

A Survey of Golden Eagles (*Aquila chrysaetos*) in the Western US: 2011 Annual Report



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ABSTRACT

*We flew aerial line transect surveys using mark-recapture procedures to estimate the number of Golden Eagles (*Aquila chrysaetos*) in three Bird Conservation Regions (BCRs) in the western U.S. between August 15 and September 15, 2011. The study area consisted of BCRs 9 (Great Basin), 10 (Northern Rockies), and 16 (Southern Rockies / Colorado Plateau). Past surveys (2003 and 2006 – 2010) have included BCR 17 (Badlands and Prairies), but this region was not surveyed in 2011. Instead, extra effort was extended in BCR 16 in an attempt to understand how increased survey effort might improve precision of abundance estimates. This evaluation of increased survey effort in BCR 16 is presented in the Appendix. The summary statistics and analyses presented in this report do not include the additional transects surveyed in BCR 16 in 2011 – only data from the original sample of transects for 2006 – 2011 are presented here. In 2011, we flew 178 transects totaling 14,285 km. We observed 117 Golden Eagle groups within 1000 m of 71 transects for a total of 135 individuals: 14 juveniles, 22 sub-adults, 64 adults, 0 unknown immature (not adults), 33 unknown adults (not juveniles), and 2 of unknown age class. We estimated that a total of 6,199 Golden Eagles (90% confidence interval: 4,732 to 8,555) were within BCR 9 during the survey, a total of 6,862 (90% confidence interval: 4,853 to 9,994) were within BCR 10, and a total of 2,917 (90% confidence interval: 2,053 to 4,228) were within BCR 16. These estimates do not include Golden Eagles that were occupying military lands, elevations above 10,000 ft, large water bodies, or large urban areas. A trend analysis on the number of Golden Eagles observed along each transect 2006 to 2011 found no significant trends (i.e., 90% credible intervals contained zero) in total numbers (all age classes) of Golden Eagles observed in individual Bird Conservation Regions or across the study area during 2006 – 2011. However, the trend analysis indicated there have been statistically significant declines in the total number of Golden Eagles classified as juveniles during the survey in the Southern Rockies / Colorado Plateau (16), and the Badlands and Prairies (17) since 2006.*

INTRODUCTION

Before the Golden Eagle survey described herein began in the western United States in 2003, the size of the Golden Eagle population in any major region of North America was unknown. In addition, it was not known whether the size of these populations had been generally increasing or decreasing over time (trend). Other than work conducted by researchers at the U.S. Geological Survey (USGS) Snake River Field Station in Boise, Idaho, few long-term monitoring studies of Golden Eagle populations have been conducted in the U.S. (Leslie 1992, Bittner and Oakley 1999, McIntyre and Adams 1999, McIntyre 2001).

Kochert and Steenhof (2002) found only four 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 loss of habitat and prey populations (Leslie 1992, Steenhof et al. 1997, Bittner and Oakley 1999). However, these four study populations represent only a small proportion of the total Golden Eagle population in the western U.S.

Kochert et al. (1999) found that territory occupancy in Idaho declined following several fires that resulted in a loss of shrub habitats and concurrent declines in jackrabbit populations. Invasions of exotic plant species and altered fire frequencies have the potential to decrease the amount of shrub land and jackrabbit populations across much of the west. In addition, as human activity and development increases throughout the west, associated pressures on Golden Eagle populations are expected to increase. Declines were seen in territory occupancy of Golden Eagles in California following extensive urbanization (Bittner and Oakley 1999, Kochert et al. 2002). Furthermore, questions remain about the potential effect of climate change on jackrabbit and Golden Eagle populations. Areas expected to show the most dramatic changes due to climate change include semi-arid and arid landscapes. Although the effects of climate change on Golden Eagle populations is currently somewhat speculative, its significance in the western U.S. may supersede that of human activity and development in the coming decades. In 2002, the U.S. Fish and Wildlife Service (USFWS) recognized the need to collect baseline data on the number of Golden Eagles in the western U.S. in order to assess the magnitude and potential effects of these threats to Golden Eagle populations.

In 2003, the USFWS contracted with Western EcoSystems Technology, Inc. (WEST) to design and conduct an aerial line transect survey for Golden Eagles across the western U.S. The goal of the 2003 survey was to develop and test methods for estimating population size and monitoring trends across Bird Conservation Regions (BCRs) 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies) within the western U.S. The first survey was conducted in late summer of 2003 (Good et al. 2004, 2007). The survey was originally designed, and then adjusted after 2003, so that we could detect an average of a 3% decline per year in the Golden Eagle population over a 20-year period with statistical power ≥ 0.8 using a 90% confidence interval (CI; equivalent to an alpha level of $\alpha = 0.1$). The results of the 2003 survey indicated that sample sizes needed to increase in order to obtain a sufficient number of observations for statistical analysis. Thus, a new systematic sample of transects was generated to increase sample sizes and provide alternate transects in case of forest fires or localized weather events. Unfortunately, funding for the survey was not available during 2004 and 2005. The survey was funded again in 2006 and has since been repeated on a yearly basis; the sample of transects and protocol was modified after 2003 so data from that year are not included in trend analyses. The two primary goals for the Golden Eagle survey (Good et al. 2007): (1) to estimate the total population size of Golden Eagles within the entire study area and within each BCR and (2) to determine the trends of Golden Eagle populations within the entire study area and within each BCR. Each survey year we fly line transects using distance sampling and mark-recapture procedures to estimate the number of Golden Eagles in the study area between August 15 and September 15. This survey window was

designed so that surveys occurred after all juvenile Golden Eagles were expected to have fledged and before most Golden Eagles had begun their fall migration (Fuller et al. 2001).

Concern over the relatively low precision (relative CI half-width > 55%; Nielson et al. 2011) of estimates of Golden Eagle density in BCR 16 during 2006 – 2010 compared to the other three BCRs led to doubling the survey effort in BCR 16 in 2011 compared to previous years. This increase was intended to provide insight into the relationship between survey effort and precision for the region (*see* Appendix). To allow for doubling of 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. This report describes the methods and results of the 2011 survey using data obtained from surveys of the original sample of transects flown in BCRs 9, 10 and 16, along with a trend analysis on data collected since 2006. Data obtained from surveying the additional transects flown in BCR 16 in 2011 were not included in this analysis in order to maintain consistency in methods and reporting since 2006. The 2003 survey data were also not included in the trend analyses due to differences in survey transects and protocol. Results from the increased sampling effort in BCR 16 are appended to this report.

STUDY AREA

The study area has consisted of Bird Conservation Regions (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. These regions cover much of the western U.S. and include habitat types ranging from low-elevation sagebrush and grassland basins to high-elevation coniferous forests and mountain meadows (Fig. 1). Areas within these regions containing Department of Defense (DOD) lands, urban areas, large bodies of water greater than 30,000 ha, and terrain above 10,000 ft were excluded from this study. These no-fly-zones represent 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 containing all four BCRs was 1,962,909 km² (Fig. 1). However, in 2011 we had to forego surveys in BCR 17 in order to markedly increase survey effort in BCR 16 as part of our assessment of survey precision (*see* Appendix). The precision of estimates had been highest in BCR 17, so we excluded that BCR from the 2011 survey. The total area in the sample frame for 2011 containing BCRs 9, 10 and 16 was 1,612,221 km² (Fig. 1).

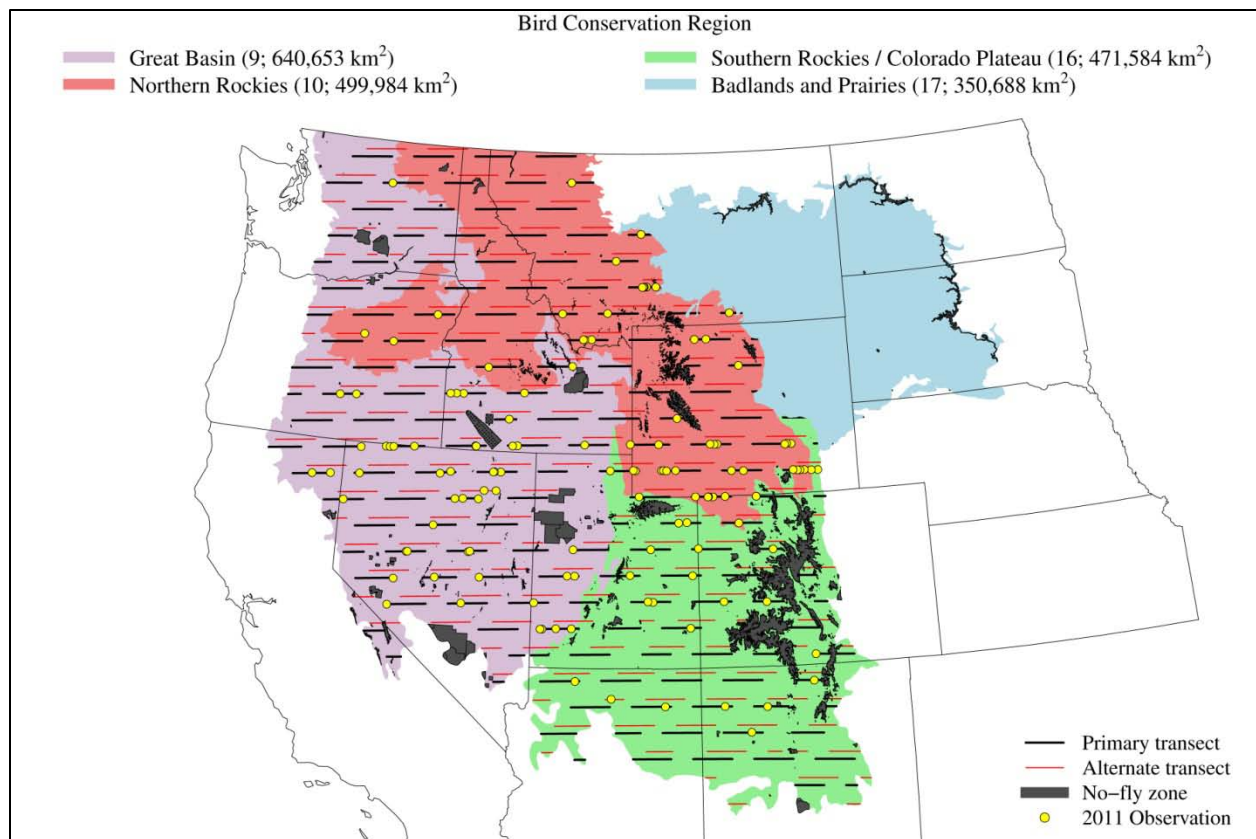


Figure 1. Study area for the annual Golden Eagle survey, with transects and observations of Golden Eagle groups from the 2011 survey. Bird Conservation Region 17 (Badlands and Prairies) was surveyed in 2003 and 2006 – 2010, but not in 2011.

