# A Survey of Golden Eagles (*Aquila chrysaetos*) in the Western U.S.: 2006–2013

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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, 2013. The study area consisted of BCRs 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies). In 2013, we flew 215 transects totaling 17,650 km. We observed 207 Golden Eagle groups within 1,000 m of 87 transects for a total of 246 individuals: 18 juveniles, 30 sub-adults, 115 adults, 1 unknown immature (not adult), 79 unknown adults (not juveniles), and 3 of unknown age class. We estimated that a total of 7,627 Golden Eagles (90% confidence interval: 5,448 to 10,413) were within the Great Basin (9) during the survey period, a total of 8,491 (90% confidence interval: 5,003 to 12,552) were within the Northern Rockies (10), a total of 4,391 (90% confidence interval: 2,288 to 6,830) were within the Southern Rockies / Colorado Plateau (16), and a total of 9,250 (90% confidence interval: 6,698 to 12,552) 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 based on numbers of Golden Eagles counted along surveyed transects. The analysis found no evidence of trends (i.e., 90% credible intervals for trend coefficients contained zero) in total numbers of Golden Eagles observed within the study area during 2006–2013; however, we detected an increase in total number of Golden Eagles observed in the Northern Rockies (10). The analysis found no evidence of trends in number of Golden Eagles classified as juveniles in individual BCRs or the entire study area during 2006–2013.*

## 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), 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), 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; Figure 1).

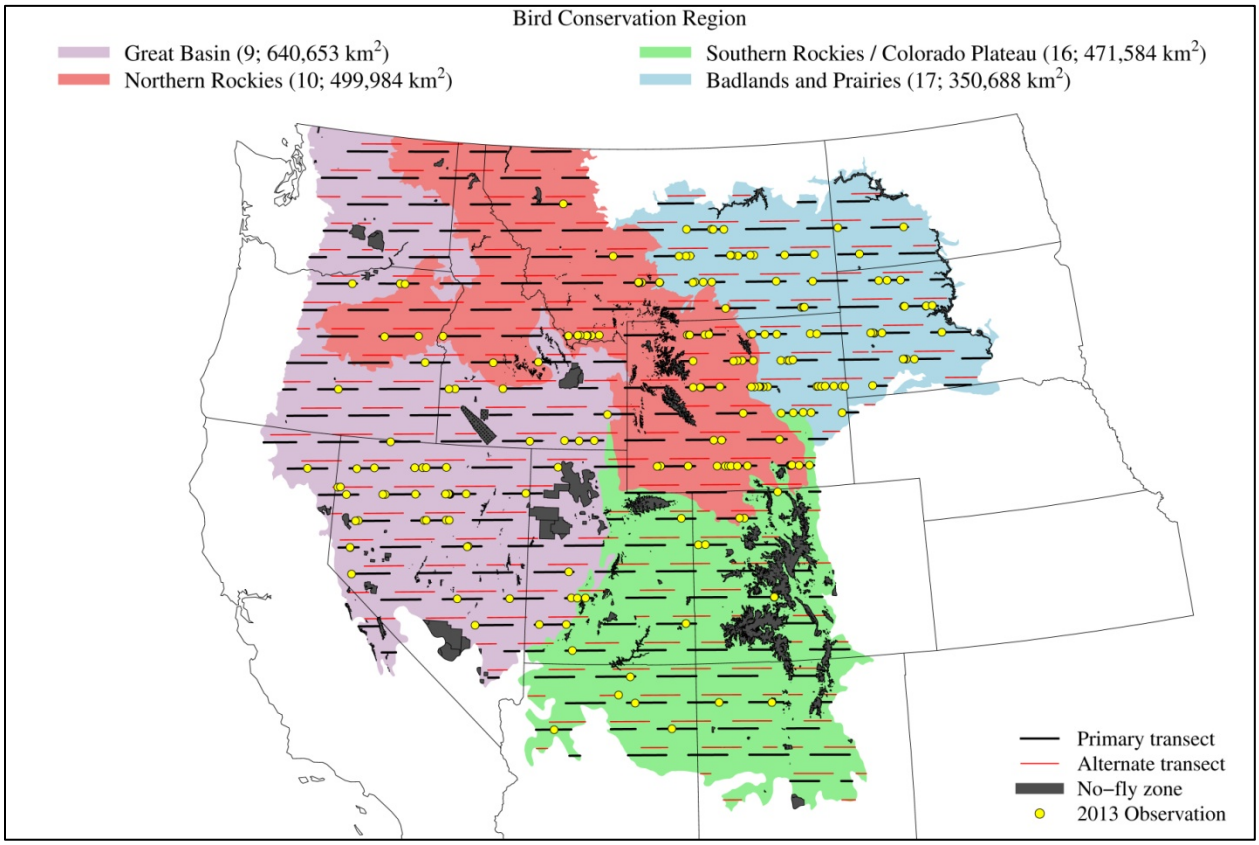


**Figure 1. Study area for the annual Golden Eagle survey, with primary and alternate transects, and observations of Golden Eagle groups observed during the 2013 survey.**

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 for detection of an average 3% decline per year in the eagle population over a 20-year period with statistical power $\geq$ 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 2006–2013 (Table 1;

Figure 1), with exception of transects in BCR 17 (Badlands and Prairies), which were not surveyed in 2011 (Nielson et al. 2012*a*). 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. Here we describe methods used for surveys conducted during 2006–2013 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) (North American Bird Conservation Initiative - NABCI - 2000) 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 2012–2013, containing all 4 BCRs, was 1,962,909 $km^2$ (Figure 1).

