Research Article

A Population Estimate for Golden Eagles in the Western United States

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ABSTRACT Researchers have suggested golden eagle (*Aquila chrysaetos*) populations may be declining in portions of their range. However, there are few baseline data describing golden eagle populations across their range in the western United States. We used aerial line transect distance methodology with a double-observer modification to estimate golden eagle population numbers in 4 bird conservation regions of the western United States. We conducted surveys from 16 August to 8 September 2003, after most golden eagles had fledged and before fall migration. The goal of our sampling strategy was to provide ≥80% power ($\alpha = 0.1$) to detect an annual rate of total population change ≥3% per year over a 20-year period. We observed 172 golden eagles across 148 transects and estimated 27,392 golden eagles (90% CI: 21,352–35,140) occurred in the study area during the late summer and early fall of 2003. Following the surveys, we used Monte Carlo simulation to determine the statistical power to detect trends in the golden eagle populations if yearly surveys were continued over a 20-year monitoring period. The simulation indicated the desired power could be achieved under the current methodology and sample size. The methods utilized in this study can be implemented for other raptor species when population estimates that include nonbreeding members of a population are needed. The results of this study can be utilized by professionals to help manage golden eagle populations and to develop conservation strategies. (JOURNAL OF WILDLIFE MANAGEMENT 71(2):395–402; 2007)

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Although the golden eagle (*Aquila chrysaetos*) is one of the most widespread raptor species in the world, little is known about population trends and status within the United States (Kochert and Steenhof 2002). With the exception of migration counts (Hoffman and Smith 2003), ongoing, long-term monitoring of golden eagle populations is limited to tracking nesting pairs in only a few local populations (Kochert and Steenhof 2002). Steenhof et al. (1997) found that nesting golden eagle populations have declined in Idaho, USA, whereas McIntyre and Adams (1999) found populations were stable in Alaska, USA. No other long-term study of golden eagle nesting populations is available in the published literature. Migration count data also indicate that some golden eagle populations may be declining in the United States (Hoffman and Smith 2003).

Although decreases in the number of nesting birds in a study area may reflect local population declines, a significant portion of golden eagle populations may not breed and are referred to as floaters (Brown 1969, Hunt 1998). The presence of a floating population complicates interpretation of trends in the number of breeding pairs in an area. For example, although the number of occupied territories in an area may remain constant, a decline in the total population size (breeders and nonbreeders) may go unnoticed as floaters fill unoccupied territories.

The golden eagle is currently protected under the Migratory Bird Treaty Act and the Eagle Protection Act. Although golden eagles are widely distributed, annual population estimates and trend data would improve management of the species. Without reliable estimates of population size and trends of golden eagles in the western United States, it is difficult for the United States Fish and Wildlife Service to determine the appropriate number of permits to issue for various take requests and ensure a sustainable golden eagle population. Population size estimates are also essential for the development of conservation strategies.

Other factors that could cause population declines such as habitat losses are also increasing. Territory occupancy in Idaho declined following several large fires in the 1990s that resulted in loss of shrub habitats and concurrent declines in black-tailed jackrabbit (*Lepus californicus*) populations (Kochert et al. 1999). Invasions of exotic plant species and alteration of fire frequencies also have the potential to decrease the amount of shrubland and thus jackrabbit populations across much of the west. A golden eagle population in California, USA, experienced declines in territory occupancy following extensive urbanization (Bittner and Oakley 1998). Overall, if human activity and development continue to increase throughout the West, associated pressures on golden eagle populations are expected to increase. Currently it is not known at what level those pressures translate into a potential golden eagle population decline. Baseline data, such as estimates of current population sizes, are needed to assess the potential effects of these threats to golden eagles.