METHODS

Survey Methods

Survey timing, methodology, equipment, observer training and experience have been consistent since 2006 (Good et al. 2009; Nielson et al. 2010a and b; Nielson et al. 2011). In addition, the sample of survey transects in BCRs 9, 10 and 16 has remained constant since 2006 (Fig. 1). Transects in the systematic sample used for surveys 2006 – 2011 were 100 km long, unless near the edges of the study area or no-fly-zones.

Two survey crews operated simultaneously within the study area. Surveys were conducted in Cessna 205 and 206 fixed-wing aircraft. The aircrafts' speed and altitude above ground level (AGL) were dictated by the flying conditions. Flying conditions were roughly defined as follows: (1) Relatively Safe - surveys over relatively flat and open terrain, and (2) Less Safe - surveys over relatively rugged terrain (steep topography, coniferous forest, and deep canyons). Within areas providing relatively safe flying conditions the surveys were conducted at an approximate air speed of 161 km/hr (100 mph) and an approximate altitude of 107 m (350 ft)

above ground level (AGL). Surveys that involved less safe flying conditions were conducted at approximately 161 km/hr (100 mph) and an approximate altitude of 150 m (500 ft) AGL.

Survey protocol dictated that as much as possible of each primary transect was to be flown. However, if more than 25 km of a primary transect could not be surveyed, for example due to a forest fire or localized weather event, the nearest available alternate transect was flown. If less than 25 km of an individual transect had to be abandoned, the survey crew documented the amount of transect not flown and kept a running total of the length of abandoned transects. Once this sum exceeded 25 km, the crew surveyed the nearest available alternate transect. This protocol ensured that we surveyed close to a total of 17,500 km of transects in 2006 – 2010, and a total of 14,400 km of transects in 2011, in an objective and efficient manner.

Surveys began at sunrise and were terminated by 1300 H each day. Early morning transects were flown from east to west in order to provide the best possible lighting for detecting Golden Eagles. Golden Eagles sighted while on transect were verified by flying off transect to the bird location(s). Birds were circled at relatively low altitudes (50 m – 75 m AGL) to confirm species identification, assign age classes, and record locations using a global positioning system (GPS). Effort was made to keep visual contact with flying birds in order to prevent them from being counted more than once on the same transect. Random movement of birds from one transect to another, although unlikely because the long distances between transects, should not have affected density estimates.

The general survey route for flying transects has been consistent from 2006 – 2011. Two crews have begun surveying transects from Laramie, WY, on August 15th, each year. Generally, BCRs 16 and 17 are flown between August 15th and August 30th, 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 are then flown between August 30th and September 15th, each year. Generally, both crews converge in southwestern Idaho around September 10th and complete the remaining transects in southern Idaho (BCR 9) by September 15th.

Measuring Perpendicular Distances to Birds. We estimated perpendicular distances from the transect line to flying and perched Golden Eagles by flying off transect and recording the location of each Golden Eagle group using a GPS. For birds observed flying, we flew to the location where the eagle was first observed. All GPS coordinates, including the actual flight path, were recorded in a laptop computer using Garmin's nRoute software (Garmin International, Inc., 1200 E. 151st St., Olathe, KS 66062).

Mark-Recapture (Double-Count) Methodology. Each crew consisted of three observers. Two of the observers were seated side-by-side in the back seats, and the third observer sat in the front-right seat of the aircraft. Mark-recapture trials (following Seber 1982, Pollock and Kendall 1987, Manly et al. 1996, and McDonald et al. 1999) were operated on the right side of the aircraft to

estimate the proportion of Golden Eagles missed during surveys (*see* Statistical Analysis: Estimating Densities and Population Totals).

The mark-recapture trials required that observers on the right side of the aircraft detected Golden Eagles independently of one another. To ensure observer independence, we installed a cardboard wall that served as a visual barrier between front and back seat observers. In addition, when a Golden Eagle group was detected by one of the double-observers on the right side of the aircraft, sufficient time (about 5 to 20 seconds) was allowed to pass before the observation was communicated to the other observers. This allowed both observers in the mark-recapture trials time to see each Golden Eagle group independently. Communication of all observations during the surveys ensured that observers did not confuse two different Golden Eagle groups for the same observation.

The observer in the front-right seat was also responsible for guiding the pilot to survey transects and recording flight paths and observations into a laptop computer. Observers alternated seats between flights in order to rotate observer positions throughout the survey. This allowed for estimating an ‘average probability of detection by the average observer’ for each position in the aircraft (*see* Statistical Analysis: Estimating Densities and Population Totals).

Aging Golden Eagles. We classified Golden Eagles observed during the surveys into one of six age classes: juvenile, sub-adult (older immature), adult, unknown immature (not adult), unknown adult (not juvenile), and unknown. Aircraft were flown off transect and each bird was circled in order to determine its age class. We attempted to have all observers view each Golden Eagle and come to a consensus on its age classification using a decision matrix (Fig. 2) developed from criteria presented by Clark (2001), Clark and Wheeler (2001), and Bloom and Clark (2002).

Tawny Bar	?	unknown immature	adult	unknown
	No	juvenile		juvenile
	Yes	sub-adult	adult	unknown adult
GOEA Aging		Yes	No	?
		White on Tail/Wings		

Figure 2. Golden Eagle age classification decision matrix used during surveys conducted 2006 – 2011.

Observer Training. All observers were experienced in Golden Eagle identification. All observers and pilots participated in a two-day training session prior to each year's survey. The goals of the training were threefold: (1) to standardize survey methodology, (2) to improve and standardize observers' abilities to identify and age Golden Eagles from the air, and (3) to provide each observer with safety training. Training for the 2011 survey included flying eleven training surveys on eight different transects on August 13 and 14 near Laramie, Wyoming. Training transects were 100 km in length and placed within areas where Golden Eagles were likely to be observed.

Statistical Methods: Estimating Densities and Population Totals

To estimate probability of detection as a function of distance from the transect line, or minimum available sighting distance, we followed a method described by Borchers et al. (2006). This method uses a combination of standard line transect (distance) analysis (Buckland et al. 2001) and mark-recapture analysis. Golden Eagle densities were calculated from the number of detected Golden Eagle groups using the formula

$$\hat{D} = \frac{n\hat{E}(s)}{2(W_2 - W_1)L\hat{P}}, \quad [1]$$

where n was the number of observed Golden Eagle groups; $\hat{E}(s)$ was the expected or average group size; W_1 and W_2 were the minimum and maximum search distances, respectively; L was the total length of transects flown (thus $2(W_2 - W_1)L$ was the total area searched); and $\hat{P}$ was the estimated average probability of detection within the area searched.

We used the mark-recapture distance analysis method described by Borchers et al. (2006) to estimate the average probability of detection ($\hat{P}$). Under the mark-recapture distance design, a distance analysis was used to model the shape of the detection function. To calibrate the detection function (i.e., determine the height), a mark-recapture analysis was used to estimate height of the detection function at a certain distance from the aircraft. Thus, the overall shape of the detection function was estimated from all observed distances, and the height of the detection function was estimated using the mark-recapture component of the survey. The scaled detection function was then integrated over the search width to estimate the average probability of detection (Borchers et al. 2006).

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 between these three observation types is the minimum observable perpendicular distance to Golden Eagle groups. Flying Golden Eagles could potentially be detected directly on or near the transect line, but perched birds could not be seen directly below the aircraft. When flying over “Open Grassland/Sage” and “Gentle Piñon Pine/Juniper” habitats, the aircraft cruised at 107 m above ground level (AGL), and as a result, there was a swath of approximately 25 m under the aircraft on either side (i.e., total of 50 m invisible swath) that could not be viewed. Calculation of the 25 m swath was obtained by sitting in the rear seat and using a clinometer to measure maximum observable downward sighting angle from the horizon (Good et al. 2007). Thus, the minimum available sighting distance (W_1) was set to 25 m for perched birds observed when flying at 107 m AGL. When flying over all other habitat types, the survey aircraft flew at an average of 150 m AGL, so W_1 was set equal to 40 m for observations of perched birds in these other habitats.

A non-monotonic kernel estimator (Wand and Jones 1995) was used to model the shapes of the detection functions. The kernel estimator has been used for analysis of the Golden Eagle survey since 2006, and for other surveys (see Chen 2000 for a review). The kernel density estimator used was of the form

$$\hat{f}(x) = (nh)^{-1} \sum_{i=1}^n K\left(\frac{x - x_i}{h}\right), \quad [2]$$

where x was a perpendicular distance within the range of observed distances, x_i was one of the n observed distances, h was a smoothing parameter (aka bandwidth), and K was a kernel function satisfying the condition $\int K(x)dx = 1$.

A Gaussian kernel function (Wand and Jones 1995) was used for analysis. Estimation of the smoothing parameter (h) followed the procedure described by Sheather and Jones (1991) as the “plug-in” method. This data-based bandwidth selection procedure used an iterative approach, whereby a numerical algorithm searched for the value for h which minimized the variance and bias in the estimates (Wand and Jones 1995). Simulations have shown that this plug-in method tends to find an optimal tradeoff between over-smoothing and inclusion of spurious detail (Jones et al. 1996). Theoretical considerations recommend taking the number of levels (l) of functional estimation (aka iterations) to be at least 2, with $l = 2$ being a common choice (Park and Marron 1992). We chose to use $l = 2$ for our analysis.