## METHODS

### Surveys

We conducted DS surveys from 15 August to 15 September each year 2006–2013, 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 to be surveyed in the event that a primary transect could not be flown 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. 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, and thus visibility was consistent with past years. Lengths of primary transects that could not be flown were recouped by surveying alternate transects within the vicinity.

Surveys began at sunrise and were terminated by 1300 hours. Early morning transects were usually 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 route for flying transects has been consistent during 2006–2013. Two crews have begun surveying transects from Laramie, Wyoming, on 15 August each year. Generally, BCRs 16 and 17 are flown between 15 August and 30 August, along with some transects in the southern portion of BCR 10 (Wyoming) and transects along the eastern border of BCR 9 (Utah and eastern Nevada). Remaining transects in BCRs 9 and 10 were usually flown between 30 August and 15 September each year. Both crews converge in southwestern Idaho around 10 September and complete the remaining transects in southern Idaho (BCR 9) by 15 September.

Relatively low precision (relative CI half-width > 55%; Nielson et al. 2012*a*) of estimates of 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, transects in BCR 17 – the BCR with historically the largest and most precise density estimates – were not surveyed. Data obtained from surveying newly added transects in BCR 16 in 2011 were collected solely to assess the value of increasing survey effort in that region and were not included in the analyses presented here in order to maintain consistency in data sources across years and in 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 a global positioning system (GPS). We also used a 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. 151$^{st}$ 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 ascribe 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 2006–2013.**

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 versus 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.

Mark-recapture trials were conducted on the right side of the aircraft during all surveys with the exception of 68 transects 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 further 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 2006–2013 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 1994) 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

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

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 1994), so we reflected the observed distances to both sides of 0 along the number line for density estimation (Chen 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 zero. Analyses of data from 2006–2013 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 $p_{2|1}(x_i)$). Logistic regression (McCullagh and Nelder 1989) was used to model the conditional probability of detection for observer $j$ ($j$=1,2) using equations

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

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 4 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, (3) quadratic, or (4) cubic 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.

While observers were independent 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). Since $\delta(x_i)$ 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 covariates 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 there were only 2 observers in the aircraft, the detection function for the front-right observer was scaled such that $\hat{f}\left(x_{\max[\hat{f}(x)]}\right) = \hat{p}_{1|2}\left(x_{\max[\hat{f}(x)]}\right)$. 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)

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

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

Separate detection functions and average group sizes were estimated 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. 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 2006–2013 has shown no evidence that detection rates are trending (e.g., that observers are improving). Given consistent survey methods since 2006, we pooled all data during 2006–2013 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 of different observation types within a given survey period. Past estimates were updated upon inclusion of 2013 survey data for estimation of average probabilities of detection.

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

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

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 $\overline{P}$ was the estimated average probability of detection within the area searched ($\widehat{P_a}$ in Buckland et al. 2001).

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 $\left(\widehat{D}_p\right)$. Then, we estimated the density of flying Golden Eagles $\left(\widehat{D}_f\right)$ using $W_1 = 0$. Finally, we estimated total density for a BCR as $\widehat{D}_p + \widehat{D}_f$. The estimated density for the entire study area was calculated 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 zero, indicating a statistically significant relationship, we used the truncation method described by Buckland et al. (2001) to estimate the average group size. Otherwise, we used the original group sizes.

We bootstrapped (Manly 2006) individual transects flown 2006–2013 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) through (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 (v3.0.2; R Development Core Team 2013) to estimate yearly densities and population totals in each BCR and the entire study area.

*Estimating trends.* Trends (average yearly increase or decrease) in the numbers of Golden Eagles observed during surveys from 2006–2013 were estimated with a Bayesian hierarchical model (Gelman and Hill 2007) fit using Markov chain Monte Carlo (MCMC) methods. Since survey protocol, observer training and skill, and survey transects were consistent during 2006–2013, we considered the probability of detection along a fixed portion of transect to also be consistent. This allowed us to analyze the raw counts of the total number of Golden Eagles observed on individual transects, rather than the projected densities, which would require incorporating variability in the estimated probabilities of detection and complicate the trend analysis. The assumption of consistent probabilities of detection, along with the structure of the hierarchical model, followed similar analyses of Breeding Bird Survey data (Thogmartin et al. 2004, 2006, Nielson et al. 2008, Sauer and Link 2011).

The hierarchical model simultaneously estimated time-trends in each BCR and across the entire study area. We used an overdispersed Poisson regression model with both fixed and random effects, and counts of Golden Eagles in 2006–2013 along each transect to model the expected value $\lambda_{ijt}$ of count $Y_{ijt}$ in BCR $i$ along transect $j$ in year $t$ as

$$\log(\lambda_{ijt}) = \log(\text{length}_{ijt}) + BCR_i + \gamma_i(t - t^*) + \delta_{it} + \omega_{ij} + \varepsilon_{ijt}, \quad [5]$$

where $t^*$ was the median year (2009.5) from which change was measured; $\gamma_i$ was the trend over time (average change per year) in BCR $i$; $\delta_{it}$ were random effects for year and BCR combinations; $\omega_{ij}$ were random transect-specific effects; $\varepsilon_{ijt}$ were overdispersed Poisson errors; and $\log(\text{length}_{ijt})$ was an offset term that adjusted for the different lengths of the transects. The model was fit using WinBUGS (v1.4.3; Speigelhalter et al. 2002).