The goals of our study were to accurately and precisely estimate golden eagle population size in the study area and to develop a survey procedure and a statistical analysis that, if replicated annually, would have ≥80% power ($\alpha = 0.1$) to detect an annual rate of total population change ≥3% per

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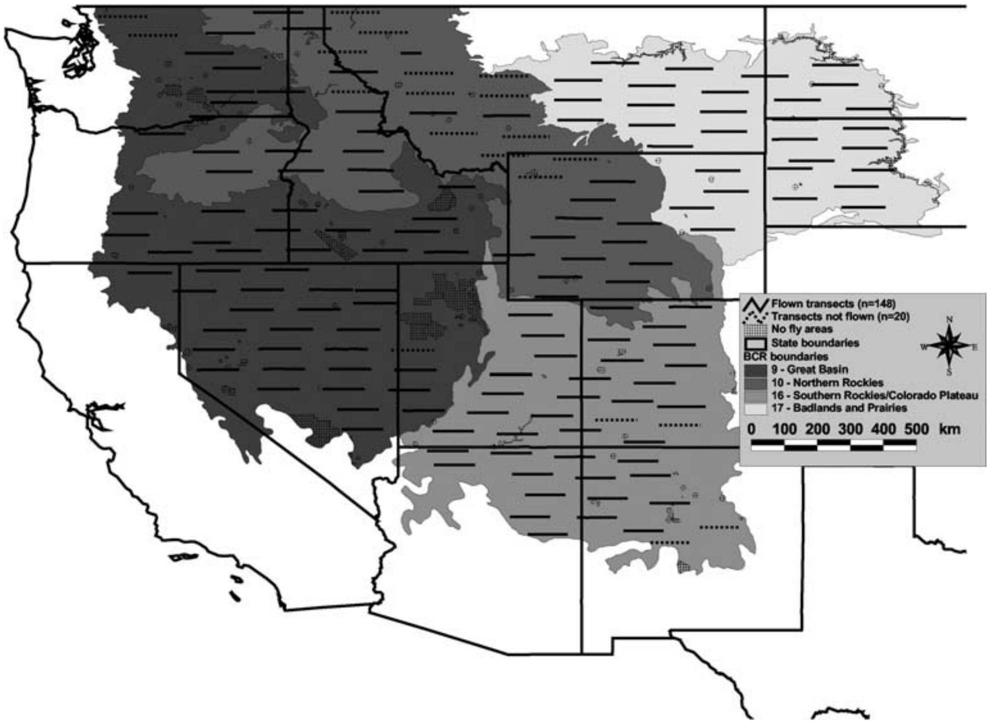

Figure 1. A map showing the 4 bird conservation regions (BCR) and transect locations where golden eagle surveys were conducted from 16 August to 8 September 2003.

year over a 20-year period. In this paper we present methods and results of the initial survey conducted in 2003.

STUDY AREA

The study area consisted of the following bird conservation regions (BCRs): 9, Great Basin; 10, Northern Rockies; 16, Southern Rockies or Colorado Plateau; and 17, Badlands and Prairies (North American Bird Conservation Initiative 2000) within the United States. The study area contained most of occupied golden eagle habitat in the United States with the exception of California and Alaska, which contain golden eagle habitat but were not included in our study. These regions covered approximately 2,033,501 km^2 of the western United States and included habitat types ranging from low-elevation sagebrush and grassland basins to high-elevation coniferous forest and mountain meadows (Fig. 1). Due to flight restrictions the study area did not include military-owned lands (e.g., military bases, training grounds), Department of Energy lands, urban areas, or large water bodies (Fig. 1). These areas comprised only 4% (73,953 km^2) of the 4 BCRs. Thus, our study area was approximately 1,959,548 km^2 in size.

METHODS

Survey Methods

We conducted aerial line transect distance surveys (Buckland et al. 2001) from 16 August to 8 September 2003, after most golden eagles had fledged and before fall migration (Fuller et al. 2001). We conducted surveys using Cessna 205 and 206 aircraft flown at approximately 161 km/hour and 107 m or 150 m above ground level (AGL), depending on terrain. We flew transects located above open habitats with gentle topography at 107 m AGL, whereas transects over rugged or mountainous terrain were flown at 150 m AGL. We determined airspeed and altitudes for surveying as the slowest and lowest we could safely fly to offer the best opportunities to spot golden eagles from the air. We consulted our pilots and the Office of Aircraft Safety when determining the survey airspeed and AGL.

We attempted to fly 168 transects each 100 km in length, using 3 different crews. However, we did not fly 20 transects due to large forest fires. On every survey flight ≥ 2 observers were present and seated on each side of the aircraft in the back seats. A third observer was present on approximately one-third of the flights and rotated among the 3 crews. The third observer was seated adjacent to the pilot in the front-right seat of the aircraft when we conducted double-observer trials on that side of the aircraft to estimate detection of golden eagles at the minimum available sighting distance (see Statistical Methods). Conventional distance methodology assumes 100% detection at the minimum available sighting distance (Buckland et al. 2001, 2004; Borchers et al. 2002), so we used the double-observer trials to verify this assumption and correct the statistical analysis if we observed <100% detection.

