ^a	1.00 (0.92, 1.09)
Overall study area	0.98 (0.93, 1.03)

^aBCR 17 was not surveyed in 2011.

DISCUSSION AND CONCLUSIONS

Estimates of abundance from DS are based on individuals within the survey strip that are available to be detected. Individuals that were not available for detection are not represented in equation [4]. Since availability bias of perched or flying birds should be consistent across surveys, it would not detract from our ability to estimate trends over time but could result in estimates of total abundance that are lower or higher compared to data from surveys conducted using other methods or during other times of the year.

An assumption of DS is that measurements of perpendicular distances from the transect line of groups observed are exact, which may have been more problematic for flying Golden Eagles. Chen (1998) and Marques (2004) reported that errors in otherwise unbiased distance measurements might lead to biased density estimation. However, we had no way of conducting trials where the exact location of a flying bird was known and could be compared to a GPS recorded distance. We recognized that accuracy near the transect line was most critical, and we made “every possible effort to ensure measurements were not biased and potential error was minimized” (Buckland et al. 2001) at all distances.

Unlike past years, the aircraft used during the 2015 summer survey were different from each other. What impact this had on survey results is unknown. Preliminary investigation suggested that visibility from each type of plane was similar. While window sizes were slightly larger in the Kodiak, increasing the viewing field of an observer, the Kodiak had underwing struts that obscured part of the viewing field for the back seat observers. In a series of training flights prior to the survey, the crew in the Kodiak did observe more eagles, on average, than the crew in the Cessna 206. That said, the sample size for this comparison was very small, and consequently there was no straightforward way to evaluate any potential differences. To what extent any differences come from the physical characteristics of the plane as opposed to the individual observers, pilots, or the order which the two aircraft flew each common transect during training (first or second) is unknown. Furthermore, if the Kodiak plane facilitated more eagle observations by that crew, we would expect that the estimated overall abundance of birds in BCRs 9 and 16 (primarily flown by the Kodiak crew) would be greatly elevated from past years, which was not the case (Table 5, Figure 7). We recognize that the different aircraft this year introduced an unquantifiable source of variation into comparisons between this year and previous surveys. We plan to use Kodiak planes for both crews in future surveys.

We pooled data across survey years to generate detection functions for estimating population totals in 2015 and retroactively for 2006–2014. We justified pooling based on the consistency of the survey across years (e.g., protocol, observer training and experience, aircraft). Pooling data across years reduced year-to-year variability in detection functions, which we believe was primarily due to small sample sizes within a given survey period. The increase in the number of Golden Eagles observed within 1,000 m of transect lines surveyed in 2013 compared to 2012, and the decrease in 2014 compared to 2013, prompted us to investigate year-to-year variability in probability of detection using a hierarchical (Gelman and Hill 2007) approach for

scaling the detection functions (equation [2]). The hierarchical models included a random effect for year, which would allow for changing detection rates or substantial year-to-year variability.

There are many definitions of trend. In a previous analysis of the Golden Eagle survey data (Nielson et al. 2014), trend was defined as the slope of a Bayesian hierarchical regression model similar to the one presented here. We adopted a new approach for this analysis based on the model developed by Millsap et al. (2013) because it included detection rates and area searched, allowing for estimation of actual densities of Golden Eagles.

Change in total population size is the ultimate indicator of overall population trend. Trend analyses for Golden Eagles (all ages) suggest that abundances in BCRs 10, 16, 17, and across the entire study area are stable, but these data also indicate an increasing trend in BCR 9 (Table 7). Wildlife managers may be able to use other indicators, such as the total number of Golden Eagles observed and classified as juveniles, to offer insight into changes in Golden Eagle population status. Trend analyses for Golden Eagles classified as juveniles suggest that juvenile abundances in BCRs 9, 10, 16, 17, and across the entire study area are stable (Table 8). In comparison, data from the 2014 summer survey showed no trends in total Golden Eagle numbers but significant downward trends in BCRs 10, 17, and the overall study area for Golden eagles classified as juveniles (Nielson et al. 2015b). We recognize that there is a level of uncertainty involved during an aerial survey when attempting to age Golden Eagles, so we are cautious about interpreting counts of juveniles in this survey. Observers are unable to classify every Golden Eagle as juvenile, sub-adult, or adult due to potentially complicating factors such as poor light, the bird's physical location, survey conditions (e.g., turbulence), and the perceived safety of circling the bird for aging. However, of all age-classes of Golden Eagles, juveniles are the easiest to distinguish, so we would expect a lower uncertainty rate for this age class than any other.