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 zero 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) ~ Uniform(0, 100). Random year by BCR effects, transect effects, and overdispersed Poisson errors were assigned mean zero normal distributions with SD ~ Uniform(0, 100). We determined the appropriate burn-in and chain length (Link et al. 2002) by visual inspection of trace plots using 5 chains and 50,000 iterations. Final models were fit using 5 chains containing 30,000 iterations following a 50,000-iteration burn-in. Ninety-percent credible intervals (CRIs; Bayesian confidence intervals) were used to determine if time trends were statistically significant at the $\alpha = 0.1$ level. If a 90% CRI for time trend at a BCR or study area level contained zero, we concluded that the observed trend was not strong enough to statistically conclude it was real. One model was fit to the total counts of Golden Eagles observed along each transect, and another was fit 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, 2012–2013). 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

In 2013, we flew 215 (partial and complete) transects totaling 17,650 km in the study area (Tables 1 and 2). We observed 207 Golden Eagle groups within 1,000 m of the transect line along 87 transects (Figure 1) for a total of 246 individuals: 18 juveniles, 30 sub-adults, 115 adults, 1 unknown immature, 79 unknown adults, and 3 of unknown age (Figure 3). 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 2006–2013. Mean group size across years was 1.21 ($SE$ = 0.01).

**Table 1. Total length (km) of transects flown in each Bird Conservation Region 2006–2013.**

| 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 |

[a]BCR 17 was not surveyed in 2011.

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 ($\overline{P}$), are shown in Figure 4.

**Table 2. Number of primary (Prm.) and alternate (Alt.) transects surveyed in each Bird Conservation Region each year 2006–2013.**

| | Great Basin (9) | | Northern Rockies (10) | | Southern Rockies / Colorado Plateau (16) | | Badlands and Prairies (17) | |
|---|---|---|---|---|---|---|---|---|
| Year | 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 |

[a]BCR 17 was not surveyed in 2011.