Perpendicular distances from line transects have a boundary at or near the transect line (i.e., there are no observations less than the minimum observable sighting distance). Because the kernel density estimator does not perform well near discontinuities such as a sharp boundary, both Chen (1999) and Venables and Ripley (2002) recommend reflecting the observed distances to both sides of the transect line for density estimation, after shifting all observed distances by the minimum sighting distance (W_1). Reflecting observed distances involved multiplying observed distances by -1 and adding them to the dataset. This resulted in a total of $2n$ positive and negative distances that were used to estimate the kernel function. Following kernel estimation, only the portion of the detection function between W_1 and W_2 was used.

The kernel estimator is a nonparametric function, and thus, it requires fewer assumptions and allows for greater flexibility in the shape of detection functions compared to the semi-parametric models available in the program Distance (Thomas et al. 2006). Analysis of the data from 2006 – 2011 have not indicated that shapes of detection functions differ between front and back seat observers, so all observations from the three observer positions in the aircraft were used to estimate the shapes of the detection functions (equation [2]).

Analysis of the mark-recapture sampling on the right side of all survey flights where three observers were present involved estimating the probability of detection by the front seat observer (observer 1) given the back seat observer (observer 2) detected a Golden Eagle group at distance x_i (labeled $p_1(x_i)$). Vice versa, probability of detection by the back seat observer given detection by the front seat observer was also estimated (labeled $p_2(x_i)$). Logistic regression (McCullagh and Nelder 1989) was used to estimate p_1 and p_2 using equations similar to

$$p_j(x_i) = \frac{\exp(\beta_{0j} + \beta_{1j}x_i)}{1 + \exp(\beta_{0j} + \beta_{1j}x_i)}, \quad [3]$$

where β_{0j} was the intercept coefficient for observer j , and β_{1j} was the slope coefficient for observer j . We considered the following logistic regression models for the mark-recapture data: (1) intercept term only (i.e., probability of mark-recapture success was constant at all distances) and (2) intercept term and a slope coefficient for 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). AICc was calculated as $AICc = -2\log(Likelihood) + 2kn/(n-k-1)$, where k was the number of parameters in the model (including intercept term), n was the number of observations used to fit the model, *Likelihood*

was the value of the logistic likelihood evaluated at the maximum likelihood estimates, and ‘log’ was the natural logarithm.

Following logistic regression analysis, we estimated the probability of detection by at least one observer on the right side of the aircraft. Let 1, 2, and 3 denote observer positions in the front-right, back-right, and back-left of the aircraft, respectively. Assuming independence between observers 1 and 2, the probability of detection on the right side of the aircraft at distance x_i by at least one observer when two observers were present was calculated as

$$\hat{p} \cdot (x_i) = \hat{p}_1(x_i) + \hat{p}_2(x_i) - \hat{p}_1(x_i)[\hat{p}_2(x_i)] \quad [4]$$

In 2008 there were 68 transects surveyed with only two observers in the aircraft (Nielson et al. 2010b). These two observers sat in the front-right and back-left positions in the aircraft. The probability of detection on the right side of the aircraft when only one observer was present on the right side was estimated using

$$\hat{p}_1(x_i), \quad [5]$$

and the probability of detection for observer 3 (back-left) was estimated using

$$\hat{p}_2(x_i). \quad [6]$$

To estimate the heights of the detection functions estimated using equation[2], we needed to identify a distance at which detections between observers on the right side of the aircraft were not influenced by unmeasured covariates (Borchers et al. 2006). We assumed detections were independent and did not depend on unmeasured covariates at the distance where the detection rates were highest. At that distance, the mark-recapture detection probability should equal the kernel estimated detection probability, so we calibrated the kernel detection function to coincide with the mark-recapture probability at that distance (Borchers et al. 2006). Because $x_{\max}[\hat{f}(x)]$ was the distance x_i at which the estimated kernel detection function was at its zenith, the detection function for the right side of the aircraft was scaled so that $\hat{f}(x_{\max}[\hat{f}(x)])$ equaled the mark-recapture probability of detection by at least one observer (Borchers et al. 2006) (equation [4]). For example, if the maximum of the kernel estimated detection function was at distance $x = 200$ m ($x_{\max}[\hat{f}(x)] = 200$), and the probability of detection by at least one observer at 200 m was estimated to be 0.8 ($\hat{p} \cdot (200) = 0.8$), the kernel function was scaled so $\hat{f}(200) = 0.8$. The detection function for the left side of the aircraft, $\hat{f}(x)$, was scaled so that

$$\hat{f}(x_{\max}[\hat{f}(x)]) = \hat{p}_2(x_{\max}[\hat{f}(x)]). \quad [7]$$

The detection function for the front-right observer when the back-right observer was not present (a few occasions in 2008; Nielson et al. 2010b), was scaled so that

$$\hat{f}(x_{\max}[\hat{f}(x)]) = \hat{p}_1(x_{\max}[\hat{f}(x)]). \quad [8]$$

Survey protocol, aircraft, observer training and experience have been very consistent since 2006. Thus, we pooled all data from 2006 – 2011 to estimate the shapes of the detection functions (equation[2]) and to scale those detection functions using the mark-recapture data

(equations[3] – [8]). Past estimates, beginning in 2006, have been updated on a yearly basis upon inclusion of a new year of survey data collected and included in estimation of average probabilities of detection.

Buckland et al. (2001) recommend dropping the longest 5% to 10% of observations to remove outliers prior to integration of the scaled detection function and estimation of the average probability of detection. Following estimation and scaling of the detection functions, we trimmed observations greater than 1000 m from the transect line. Thus, the maximum allowable distance for observations of perched or flying birds to be used in density estimation was $W_2 = 1000$ m.

During the surveys, larger groups of Golden Eagles may have been more visible at longer distances compared to smaller groups. In addition, group sizes may have been different, on average, for flying Golden Eagles compared to observations of perched birds – again possibly due to visibility bias. A pre-analysis screening was used to identify whether group sizes in each year 2006 – 2011 were correlated with perpendicular distances. If group size was not significantly correlated with perpendicular distance based on a 90% CI for Pearson's correlation statistic (r), average group size for each observation type was computed by averaging across all distances ≤ 1000 m. Otherwise, truncation (Buckland et al. 2001) was used to estimate average group size. Recognizing that changes in productivity could affect changes in average group size, average group size was estimated separately for each survey year.

Bootstrapping (Manly 2007) was used to estimate 90% CIs for projected Golden Eagle densities and population totals within each BCR and the entire study area. This process involved taking 10,000 simple random samples with replacement of transects flown and re-running the analysis to produce new estimates of densities and population totals. We calculated CIs based on the central 90% of the bootstrap distribution (the "Percentile Method") for each parameter.

Data from the original sample of transects surveyed in 2006 – 2011 were used to estimate Golden Eagle abundance during 2006 – 2011. We used the R language and environment for statistical computing (v2.14.0; R Development Core Team 2011) to estimate yearly densities and population totals in each BCR and the entire study area.

Statistical Methods: Estimating Trends

Trends (average yearly increase or decrease) in the numbers of Golden Eagles observed during surveys from 2006 – 2011 were estimated using a Bayesian hierarchical model (Gelman and Hill 2007) fit using Markov chain Monte Carlo (MCMC) methods. We followed trend analysis methods used for Breeding Bird Survey data (Thogmartin et al. 2004 and 2006; Nielson et al. 2008; Sauer and Link 2011). Since survey protocol, observer training and skill, and survey transects were consistent during 2006 – 2011 we considered the probability of detection along a fixed portion of transect to also be consistent across the 6 years. This allowed us to analyze the raw counts of the total number of Golden Eagles observed on individual transects, rather than the projected densities. Analyzing projected densities would require incorporating variability in the estimated probabilities of detection and complicate the trend analysis. The hierarchical model simultaneously estimated time-trends in each BCR and across the entire study area. The model

was an overdispersed Poisson regression model with both fixed and random effects. Using counts of Golden Eagles in 2006 – 2011 along each transect we modeled the expected value λ_{ijt} of count Y_{ijt} in BCR i along transect j in year t as

$$\log(\lambda_{ijt}) = \log(\text{length}_{ijt}) + BCR_i + \gamma_i(t - t^*) + \delta_{it} + \omega_{ij} + \varepsilon_{ijt}, \quad [9]$$

where t^* was the median year (2008.5) from which change was measured, γ_i was the trend over time (average change per year) in BCR i , δ_{it} were random effects for year/BCR combinations, ω_{ij} were random transect-specific effects, ε_{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; Spiegelhalter et al. 2003).

We used 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 means equal to the study-area parameters and standard deviations (SD) $\sim$ Uniform (0, 100). Random year/BCR effects, transect effects, and overdispersed Poisson errors were assigned mean zero normal distributions with SD $\sim$ 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 five chains containing 30,000 iterations following a 50,000-iteration burn-in. Ninety-percent credible intervals (Bayesian confidence intervals) were used to determine if time-trends were statistically significant at the $\alpha = 0.10$ level. If a 90% credible interval 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 (at the $\alpha = 0.10$ level). 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. Data from the original sample of transects surveyed in 2006 – 2011 were used to estimate trends from 2006 – 2011.

RESULTS

In 2011, we flew 178 (partial and complete) transects totaling 14,285 km in BCRs 9, 10, and 16 (Table 1). The number of primary and alternate transects flown in each BCR each year 2006 – 2011 are presented in Table 2. We observed 117 Golden Eagle groups within 1000 m of the transect line along 71 transects (Fig. 1) for a total of 135 individuals: 14 juveniles, 22 sub-adults, 64 adults, 0 unknown immatures, 33 unknown adults, and 2 of unknown age (Fig. 3).

Table 1. Total length (km) of transects flown in each Bird Conservation Region 2006 – 2011. The Badlands and Prairies (17) was not surveyed in 2011.