We established transects by randomly placing a systematic grid of east–west transects over the study area. We oriented transects east–west so that light conditions affected each side of the aircraft to approximately the same degree and to allow pilots to fly east–west in the morning hours and west–east in early afternoon to avoid looking directly into the sun. We moved transects that contained large water bodies (covering >10% of the transect), urban areas, or restricted airspace (e.g., Department of Defense or Department of Energy lands) the minimum distance to a new location that allowed inclusion in the study.

All observers had prior experience identifying golden eagles. Additionally, all observers participated in a 3-day training session to improve and standardize survey protocol and identification and aging of golden eagles. The aging and identification portion of the training was led by W. S. Clark, a recognized expert in golden eagle identification and aging (Clark 2001, Clark and Wheeler 2001). We conducted practice flights over sagebrush–grassland habitats in southern Wyoming, USA.

We verified golden eagles sightings by flying off transect to obtain a closer view of the eagle. We circled perched birds at low altitudes (50 m AGL) to confirm species identification, to age the individual, and to obtain Global Positioning System (GPS) locations that we later used to measure distances of observations from the transect line. If a flying golden eagle was observed, we recorded the location on the transect line where the bird's original location (i.e., where it was first observed) was perpendicular to the transect line, and we visually estimated the perpendicular distance to the flying bird's original location. In addition, we calibrated visual estimates by using real-time GPS flight tracking and by flying over identified landmarks on the ground directly below where the flying golden eagle was first detected. We recorded actual flight paths, airspeed, and AGL using real-time GPS tracking. We noted in the general comments section of the field data form any golden eagles spotted while we were flying off-transect, but we did not use these sightings to estimate population densities.

We classified golden eagles into 1 of 6 age classes: 1) adult, 2) unknown adult (ad or older immature), 3) older immature (sub-adult), 4) juvenile, 5) unknown immature (juv or older immature), and 6) unknown. We assigned birds to age classes based upon visible plumage characteristics (Clark 2001, Clark and Wheeler 2001, Bloom and Clark 2002). For more details on the justification, methods, and results of our efforts, see Good et al. (2004).

Estimating Population Totals

Conventional line transect methodology assumes known detection at or near the transect line or minimum available sighting distance (Buckland et al. 2001, 2004; Borchers et al. 2002). We used a double-observer modification (Manly et al. 1996, McDonald et al. 1999, Buckland et al. 2004) to allow for estimation of detection at the minimum available sighting distance by the rear-seat observers. We installed a cardboard visual barrier between the front- and rear-seat observers to ensure observer independence on the right side of the aircraft during the double-observer trials.

Observers were not able to view perched eagles directly under the aircraft, and the width of this unviewable area depended on survey altitude. We used a clinometer to measure the maximum downward sighting angle from the rear seat of the aircraft, and then applied simple geometry to calculate the width of un-viewable area during the surveys. We estimated the minimum available sighting distance (W_1) for both AGLs. When flying at 107 m AGL there was a swath of approximately 25 m under the aircraft on either side (50 m total) that could not be viewed, so $W_1 = 25$ m. When flying at 150 m AGL, there was a swath of approximately 40 m under the aircraft on either side (80 m total) that could not be viewed, so $W_1 = 40$ m. We assumed $W_1 = 0$ m for flying birds because they could potentially be seen very close to the aircraft. Global Positioning Systems recorded locations of observed eagles, and flight paths revealed that the calculated minimum available sighting distances were accurate.

We considered potential maximum sighting distances the same for observations of flying and perched golden eagles detected from 107 m or 150 m AGL. Buckland et al. (2001) recommend excluding the longest 5% to 10% of the observations in order to remove extreme outliers in the data. We chose to drop 8 observations (5.7%) with the greatest distances from transect, which provided a maximum sighting distance of $W_2 = 1{,}000$ m.