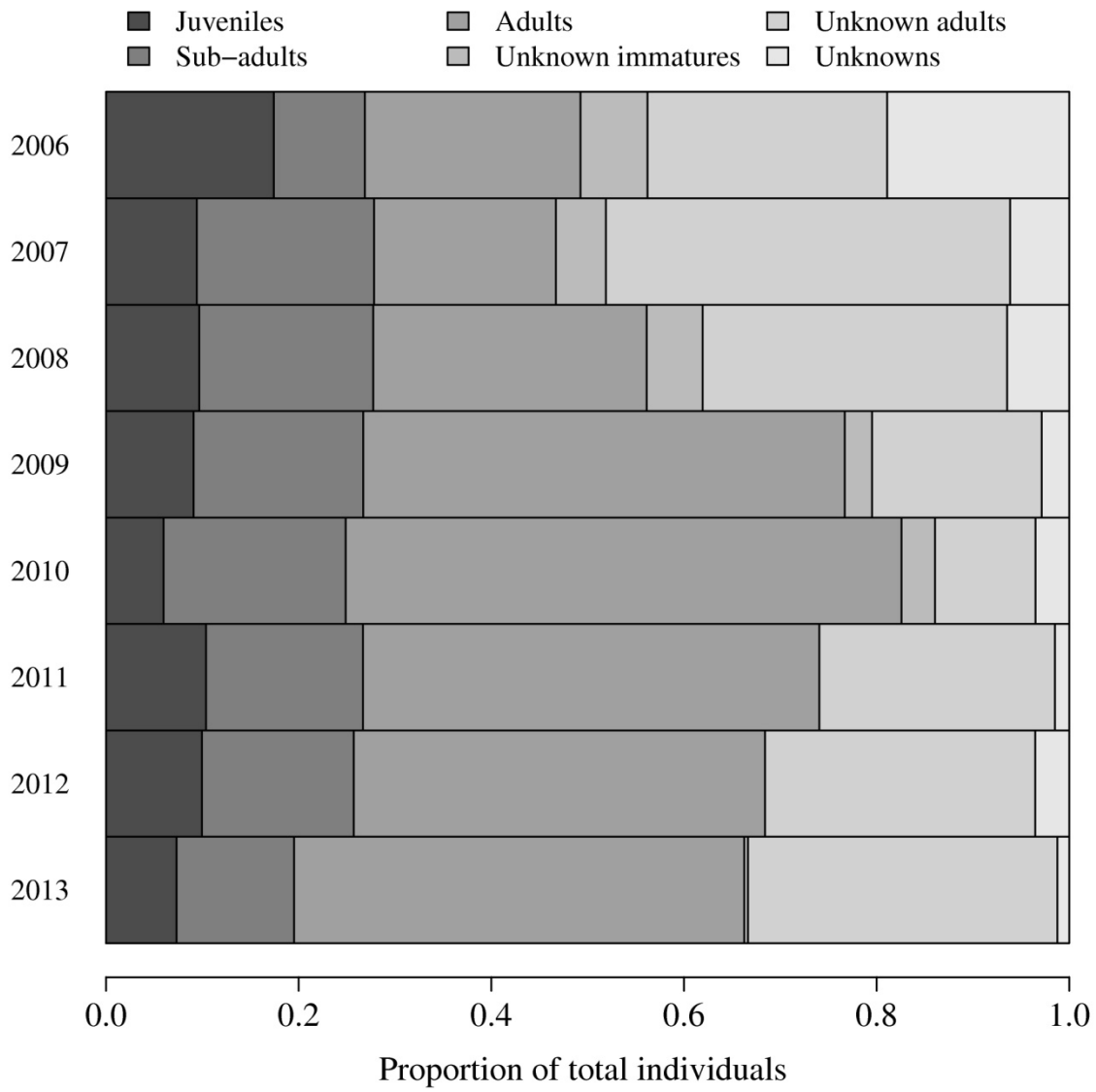


**Figure 3. Age classifications of all Golden Eagles observed within 1,000 m of transect lines surveyed in 2006–2013.**

**Table 3. Numbers of Golden Eagle groups observed within 1,000 m of survey transects in 2006–2013 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 |
| Total | 713 | 128 | 402 | 1,243 |

[a]BCR 17 was not surveyed in 2011.

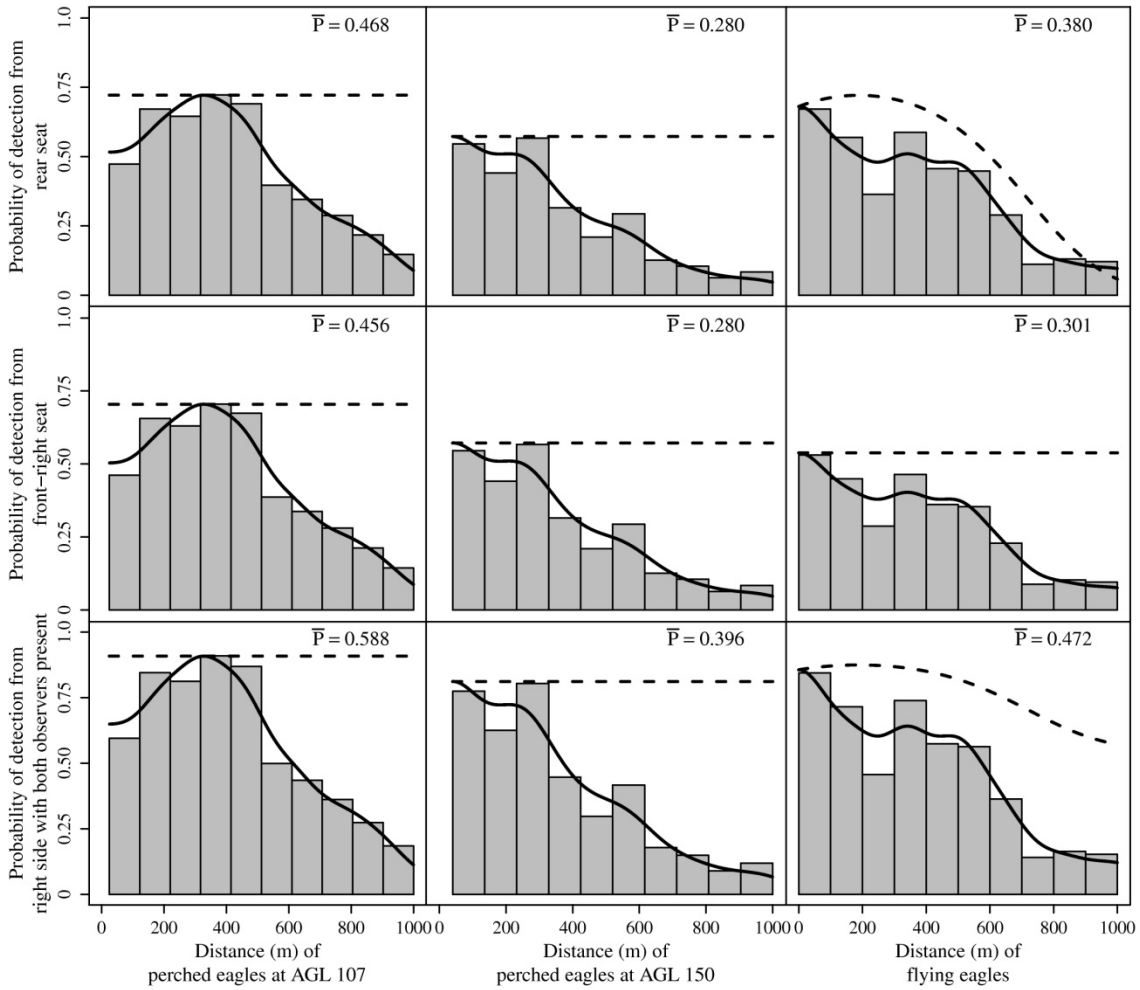


**Figure 4. Probability of detection of perched Golden Eagle groups from 107 and 150 m above ground level (AGL) and probability of detection of flying Golden Eagle groups. Dashed lines represent probabilities of detection estimated from mark-recapture sampling. Solid lines represent scaled detection 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), we projected a total of 7,627 Golden Eagles (90% CI: 5,448–10,413) in BCR 9, 8,491 (90% CI: 5,003–12,552) in BCR 10, 4,391 (90% CI: 2,288–6,830) in BCR 16, and 9,250 (6,698–12,552) in BCR 17 (excluding no-fly zones) during late summer of 2013 (Table 5, Figure 5).