Year	Great Basin	Northern Rockies	Southern Rockies / Colorado Plateau	Badlands and Prairies	Total
	(9)	(10)	(16)	(17)	
2006	6016	4606	3966	3143	17,731
2007	5857	4570	3998	3245	17,670
2008	5770	4546	3975	3129	17,420
2009	5915	4728	3807	3147	17,597
2010	5911	4557	3939	3201	17,608
2011	5820	4585	3880	--	14,285

Table 2. Number of primary (Prm.) and alternate (Alt.) transects surveyed in each Bird Conservation Region each year 2006 – 2010.

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

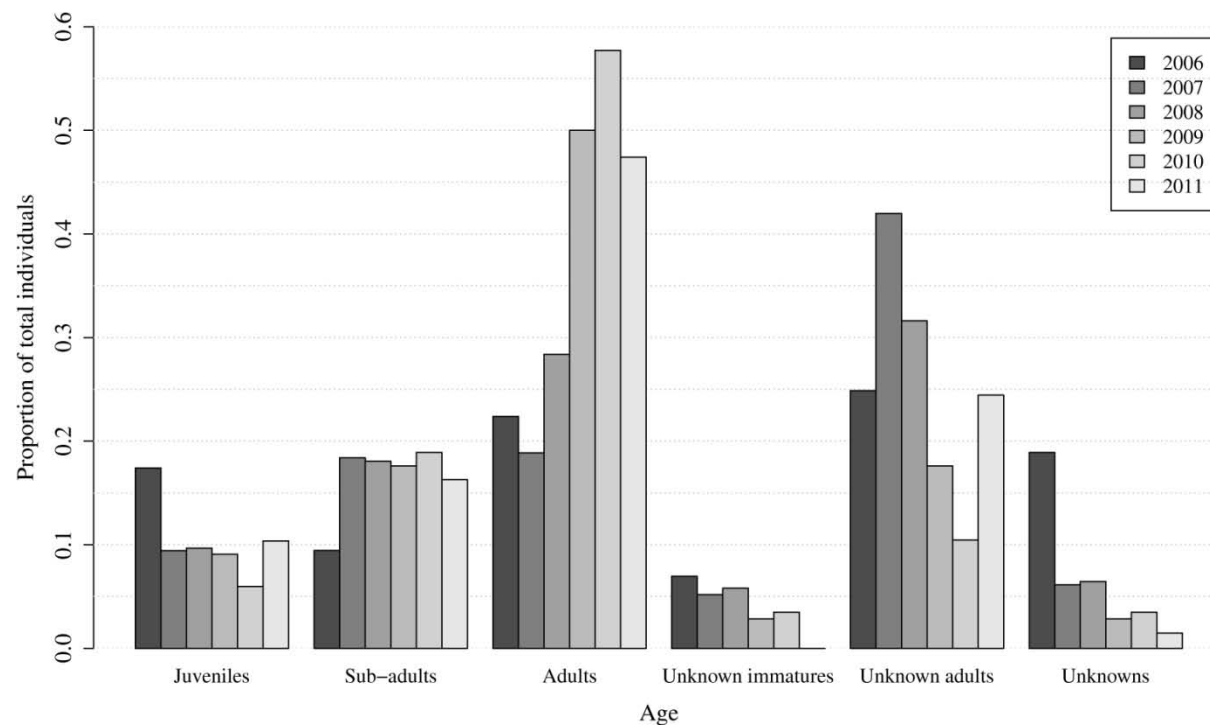


Figure 3. Age classifications of all Golden Eagles observed within 1000 m of transect lines surveyed in 2006 – 2011.

Average Golden Eagle group size did not increase with perpendicular distance from the aircraft in any year (Table 3). Mean size of observed Golden Eagle groups within 1000 m of the transect line in 2011 was 1.15 (SE = 0.036; Table 3).

Table 3. Average group size of Golden Eagles observed within 1000 m of the transect line in 2006 – 2011, along with Pearson's coefficient for correlation between group size and distance from the transect line. Standard Errors (SEs) are in parentheses.

Year	Average group size (SE)	Pearson's correlation coefficient (SE)
2006	1.27 (0.045)	0.014 (0.080)
2007	1.23 (0.040)	-0.053 (0.077)
2008	1.17 (0.034)	0.075 (0.087)
2009	1.18 (0.034)	-0.026 (0.082)
2010	1.20 (0.036)	-0.009 (0.078)
2011	1.15 (0.036)	0.232 (0.091)
All Years	1.20 (0.016)	0.022 (0.033)

We used post-stratification (observed perched from 107 m AGL, perched from 150 m AGL, or flying) for estimation of detection functions (equation [2]) and probability of detection based on mark-recapture sampling (equations [3] – [8]). The total number of observations of each type is shown in Table 4. Scaled detections functions, along with estimated average probabilities of detection ($\hat{P}$) are shown in Figs. 4 through 6.

Table 4. Numbers of Golden Eagle groups observed within 1000 m of survey transects in 2006 – 2011 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	75	9	74	158
2007	115	11	46	172
2008	73	8	52	133
2009	91	15	43	149
2010	97	21	50	168
2011	67	17	33	117
Total	518	81	298	897

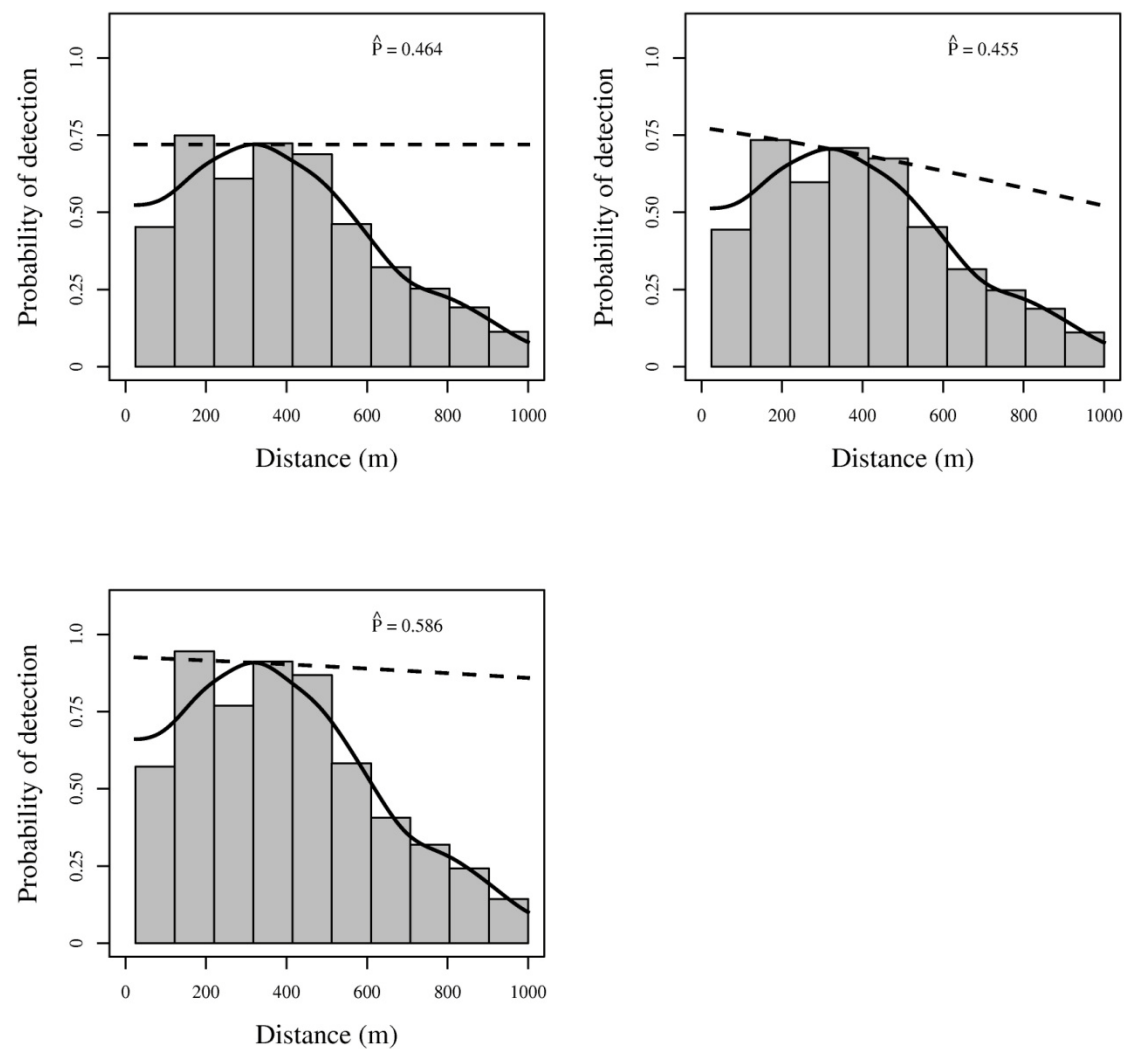


Figure 4. Probability of detection of perched Golden Eagle groups from 107 m AGL from back seats of the aircraft (top left), front seat of the aircraft when there was not a double-observer present (top right; 2008 only), and right side of the aircraft when both observers were present (bottom left). Dashed lines represent probabilities of detection estimated from mark-recapture sampling. Solid lines represent scaled detection functions that were integrated to estimate average probability of detection within the search width. Average probability of detection ($\hat{P}$) within the search width was estimated by integrating the solid line and dividing by the search width. Histograms show the relative numbers of observations in each distance interval.