We estimated the detection rates of eagles at W_1 by the rear-seat observers using the double-observer trials. We based these estimates on 3 assumptions. The first assumption was that all golden eagles at the minimum available sighting distances were available to be seen. No statistical procedure exists for correction of availability bias at the minimum available sighting distance unless a sample of animals with known locations can be obtained, and so estimates of density and abundance must be considered conservative. The second assumption was that golden eagles sighted by the front-seat observer during the double-observer trials were a random sample of eagles available. The third assumption was that the probability of detection of a golden eagle group of size s at distance x from the transect line could be approximated using logistic regression. We fit logistic regression models for the probability of detection from the rear-seat using SAS PROC GENMOD (SAS Institute 2000). We based these models on golden eagles sighted by the front-seat observer that were either seen or missed by the rear-seat observer. Given that there were 3 minimum available sighting distances (flying, perched from 107 m AGL, perched from 150 m AGL), it was necessary to have 3 detection functions. We used the logistic model containing distance from transect and possibly group size as predictor variables. We implicitly treated habitat type as a covariate for perched birds because the major habitat types corresponded to the different flying protocols and because the analysis was stratified according to observations in open habitat types (e.g., grassland and sage habitats) and rugged habitat types (e.g., forested and mountainous habitats). We obtained a final logistic model for each of the 3 types of detections based on Akaike's Information Criterion adjusted for small sample size (AIC_c). We then estimated probability of detection at the minimum available sighting distance by including W_1 into the final logistic model.

Following estimation of detection at the minimum available sighting distance, or $\hat{g}(W_1)$, we estimated golden eagle density by,

$$\hat{D} = \frac{n\hat{E}(s)}{\hat{g}(W_1)2(W_2 - W_1)L\hat{P}}. \qquad (1)$$

where n was the number of observed eagle groups, $\hat{E}(s)$ was the expected group size, $2(W_2 - W_1)L$ was the area searched while flying at a given AGL (i.e., different habitat classes), $\hat{g}(W_1)$ was the probability of detecting a golden eagle group at or near the minimum available sighting distance by the rear-seat observers, and $\hat{P}$ was the average probability of detecting a golden eagle within the search area, given detection at the minimum available sighting distance (McDonald et al. 1999, Buckland et al. 2001). Thus, division by $\hat{g}(W_1)$ adjusted for groups missed on or near the transect line, and division by $\hat{P}$ adjusted for the additional golden eagle groups missed due to increasing perception and availability bias as distance from the transect line increased.

We used appropriate poststratification (flying, perched from 107 m AGL, perched from 150 m AGL) for estimating different values of $\hat{P}$ in equation (1) using conventional distance analysis procedures and the program DISTANCE (Thomas et al. 2002). Estimates of $\hat{P}$ for each type of detection were obtained by fitting multiple models to the distance data, selecting the model with the lowest AIC$_c$, integrating the final function over the search width (W_1 to W_2), and dividing by $W_2 - W_1$ (Buckland et al. 2001). If the final logistic models for the probability of detection at W_1 did not depend on group size we used truncation (Buckland et al. 2001) to estimate the expected group size for each stratum. That is, we only used observations within 300 m of the transect line to estimate the mean group size to limit the effect of size bias (i.e., larger groups may be detectable at greater distances than smaller groups). If the final logistic model for an observation type depended on group size, we then conducted a separate analysis for each group size.

We used golden eagle groups observed by the rear-seat observers for estimating $\hat{P}$. Four models were fit for each type of observation, including uniform key functions with cosine or simple polynomial expansions, a half-normal key function with a hermite polynomial expansion, and a hazard-rate key function with a cosine expansion. We determined the number of expansion terms in the model by a stepwise model building process that used the second-order variant of AIC$_c$ to determine the most parsimonious model. We chose these 4 semiparametric models because they were considered sufficiently flexible, could yield robust model estimation, and satisfied the shape criterion described by Buckland et al. (2001). We believed our perpendicular distances to perched eagles were relatively accurate due to the use of GPS technology to record their locations. However, estimating distances to flying eagles was more problematic and may have contained more error, so we binned these distances for the analysis (Buckland et al. 2001). We chose 5 bins of equal width from the transect: 0–200 m, 200–400 m, 400–600 m, 600–800 m, and 800–1000 m.