**Table 4. Estimated mean densities of Golden Eagles (#/km$^2$) of all ages in each Bird Conservation Region (excluding no-fly zones) in 2003 and 2006–2013[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<br>0.0120 | 0.0090 | 0.0170<br>0.0040 | 0.0100 | 0.0140<br>0.0060 | 0.0180 | 0.0250<br>0.0130 |
| 2006 | 0.0068 | 0.0102<br>0.0041 | 0.0122 | 0.0192<br>0.0068 | 0.0092 | 0.0132<br>0.0059 | 0.0277 | 0.0395<br>0.0187 |
| 2007 | 0.0094 | 0.0131<br>0.0065 | 0.0142 | 0.0228<br>0.0079 | 0.0060 | 0.0089<br>0.0031 | 0.0249 | 0.0342<br>0.0175 |
| 2008 | 0.0069 | 0.0102<br>0.0045 | 0.0143 | 0.0206<br>0.0094 | 0.0033 | 0.0052<br>0.0017 | 0.0179 | 0.0257<br>0.0118 |
| 2009 | 0.0076 | 0.0107<br>0.0052 | 0.0141 | 0.0219<br>0.0085 | 0.0054 | 0.0087<br>0.0024 | 0.0171 | 0.0251<br>0.0105 |
| 2010 | 0.0091 | 0.0134<br>0.0057 | 0.0151 | 0.0216<br>0.0090 | 0.0055 | 0.0069<br>0.0024 | 0.0233 | 0.0339<br>0.0150 |
| 2011 | 0.0100 | 0.0133<br>0.0071 | 0.0140 | 0.0197<br>0.0096 | 0.0063 | 0.0086<br>0.0040 | –[b] | –[b]<br>–[b] |
| 2012 | 0.0100 | 0.0146<br>0.0063 | 0.0130 | 0.0189<br>0.0084 | 0.0086 | 0.0121<br>0.0046 | 0.0142 | 0.0202<br>0.0095 |
| 2013 | 0.0119 | 0.0163<br>0.0085 | 0.0170 | 0.0252<br>0.0100 | 0.0093 | 0.0145<br>0.0048 | 0.0264 | 0.0358<br>0.0191 |

[a]Estimates for 2006–2013 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006–2012 have been updated and are slightly different than those presented in previous reports.

[b]BCR 17 was not surveyed in 2011.

**Table 5. Estimated numbers of Golden Eagles of all ages in each Bird Conservation Region (excluding no-fly zones) in 2003 and 2006–2013[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<br>7,522 | 4,831 | 8,580<br>2,262 | 4,998 | 7,275<br>3,199 | 6,624 | 9,207<br>4,611 | 27,392 | 35,369<br>21,556 |
| 2006 | 4,383 | 6,520<br>2,658 | 6,088 | 9,568<br>3,421 | 4,343 | 6,215<br>2,813 | 9,712 | 13,835<br>6,577 | 24,525 | 32,034<br>19,095 |
| 2007 | 6,054 | 8,337<br>4,203 | 7,115 | 11,399<br>3,993 | 2,810 | 4,171<br>1,488 | 8,745 | 11,990<br>6,142 | 24,723 | 31,642<br>19,543 |
| 2008 | 4,431 | 6,488<br>2,886 | 7,174 | 10,261<br>4,710 | 1,539 | 2,430<br>811 | 6,267 | 8,981<br>4,148 | 19,410 | 24,847<br>15,408 |
| 2009 | 4,853 | 6,803<br>3,389 | 7,055 | 10,921<br>4,274 | 2,567 | 4,075<br>1,147 | 6,009 | 8,803<br>3,685 | 20,482 | 26,295<br>15,991 |
| 2010 | 5,807 | 8,584<br>3,696 | 7,563 | 10,769<br>4,536 | 2,574 | 3,226<br>1,138 | 8,170 | 11,864<br>5,283 | 24,113 | 29,445<br>18,542 |
| 2011 | 6,424 | 8,518<br>4,564 | 7,021 | 9,817<br>4,841 | 2,979 | 4,048<br>1,927 | –[b] | –[b]<br>–[b] | –[b] | –[b]<br>–[b] |
| 2012 | 6,408 | 9,296<br>4,078 | 6,498 | 9,434<br>4,211 | 4,050 | 5,668<br>2,191 | 4,965 | 7,054<br>3,365 | 21,920 | 26,963<br>17,491 |
| 2013 | 7,627 | 10,413<br>5,448 | 8,491 | 12,552<br>5,003 | 4,391 | 6,830<br>2,288 | 9,250 | 12,552<br>6,698 | 29,757 | 36,936<br>23,835 |

[a]Estimates for 2006–2013 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006–2012 have been updated and are slightly different than those presented in previous reports.

[b]BCR 17 was not surveyed in 2011.