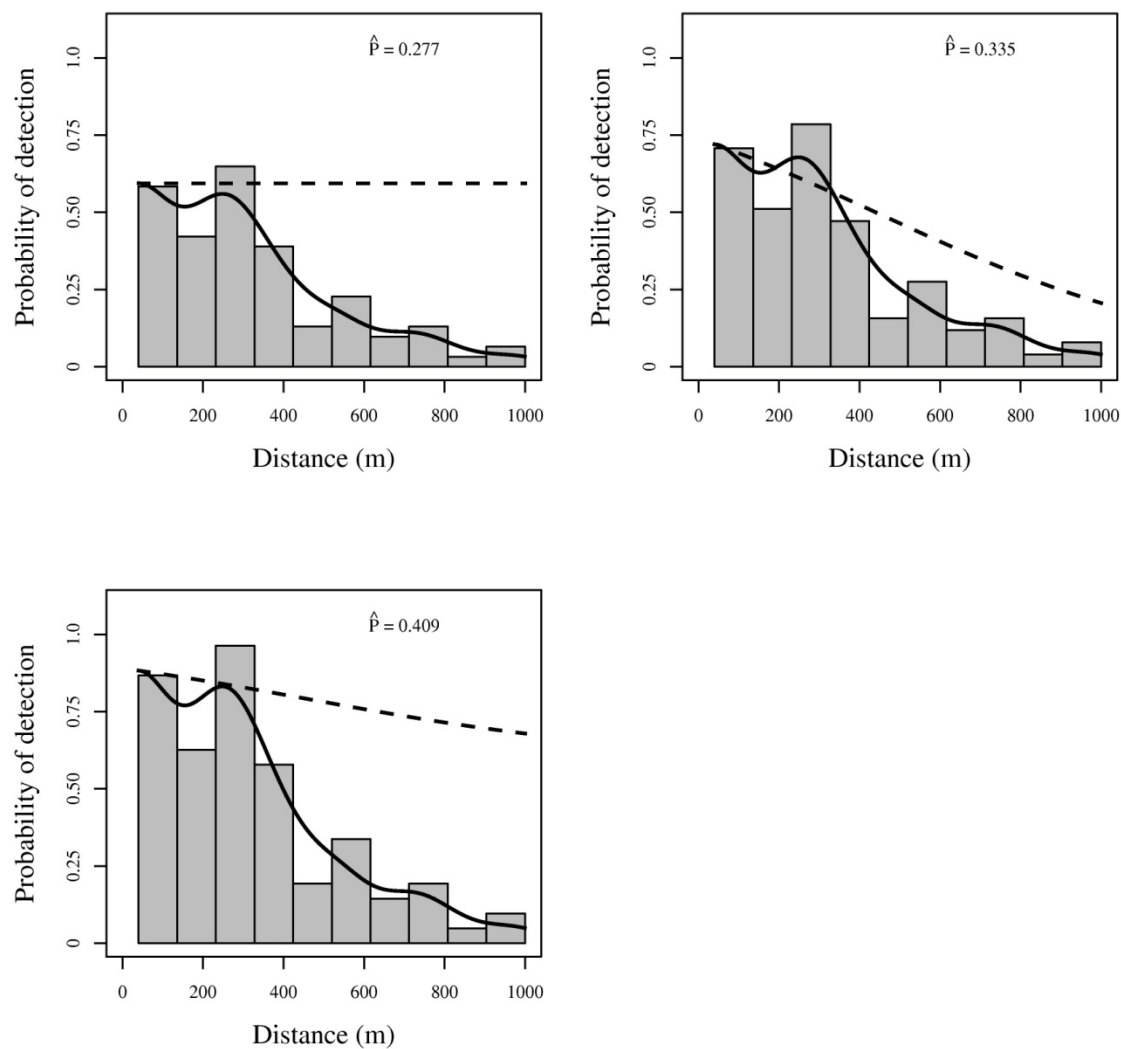


Figure 5. Probability of detection of perched Golden Eagle groups from 150 m AGL from back seats of the aircraft (top left), front seat of the aircraft when there was not a double-observer present (top right; 2008 only), and right side of the aircraft when both observers were present (bottom left). Dashed lines represent probabilities of detection estimated from mark-recapture sampling. Solid lines represent scaled detection functions that were integrated to estimate average probability of detection within the search width. Average probability of detection ($\hat{P}$) within the search width was estimated by integrating the solid line and dividing by the search width. Histograms show the relative numbers of observations in each distance interval.

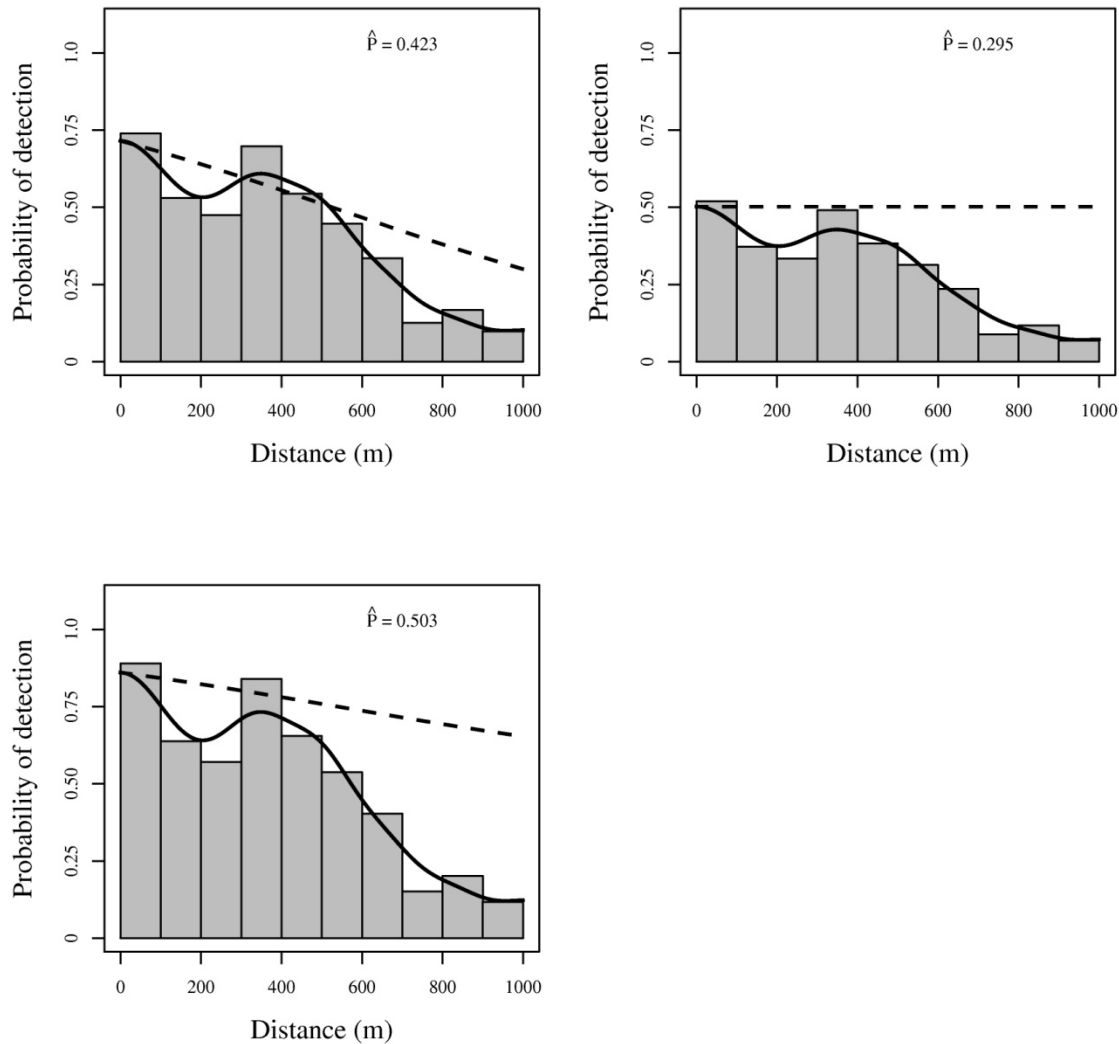


Figure 6. Probability of detection of flying Golden Eagle groups from back seats of the aircraft (top left), front seat of the aircraft when there was not a double-observer present (top right; 2008 only), and right side of the aircraft when both observers were present (bottom left). Dashed lines represent probabilities of detection estimated from mark-recapture sampling. Solid lines represent scaled detection functions that were integrated to estimate average probability of detection within the search width. Average probability of detection ($\hat{P}$) within the search width was estimated by integrating the solid line and dividing by the search width. Histograms show the relative numbers of observations in each distance interval.

Based on estimated densities of Golden Eagles within each BCR (Table 5), we projected a total of 6199 Golden Eagles (90% CI: 4732 – 8555) in BCR 9, 6862 (90% CI: 4853 – 9994) in BCR 10, and 2917 (90% CI: 2053 – 4228) in BCR 16 (excluding military lands, elevations above 10,000 ft, large water bodies, large urban areas, and the Badlands and Prairies) during late summer of 2011 (Table 6; Fig. 7).

Table 5. Estimated mean densities of Golden Eagles (#/km²) of all ages in each Bird Conservation Region (excluding military lands, elevations above 10,000 ft, large water bodies, and large urban areas) in 2003 and 2006 – 2011¹. Upper and lower limits for ninety-percent confidence intervals are to the right of each estimate.

Year	Great Basin		Northern Rockies		Southern Rockies / Colorado		Badlands and Prairies	
	(9)		(10)		Plateau (16)		(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	0.0101 0.0041	0.0117	0.0190 0.0069	0.0089	0.0137 0.0060	0.0266	0.0385 0.0192
2007	0.0093	0.0131 0.0066	0.0138	0.0225 0.0081	0.0057	0.0090 0.0034	0.0247	0.0342 0.0177
2008	0.0066	0.0101 0.0044	0.0142	0.0204 0.0096	0.0031	0.0052 0.0017	0.0173	0.0254 0.0118
2009	0.0074	0.0107 0.0053	0.0138	0.0216 0.0086	0.0054	0.0091 0.0026	0.0169	0.0257 0.0104
2010	0.0088	0.0139 0.0056	0.0147	0.0219 0.0096	0.0053	.00091 0.0029	0.0229	0.0338 0.0153
2011	0.0097	0.0134 0.0073	0.0137	0.0200 0.0097	0.0062	0.0090 0.0043	-- ²	-- --

¹Estimates for 2006 – 2011 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006 – 2010 have been updated and are slightly different than those presented in previous reports.

²BCR 17 was not surveyed in 2011.