Although it is tempting to examine the results of this study and attempt to draw conclusions regarding the effects of increasing development or changes in habitat or climate, golden eagle populations have been shown to fluctuate on roughly a 10-year cycle (Kochert and Steenhof 2002). We are unsure how the current populations may be influenced by such cycles. In addition, populations in several regions may be in different phases of decadal cycles at any 1 point in time.

We began to use an age classification matrix (Figure 2) in 2006. During subsequent survey years, the proportion of golden eagles classified as unknown immature and the proportion classified as unknown generally declined through 2014 but increased in 2015 back to 2006-levels (Figure 5). These decreased proportions could represent increased ability of observers to determine whether a given eagle was a juvenile, sub-adult, or adult. We found no evidence to suggest that age classifications were incorrect in initial years. Rather, we were less confident and thus classified a larger proportion of individuals as unknown immature, unknown adult, or of unknown age (Figure 5). Regardless, if all golden eagles classified as unknown immature or as unknown age were re-classified as juveniles, we would expect estimates of juvenile trends to be similar to those reported here. Therefore, uncertainty in age classification did not likely confound the trend estimates for juveniles reported herein.

This monitoring program has already proven to be of additional value beyond estimating the size and trends of summer Golden Eagle populations in the four BCRs surveyed. Millsap et al. (2013) used the survey data to determine that Breeding Bird Survey (BBS) data were in fact providing useful trend information even though the BBS ignores probability of detection and occurs along roadsides and occurs prior to fledging from nests. They also developed adjustment factors that were used to scale BBS counts in other regions not covered in the western-wide survey to provide estimates of Golden Eagle densities. We are currently using Golden Eagle observations from our survey to develop a landscape-scale resource selection function that relates Golden Eagle densities to habitat characteristics such as terrain ruggedness and measures of greenness. Furthermore, similar surveys conducted during the winter months (mid-January to mid-February) have indicated a temporal influence on survey results. Two previous winter surveys (Nielson and McManus 2014, Nielson et al. 2015a) documented higher Golden Eagle abundances across the four BCRs compared to adjacent summer surveys.

Our recommendations for future of this Golden Eagle survey are based on its two primary goals (Good et al. 2007): 1) to estimate the total abundance of Golden Eagles within the entire study area and within each BCR and 2) to determine the trends of Golden Eagle abundance within the entire study area and within each BCR. We recommend that any future surveys be conducted using the same methods used in 2006–2010 and 2012–2015, unless sufficient funds are available to increase sampling effort in one or more of the individual BCRs while maintaining historical levels of effort across the entire study area. The surveys should continue to use the sample of transects generated in 2006, as well as the same survey protocol and data analysis methods used during 2006–2010 and 2012–2015. We expect that repeated surveys of the same transects, using the same protocol, will provide us with greater power to detect trends than a design based on selection of new transects each year. Given the roughly 10-year cycle of Golden Eagle populations, this year's survey is the 10th year, and the resulting information represents a robust data set for trend analysis and a foundation of any future monitoring strategy.

Should funding for continuing surveys on the current annual cycle diminish, we recommend using this 10-year data set to conduct a series of simulations to explore efficient ways to allocate a reduced sampling effort to both the summer and winter surveys. For example, it might be appropriate to survey 2 of the 4 BCRs every summer and winter, alternating between BCRs every year. Power simulations should be used to provide a framework for informing future survey effort, along with budget constraints and logistical concerns.

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