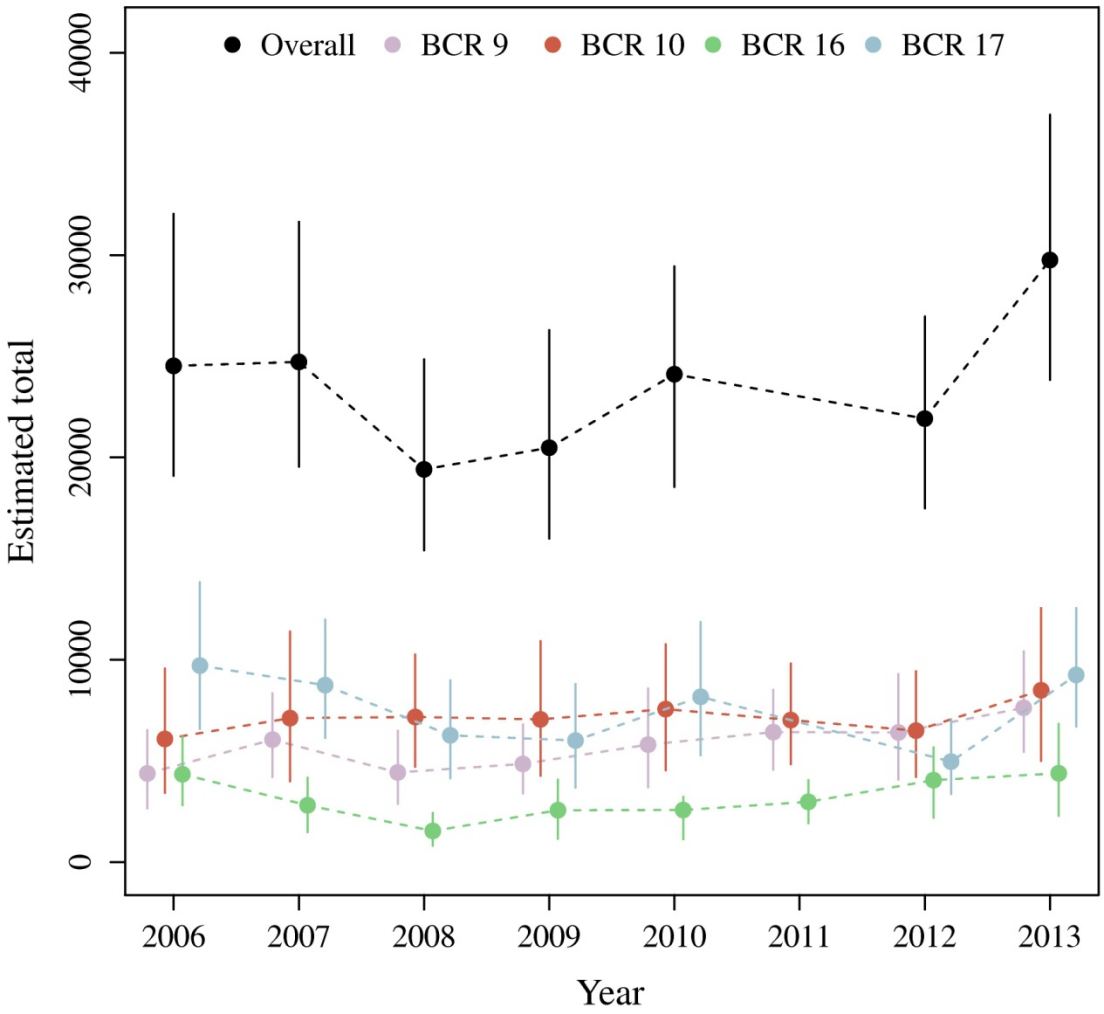


**Figure 5. Estimates with 90% confidence intervals (vertical lines), of the total number of Golden Eagles (all ages) within each Bird Conservation Region (BCR) and across the entire study area (excluding no-fly zones) in late summer (15 August–15 September) 2006–2013. The BCRs are: 9 (Great Basin), 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 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 116 Golden Eagles would have been classified as juveniles in BCR 9 (90% CI: 1–355), 662 in BCR 10 (90% CI: 220–1215), 440 in BCR 16 (90% CI: 3–935), and 861 in BCR 17 (90% CI: 370–1541) during the late summer of 2013 (excluding no-fly zones; Table 6; Figure 6).

**Table 6. Estimated numbers of juvenile Golden Eagles in each Bird Conservation Region (excluding no-fly zones), in 2003 and 2006–2013[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<br>544 | 1,286 | 2,634<br>628 | 498 | 1,216<br>204 | 2,072 | 3,312<br>1,296 | 5,046 | 6,839<br>3,723 |
| 2006 | 816 | 1,451<br>323 | 1,522 | 2,595<br>705 | 679 | 1,322<br>154 | 1,405 | 2,426<br>579 | 4,420 | 6,316<br>2,993 |
| 2007 | 522 | 969<br>193 | 1,086 | 2,266<br>177 | 0 | –[b]<br>–[b] | 833 | 1,478<br>318 | 2,441 | 3,901<br>1,345 |
| 2008 | 538 | 1,170<br>4* | 979 | 1,552<br>512 | 257 | 582<br>2* | 246 | 735<br>2* | 2,018 | 3,124<br>1,184 |
| 2009 | 226 | 540<br>2* | 1,103 | 1,998<br>437 | 129 | 371<br>1* | 446 | 782<br>126 | 1,902 | 2,962<br>1,075 |
| 2010 | 484 | 1,056<br>98 | 573 | 1,284<br>5* | 143 | 450<br>1* | 210 | 486<br>2* | 1,410 | 2,408<br>622 |
| 2011 | 689 | 1,288<br>229 | 1,054 | 1,856<br>386 | 0 | –[b]<br>–[b] | –[c] | –[c]<br>–[c] | –[c] | –[c]<br>–[c] |
| 2012 | 1,306 | 2,593<br>351 | 241 | 691<br>2* | 150 | 460<br>1* | 339 | 692<br>80 | 2,035 | 3,473<br>942 |
| 2013 | 116 | 355<br>1* | 662 | 1215<br>220 | 440 | 935<br>3* | 861 | 1,541<br>370 | 2,077 | 3,151<br>1,235 |