Table 6. Estimated numbers of Golden Eagles of all ages in each Bird Conservation Region (excluding military lands, elevations above 10,000 ft, large water bodies and large urban areas) in 2003 and 2006 – 2011¹. Upper and lower limits for ninety-percent confidence intervals are to the right of each estimate.

Year	Great Basin		Northern		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)		Total	
	(9)		Rockies (10)							
2003	10,939	15,754 7522	4831	8580 2262	4998	7275 3199	6624	9207 4611	27,392	35,369 21,556
2006	4207	6449 2652	5870	8580 2262	4210	6422 2845	9316	13,498 6759	23,601	31,575 19,360
2007	5942	8384 4285	6908	9460 3479	2697	4203 1643	8661	11,969 6219	24,206	31,458 20,000
2008	4246	6434 2843	7080	11,218 4053	1477	2431 827	6057	8904 4168	18,858	24,404 15,641
2009	4740	6798 3414	6894	10,780 4349	2527	4266 1256	5914	8999 3671	20,074	26,392 16,303
2010	5634	8889 3646	7347	10,917 4816	2512	4280 1407	8038	11,832 5373	23,530	30,468 19,434
2011	6199	8555 4732	6862	9994 4853	2917	4228 2053	-- ²	-- --	-- ²	-- --

¹Estimates for 2006 – 2011 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006 – 2010 have been updated and are slightly different than those presented in previous reports.

²BCR 17 was not surveyed in 2011.

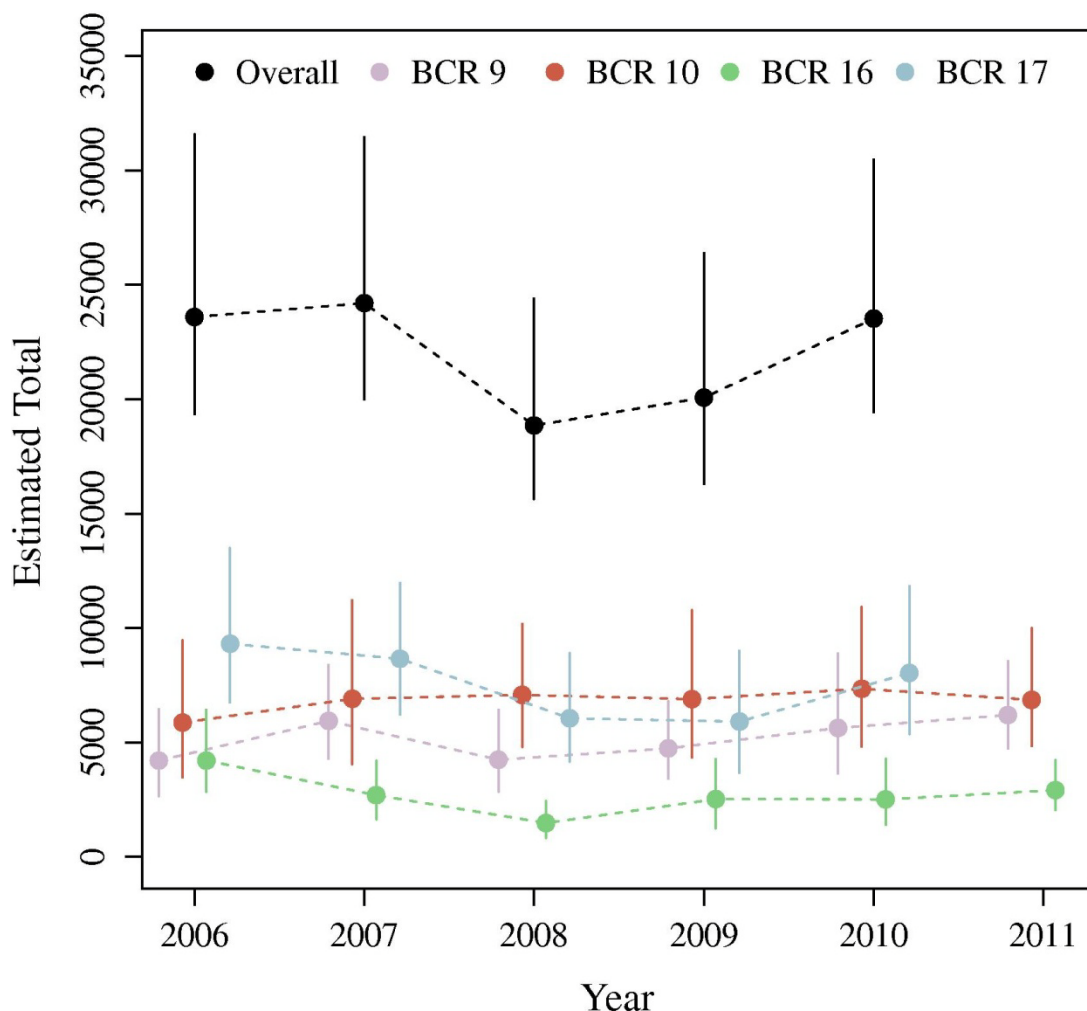


Figure 7. Estimates, including 90% confidence intervals (vertical lines), for the total number of Golden Eagles (all ages) within each Bird Conservation Region (BCR) and across the entire study area (excluding military lands, elevations above 10,000 ft, large water bodies, and large urban areas) in late summer (August 15 – September 15) 2006 – 2011. The BCRs are: 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies). The BCR 17 was not surveyed in 2011, so estimates for BCR 17 and Overall are not presented for that year. Estimates from the 2003 survey (1st year of survey) are excluded due to a change in survey protocol and transects after the initial survey.

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 665 Golden Eagles would have been classified as juveniles in BCR

9 (90% CI: 227 – 1290), and 1030 in BCR 10 (90% CI: 373 – 1920; Table 7; Fig. 8). Zero Golden Eagles observed in BCR 16 were classified as juveniles in 2011.

Table 7. Estimated numbers of juvenile Golden Eagles in each Bird Conservation Region (excluding military lands, elevations above 10,000 ft, large water bodies and large urban areas), in 2003 and 2006 – 2011¹. Upper and lower limits for ninety-percent confidence intervals are to the right of each estimate.

Year	Great Basin		Northern		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)		Total	
	(9)		Rockies (10)							
2003	1190	2605 544	1286	2634 628	498	1216 204	2072	3312 1296	5046	6839 3723
2006	783	1424 322	1468	2602 708	658	1332 159	1347	2459 582	4256	6289 2970
2007	513	963 192	1054	2229 165	0	NA NA	825	1473 324	2392	3836 1359
2008	515	1165 4*	966	1538 520	247	590 2*	238	712 2*	1966	3043 1195
2009	221	549 2*	1078	1991 443	127	375 1*	439	794 131	1865	2963 1096
2010	470	1084 90	557	1285 92	140	449 1*	207	497 2*	1374	2442 610
2011	665	1290 227	1030	1920 373	0	NA NA	-- ²	-- --	-- ²	-- --

¹Estimates for 2006 – 2011 were obtained by pooling observations across years to improve estimates of detection probabilities. Thus, estimates for 2006 – 2010 have been updated and are slightly different than those presented in previous reports.

²BCR 17 was not surveyed in 2011.

*Lower limits set to number observed during survey.

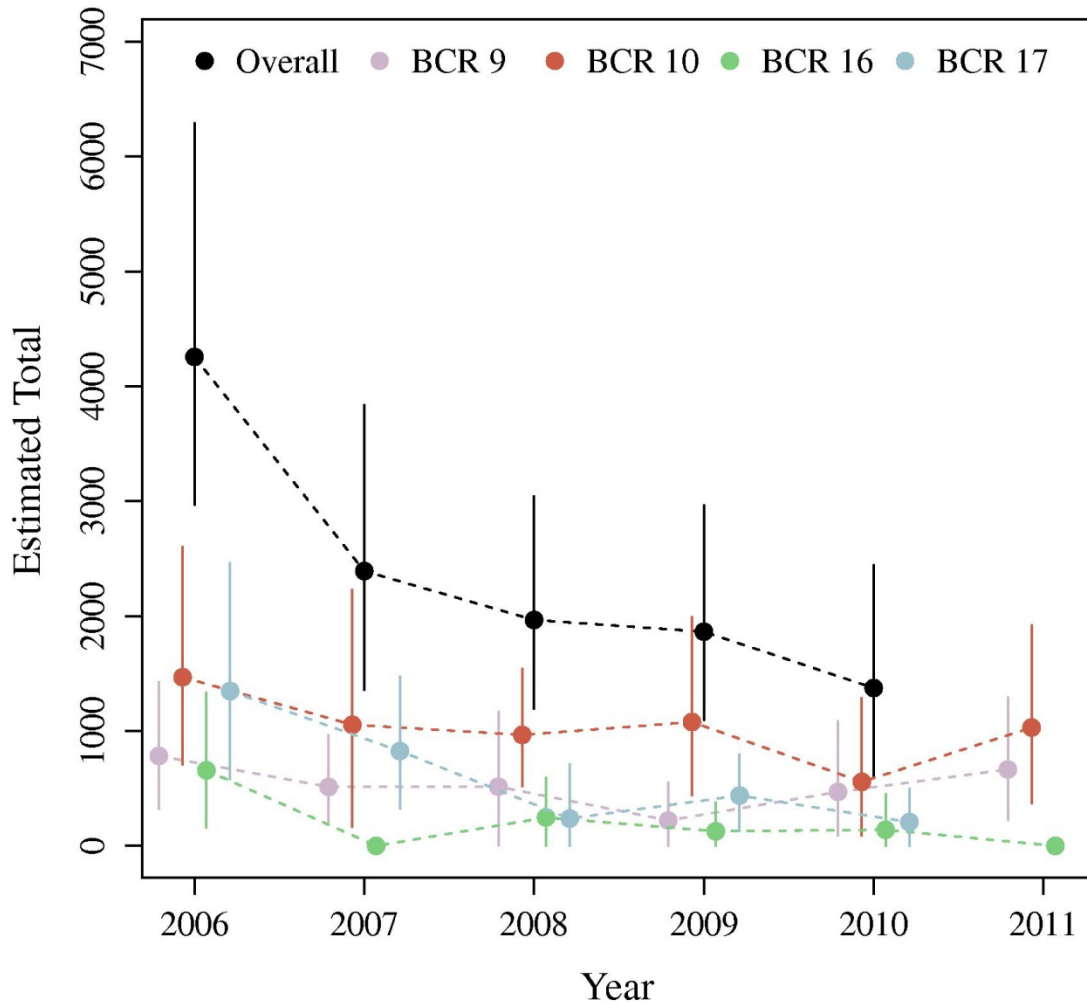


Figure 8. Estimates, including 90% confidence intervals (vertical lines) of the total number of juvenile Golden Eagles within each Bird Conservation Region (BCR) and across the entire study area (excluding military lands, elevations above 10,000 ft, large water bodies, and large urban areas) in late summer (August 15 – September 15) 2006 – 2011, 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 Southern Rockies / Colorado Plateau in 2007 or 2011, so confidence intervals are not presented for those years. The Badlands and Prairies was not surveyed in 2011, so estimates for BCR 17 and Overall are not presented for that year. Estimates from the 2003 survey (1st year of survey) are excluded due to a change in survey protocol and transects after the initial survey.

Trends in Abundance

We did not detect significant trends (i.e., 90% credible intervals contained zero) in the total numbers (all age classes) of Golden Eagles observed in individual BCRs or across the entire study area during 2006 – 2011, although all point estimates for BCRs 9, 10, and 17 and the overall study area were positive (Table 8).

Table 8. Time-trend estimates (average number of observations per km of transect) for numbers of Golden Eagles (all ages), based on the fit of a Bayesian hierarchical model fit to counts along each transect 2006 – 2011. Bird Conservation Region 17 was not surveyed in 2011.

Region	Time-trend (90% CI)
Great Basin (9)	0.0753 (-0.0094, 0.1680)
Northern Rockies (10)	0.0527 (-0.0319, 0.1424)
Southern Rockies / Colorado Plateau (16)	-0.0111 (-0.1113, 0.0797)
Badlands and Prairies (17)	0.0269 (-0.0636, 0.1145)
Overall study area	0.0361 (-0.0797, 0.1515)

We detected significant negative trends (i.e., 90% credible intervals were less than zero) in the total number of Golden Eagles classified as juveniles in the Southern Rockies / Colorado Plateau (16) during 2006 – 2011 and in the Badlands and Prairies (17) during 2006 – 2010 (Table 9). We did not detect significant trends (i.e., 90% credible intervals contained zero) in the numbers of juvenile Golden Eagles observed in the Great Basin (9), Northern Rockies (10), or across the entire study area during 2006 – 2011 (Table 9).

Table 9. Time-trend estimates (average number of observations per km of transect) for numbers of juvenile Golden Eagles, based on the fit of a Bayesian hierarchical model fit to counts of Golden Eagles classified as juveniles along each transect 2006 – 2011. Bird Conservation Region 17 was not surveyed in 2011.

Region	Time-trend (90% CI)
Great Basin (9)	-0.0423 (-0.2893, 0.2313)
Northern Rockies (10)	-0.2045 (-0.4255, 0.0044)
Southern Rockies / Colorado Plateau (16)	-0.2346 (-0.4646, -0.0249)
Badlands and Prairies (17)	-0.2661 (-0.5254, -0.0409)
Overall study area	-0.1868 (-0.4895, 0.1048)

DISCUSSION AND CONCLUSIONS

Standard distance analysis methods for estimating mean probability of detection utilize semi-parametric models to force estimated detection functions to be highest at the minimum available sighting distance and to decrease monotonically out to the maximum sighting distance. These semi-parametric distance models can be fitted using the program Distance (version 5.0 release 2; Thomas et al. 2006). However, lower detection probabilities at the nearest available sighting distance have been documented for surveys from fast moving aircraft (e.g., Becker and Quang 2009). Given the speed at which the aircraft moves, objects closer to the transect line can be in the observers' field of view for less time, and thus, more difficult to detect. Indeed, detection functions for perched birds estimated from Golden Eagle survey data collected 2006 – 2011 had a substantial peak around 300 m from the transect line (Fig. 4). For this reason, since 2006, we have not utilized standard distance analysis methods available in the program Distance (Thomas et al. 2006) due to the superior flexibility of the kernel-based method.

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. Golden Eagles have been shown to prefer open grassland and shrub-steppe habitats over forested areas for hunting (Kochert et al. 2002), and we suspect that Golden Eagle densities and probability of detection were much lower in the rugged or forested habitats. For the Golden Eagle survey data, it appears as though the shapes of the detection functions, along with average probabilities of detection, were quite different across the major observation types (Figs. 4 – 6).

Survey data from 2006 – 2011 were pooled to estimate detection functions, which were used to estimate population totals in 2011 and retroactively for 2006 – 2010. We felt this pooling was justified given the consistency of the survey (i.e., protocol, observer experience, aircraft, etc.). Pooling data across years reduced year-to-year variability in the estimated detection functions, which we believe was primarily due to small sample sizes within a given survey period.

There are many ways to analyze data for trend, and the Bayesian hierarchical modeling approach we adopted is an efficient method for accounting for the different sources of variation in the data. The hierarchical model also allows for simultaneous estimation of BCR-level trends and the overall trend across the entire study area. In addition, the MCMC approach to fitting a hierarchical model can easily accommodate missing observations – e. g., when transect i is not surveyed due to forest fire, or if transect i is surveyed only once 2006 – 2011 (e.g., alternate transect). Considering probability of detection as consistent from year-to-year on each transect, but varying from transect to transect, precluded the need to estimate time-trends for the estimated total number of Golden Eagles, which contain more variability than the raw counts.

Trend analyses for total abundance of Golden Eagles (all ages) suggest that populations in the individual BCRs and in the entire study area are stable (Table 8). This conclusion is not totally corroborated by the estimated population sizes, because of the relatively large standard errors associated with the point estimates (Table 6, Figure 7). Although there is no empirical evidence for a decrease or increase in population size in the entire study area, patterns for

individual BCRs are less clear. Also, the trend analysis was based on only 6 years (2006 – 2011) of survey data, so our conclusion should be viewed with caution. In addition, the survey was designed to detect an average of a 3% change per year over a 20-year period with a power of 80%, so we expect that only substantial changes in population size could be detected with high power after only 6 years of surveys.

Change in total population size is the ultimate indicator of overall population trend. However, other indicators may be examined to gain further insight into population status. One indicator used during 2006 – 2011 surveys is the total number of Golden Eagles observed and classified as juveniles. Tracking the number of juveniles observed each year can give wildlife managers early insight to potential changes in Golden Eagle populations. However, we should be cautious about interpretation of the juvenile counts from the Golden Eagle survey. These counts reflect the number of Golden Eagles detected and classified as juveniles using the age classification matrix (Fig. 2). Unfortunately, it is not possible to classify every Golden Eagle observed during the survey as juvenile, sub-adult or adult, so the ‘unknown’ classifications are needed. There are a variety of reasons why a Golden Eagle might be classified as either an unknown sub-adult (not an adult), unknown adult (not a juvenile), or of unknown age. These include poor light, the bird’s physical location, survey conditions (e.g., turbulence), and the perceived safety of circling the bird for aging. For example, a Golden Eagle perched lower in a tree, sitting the shadow of a rock, or just below a cliff’s edge may be difficult to age.

We began to use an age classification matrix (Fig. 2) in 2006. During subsequent survey years, the proportion of Golden Eagles classified as unknown immature and the proportion classified as unknown have declined (Fig. 3). These decreased proportions could represent increased confidence in our ability to determine whether a given Golden Eagle is a juvenile, sub-adult, or adult. In addition, our views of eagles have improved due to increased ability of our survey pilots to safely circle 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 (Fig. 3). Regardless, it is important to consider that if a proportion (e.g., 50%) or even 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 uncertainty in age classification confounds the trend estimates for juveniles reported herein.

We estimated negative trends in the total number of observed Golden Eagles classified as juveniles in the Southern Rockies / Colorado Plateau (16) during 2006 – 2011, and the Badlands and Prairies (17) during 2006 – 2010 (Table 9). The estimated time-trend coefficient for BCR 16 was -0.2346 (90% credible interval from -0.4646 to -0.0249). Based on this estimate, there has been an average decline of 21% ($[\exp(-0.2346)-1] \times 100\% = -21\%$) per year in the numbers of juvenile Golden Eagles observed per km of transect in the region. The estimated coefficient for time-trend for juvenile Golden Eagles in the Badlands and Prairies was -0.2661 (90% credible interval from -0.5254 to -0.0409). Based on this estimate, there has been an average decline of

23% per year, 2006 – 2010, in the numbers of juvenile Golden Eagles observed per km of transect in the region.

Causes of estimated declines in the total number of observed Golden Eagles classified as juveniles (Table 9) are unknown. A drop in number of juveniles observed during a survey year may be an indication of decreased productivity, and consecutive years of low juvenile numbers may provide early indications of longer term population declines. Environmental factors such as drought or reduced prey populations may play a part in the potential decrease. However, annual mortality rates of juveniles may be high or productivity may be low, and if enough ‘floaters’ are available in a non-decreasing adult population, the breeding population may be stable. Again, because the trend analysis was based on only 6 years of survey data, our results should be viewed with caution.

While 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). It is not clear how the current populations may be influenced by such cycles. In addition, populations in different regions may be in different phases of decadal cycles at any one point in time. Jackrabbit (*Lepus spp*) and cottontail (*Sylvilagus spp*) populations within northeast Wyoming and southeast Montana appeared to be at historical highs between 2003 and 2006 (Tosches 2006). In southwest Idaho, prey densities and severe weather were limiting factors for Golden Eagle populations during a 23-year study (Steenhof et al. 1997).