[a]Estimates for 2006–2013 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006–2012 have been updated and are slightly different than those presented in previous reports.

[b]No juveniles were observed in BCR 16 in 2007 or 2011.

[c]BCR 17 was not surveyed in 2011.

*Lower limit adjusted up to number observed during survey.

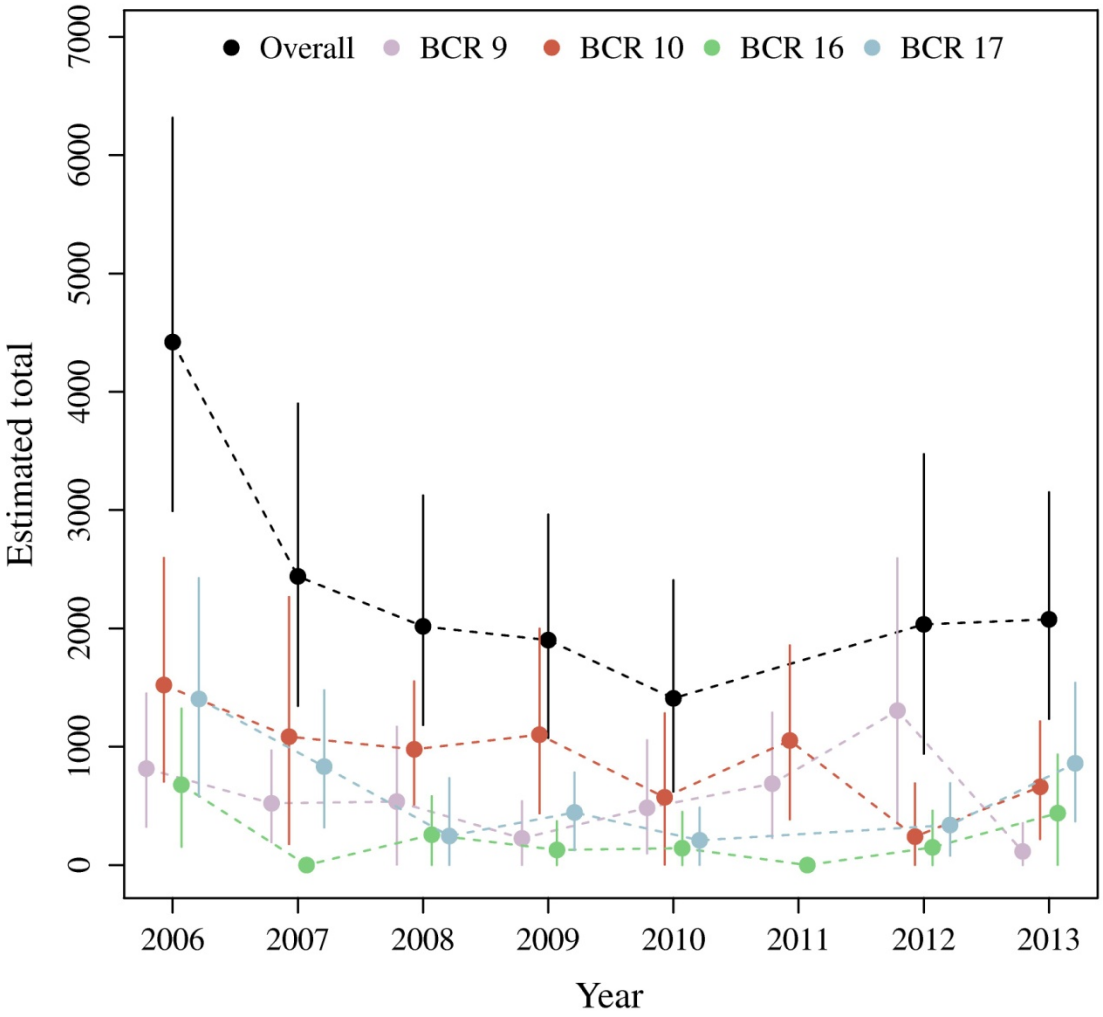


**Figure 6. Estimates with 90% confidence intervals (vertical lines), of the total number of juvenile Golden Eagles within each Bird Conservation Region (BCR) and across the entire study area (excluding no-fly zones) in late summer (15 August to 15 September) 2006–2013, based on the number of Golden 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 Overall are not presented for that year.**

## Trends in Abundance

We did not detect significant trends (i.e., 90% CRIs encompassed zero) in the total numbers of Golden Eagles observed in BCRs 9, 16, 17, or across the entire study area during 2006–2013 (Table 7). We detected a significant increase (i.e., 90% CRI was > 0) in BCR 10, which indicated an average increase of 5% ($[\exp(0.0495)-1]\times 100\% = 5\%$) per year during 2006–2013 in the numbers of Golden Eagles observed per km of transect in BCR 10 (Table 7).