Our recommendations for future surveys are based the two primary goals for the Golden Eagle survey (Good et al. 2007): (1) to estimate the total population size of Golden Eagles within the entire study area and within each BCR and (2) to determine the trends of Golden Eagle populations within the entire study area and within each BCR. We recommend that any future surveys be conducted using the same methods as used in 2006 – 2010, 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 analysis methods used from 2006 – 2010. Repeated surveys of the same transects, using the same protocol, is expected to have higher power to detect trends than a design based on selection of new transects each year. Following additional years of surveys using under this protocol, the FWS would have more information to evaluate how frequently surveys should be conducted (e.g., every year vs. every 2 years).

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APPENDIX

Evaluation of increased survey effort in the Southern Rockies / Colorado Plateau

Estimates of Golden Eagle abundance in BCR 16 (Southern Rockies / Colorado Plateau) during 2006 – 2010 have been less precise than estimates in other BCRs during the same period (Nielson et al. 2011). The relative confidence interval (CI) half-width for the total number of Golden Eagles in BCR 16 in 2010 was 49%, compared to relative CI half-widths between 40% and 41% for the other three BCRs. In addition, the proportion of Golden Eagles classified as juveniles has been lower in BCR 16. In fact, zero juvenile Golden Eagles were observed in BCR 16 in 2007, and only one was observed in each of 2009 and 2010.

Concern over the relatively low precision of estimates of Golden Eagle abundance in BCR 16 during 2006 – 2010, along with the relatively low number of observations of Golden Eagles classified as juveniles prompted increased survey effort in BCR 16 in 2011 compared to previous years. To keep survey costs comparable to previous years, a BCR having population estimates with relatively high precision (Badlands and Prairies; 17) was omitted from the 2011 survey. The objective of this change, proposed for a single survey year, was to better understand the tradeoffs between increased sampling precision and survey effort, which could inform decisions on alternate approaches for the annual Golden Eagle survey.

We increased the survey effort in BCR 16 by doubling the density of primary transects in our systematic grid of sampled transects (Fig. A1). Primary and alternate transects were flown in the same general order and at the same time (late August) as during 2006 – 2010. The additional transects surveyed for this investigation into sample effort and precision were flown approximately one week following the original sample of transects and in a similar pattern going south from Laramie, WY through CO to NM, and then over to AZ and up through eastern UT. The timing of surveys along the original sample of transects in BCRs 9, 10 and 16 stayed consistent in 2011 compared to 2006 – 2010. And, because we did not include the additional transects in BCR 16 in our primary analyses for 2011 (i.e., abundance estimation and trend analyses), our doubling of survey effort in BCR 16 likely had negligible impact on our ability to detect long-term trends in any BCR.

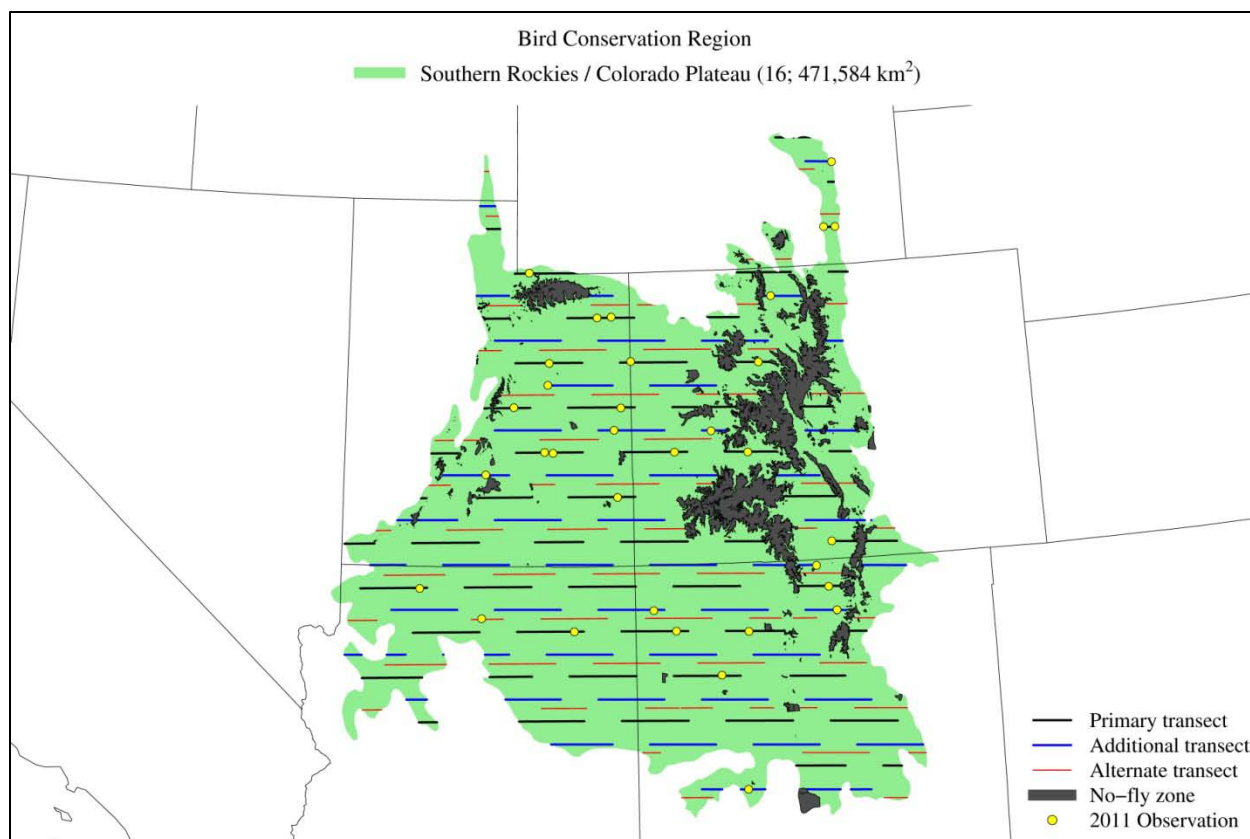


Figure A1. Locations of the original sample of transects (Primary and Alternate) and the additional transects flown in Bird Conservation Region 16 in 2011, with locations of Golden Eagle groups observed along all transects during the 2011 survey.

We surveyed 3880 km of transect along 57 primary and two alternate transects in BCR 16 in 2011, and 3927 km of transect along 56 additional transects (Table A1). We observed 23 Golden Eagles in 20 groups along within 1000 m of the original transects in BCR 16 in 2011, while only 12 individuals in nine groups were seen within 1000 m along the additional transects (Table A1).

Using data from only the original transects in Southern Rockies / Colorado Plateau (16), we estimated a total of 2917 Golden Eagles in BCR 16 during the late summer study period in 2011 (90% CI: 2055 – 4228) (Table A1). Based on surveys of the additional transects only, we estimated a total of 1609 Golden Eagles in BCR 16 for the same period in 2011 (90% CI: 825 – 2793). Using the combined data from surveys along all transects, we estimated a total of 2259 Golden Eagles (90% CI: 1669 – 3191).

Increasing survey effort by nearly doubling the density of transects in the BCR 16 resulted in a modest improvement in the precision of our estimate of total abundance within that region for 2011. The relative 90% CI half-width for the estimated abundance in BCR 16 based on the original transects only was 37%. The relative 90% CI half-width based on the additional transects only was 61%, indicating there was more variability in the number of Golden Eagles

observed across the additional transects compared to the original sample. The combined estimate based on all transects surveyed in 2011 had a relative 90% CI half-width of 33%. Thus, the increased survey effort resulted in a modest improvement in the precision of our estimate of total abundance in BCR 16 (relative half-width of the 90% CI decreased from 37% to 33%). However, the combined estimate could be more accurate. Our estimate of abundance based on the original transects may be too high, and an estimate based only on the additional transects may be too low.

Table A1. Comparison of survey results for the original transects, additional transects, and both sets of transects combined in Bird Conservation Region 16 in 2011, including estimated abundance of Golden Eagles (all ages) and the estimated number that would have been classified as juveniles in 2011. Upper and lower limits for 90% CIs are to the right of each estimate. Estimates do not include Golden eagle occupying military lands, elevations above 10,000 ft, large water bodies, or large urban areas at the time of the survey

Sample of Transects	Length (km) surveyed	# of Golden Eagles observed	Abundance (all ages)		Abundance (juveniles)	
Original	3881	23	2917	4228 2055	0	NA NA
Additional	3927	12	1609	2793 825	115	276 1*
Combined	7808	35	2259	3191 1669	56	156 1*

*Lower limits set to number observed during survey.

No Golden eagles observed along the original set of transects were classified as juveniles in 2011 (down from two in 2010). One Golden Eagle observed along the additional transects was classified as a juvenile, so our final estimate based on all transects surveyed in the Southern Rockies / Colorado Plateau (16) is at least non-zero and has an associated measure of precision (Table A1). Detections of Golden Eagles classified as juveniles were too few to compare precision, however (zero detected in sample of original transects, one detected in additional transects).

Limited contrast between the estimate of population abundance based on the original transects and that from the original plus additional sample of transects in BCR 16 may be attributed largely to sampling variability, namely differences in habitat flown and local densities. For example, sampling variance inherent in the additional transects data exceeded that in the data from the original transects. The converse could easily occur in another survey year or with a different sample of additional transects. Alternatively, some Golden Eagles may have moved from the BCR prior to the survey of additional transects, which was conducted about one week

following the survey of original transects. In addition, different crews surveyed the original and additional transects. Most likely, the difference resulted from a combination of factors.

Our recommendations for future surveys are based on the two primary goals for the Golden Eagle survey (Good et al. 2007): (1) to estimate the total population size of Golden Eagles within the entire study area and within each BCR and (2) to determine the trends of Golden Eagle populations within the entire study area and within each BCR. The change in methods for 2011 to forego surveys in the Badlands and Prairies (17) in an attempt to improve precision in the Southern Rockies / Colorado Plateau (16) did not seem to justify the short term loss of information for the Badlands and Prairies (17), although long term characterization of population trend for the BCR probably was unaffected. If we had seen precision increase by around 10% or more with the increased survey effort, then modifications to survey effort in BCR 16 may be justified for future surveys.