**Table 7. Estimates of time-trend coefficients from the Bayesian hierarchical Poisson model fit to counts of Golden Eagles (all ages) detected along each transect in 2006–2013, with 90% credible intervals (CRI).**

| Region | Trend coeff. (90% CRI) |
|---|---|
| Great Basin (9) | 0.0456 (–0.0002, 0.0907) |
| Northern Rockies (10) | 0.0495 (0.0012, 0.0998) |
| Southern Rockies / Colorado Plateau (16) | 0.0271 (–0.0247, 0.0783) |
| Badlands and Prairies (17) [a] | 0.0128 (–0.0505, 0.0739) |
| Overall study area | 0.0338 (–0.0283, 0.0947) |

[a]BCR 17 was not surveyed in 2011.

We detected no significant trends (i.e., 90% CRIs contained zero) in the total number of Golden Eagles classified as juveniles in individual BCRs or the entire study area during 2006–2013 (Table 8).

**Table 8. Estimates of time-trend coefficients from the Bayesian hierarchical Poisson model fit to counts of Golden Eagles detected and classified as juvenile along each transect in 2006–2013, with 90% credible intervals (CRI).**

| Region | Trend coeff. (90% CRI) |
|---|---|
| Great Basin (9) | –0.0732 (–0.1987, 0.0557) |
| Northern Rockies (10) | –0.0885 (–0.2219, 0.0477) |
| Southern Rockies / Colorado Plateau (16) | –0.0924 (–0.2312, 0.0432) |
| Badlands and Prairies (17) [a] | –0.1297 (–0.2827, 0.0289) |
| Overall study area | –0.0966 (–0.2508, 0.0540) |

[a]BCR 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.

We pooled data across survey years to generate detection functions for estimating population totals in 2013 and retroactively for 2006–2012. 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 sharp increase in the number of Golden Eagles observed within 1,000 m of transect lines surveyed in 2013 compared to 2012 (Nielson et al. 2012*b*) 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 trending detection rates or substantial year-to-year variability. However, results of this analysis (total Golden Eagle abundance in 2013 = 28,694) were not statistically significantly different (i.e., 90% CIs overlapped) from the analysis that pooled the observations across years to estimate probabilities of detection, indicating that detection rates have been similar 2006–2013.

The kernel estimator is a nonparametric function that requires fewer assumptions and allows for greater flexibility in the shape of detection functions compared to semi-parametric models available in the program Distance (Thomas et al. 2006). Unfortunately, kernel-based detection functions do not easily allow for inclusion of covariates, other than distance from the transect line, that might influence probability of detection. Thus, we post-stratified the analysis based on observation type (perched versus flying) and AGL, which is a surrogate for major habitat type (open versus forested or rugged).

There are many ways to analyze counts for changes over time. We adopted a Bayesian hierarchical modeling approach, which is an efficient method for accounting for several sources of variation in the data – from random residual error to differences between individual transects, BCRs, and years. In addition, the MCMC approach to fitting a hierarchical model can easily

accommodate missing observations, e. g., when a primary transect is not surveyed due to forest fire, or if an alternate transect is only surveyed once.

Kochert and Steenhof (2002) found only 4 long-term studies of nesting Golden Eagles in the U.S. These studies were scattered across Alaska, Idaho, California, and Colorado. Populations evaluated in Colorado, California, and Idaho were described as declining, presumably because of reductions in habitat and prey populations (Leslie 1992, Steenhof et al. 1997, Bittner and Oakley 1999). However, these 4 study populations represent only a small proportion of the total Golden Eagle population in the western U.S.

Trend analyses for Golden Eagles (all ages) suggest that abundance in BCR 10 is increasing, while abundances in BCRs 9, 16, 17, and across the entire study area are stable (Table 7). A single juvenile Golden Eagle was observed in BCR 9 in 2013, resulting in a drop in estimated number of juveniles in BCR 9 from 2012, when 11 juveniles were observed in that BCR. Even so, trend analyses for Golden Eagles classified as juveniles did not indicate decreasing abundance within individual BCRs or across the study area (Table 8).

Change in total population size is the ultimate indicator of overall population trend. 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. 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. It is not possible to classify every Golden Eagle observed 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.

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 have declined (Figure 3). These decreased proportions could represent increased ability of observers to determine whether a given Golden Eagle was a juvenile, sub-adult, or adult. In addition, our views of Golden Eagles have improved due to increased ability of our survey pilots to safely circle Golden Eagles to allow us to classify age. There is 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 3). 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, it is unlikely that uncertainty in age classification confounds 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 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 be used to scale BBS counts in other regions not covered in the western-wide survey to estimates of Golden Eagle densities. In addition, we are currently using Golden Eagle observations from our survey to develop a landscape-scale resource selection function (Manly et al. 2001) that relates Golden Eagle densities to habitat characteristics such as terrain ruggedness and measures of greenness.

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 future surveys be conducted using the same methods used in 2006–2010 and 2012–2013, 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 2012–2013. 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 survey needs to continue at least through 2015 to allow a robust interpretation of the trend data and development of a strategy for future monitoring.

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