We bootstrapped the individual transects to estimate the variance and bias of estimated golden eagle densities and totals within each BCR and the entire study area. The bootstrap process involved taking 1,000 independent samples with replacement of 148 transects from the flown transects and producing 1,000 estimates of golden eagle densities and totals within each BCR and the entire study area. We calculated 90% confidence intervals (CI) for densities and totals using the central 90% of the bootstrap distribution (Manly 1997). We calculated bias of $\log_{10}(\hat{N})$ as

$$Bias[\log_{10}(\hat{N})] \approx Mean[\log_{10}(\hat{N}_B)] - \log_{10}(\hat{N}). \qquad (2)$$

where $Mean[\log_{10}(N_B)]$ was the mean of the bootstrap estimates from the 1,000 samples. We used logarithms because they have been found to make the distributions of estimates more symmetric (Manly et al. 1996).

Statistical Analysis: Evaluation of Sample Size

To determine if the existing target sample size of 166 100-km transects would allow us to meet the desired levels of power and precision, we conducted a Monte Carlo type computer simulation that estimated the power to detect an annual 3% population decline, compounded annually over 20 years, using a test of size $\alpha = 0.1$. We simulated a declining population in our investigation because a decreasing trend in the golden eagle population is potentially of more concern than an increasing trend. However, the properties of the sample sizes should also hold for populations increasing $\geq$3% per year because the relative differences in population sizes is smaller for a decreasing population.

We estimated necessary minimum sample sizes for both estimating trend and net change for detecting a population decline with 80% power. We first tested trend in population size by examining the slope statistic from a linear regression analysis with time as the independent variable. The simulated decrease in population size was exponential; hence we conducted the test using a logarithmic transformation to a straight line. The second method tested for a net change in abundance between two surveys by calculating a 90% confidence interval for a difference in two population totals.

We began simulations by applying a 3% decline each year, compounded annually, to the golden eagles observed on the 2003 surveys. We applied this decline to the survey data by randomly removing $(1 - 0.97^{year,-1})100\%$ of the golden eagles observed in 2003 for year i ($i = 2, 3, \ldots, 20$). We then randomly selected t_i transects with replacement from BCR j for year i, based on the proportion of the study area occupied by the BCR and the total sample size under investigation (150 transects, 175 transects, or 200 transects). Using this sampled data we estimated 1) the total number of golden eagle groups in each of the 4 BCRs for each sample and 2) the total area surveyed. We randomly selected the expected group sizes and probabilities of detection [$\hat{g}(W_1)$ and $\hat{P}$] for each type of observation from their respective bootstrap distributions. We then estimated total golden eagles in the study area for each year $i = 2, 3, \ldots, 20$, and we fit a linear trend to the log (base 10) transformed totals. A 2-tailed t-test determined if a significant ($\alpha = 0.1$) slope was fit to the golden eagle totals. We repeated this process 5,000 times for each sample size. We calculated the power of the test for a linear trend in the log-transformed data as the percentage of the 5,000 iterations that resulted in a declaration of a significant trend.

To evaluate power to detect a net change in 2 population totals using the simulated data, we calculated a 90% confidence interval for the difference between 2 totals: year 1 and year 5, year 1 and year 10, year 1 and year 15, and year 1 and year 20. We calculated these confidence intervals as

$$(\hat{T}_1 - \hat{T}_i) \pm 1.64\sqrt{\frac{s_1^2}{n_1} + \frac{s_i^2}{n_i}} \qquad (3)$$

where $i = 5$, 10, 15, or 20, $n_1 = 148$ = number of transects flown in 2003, $s_i^2 = s_i^2$ = estimated population variance from 2003 surveys, and n_i = 150, 175, or 200. If the 90% confidence interval did not contain zero we declared there was a significant difference between the 2 totals; otherwise we detected no significant difference. We calculated the power of this test for net change as the percentage of the 5,000 iterations that resulted in a declaration of a significant difference between the 2 yearly totals.

When estimating power of these tests we also estimated the statistical size of the test (i.e., Type I Error rate) to determine if the rejection rate of a correct null hypothesis (e.g., no trend) was close to the nominal level ($\alpha = 0.1$). We estimated statistical size for the method of fitting a linear trend to the estimated totals by applying the same procedures described above to data that did not exhibit a positive or negative decline in population numbers. We calculated statistical size as the percentage of 5,000 iterations that resulted in a declaration of a significant trend when one was not actually present.

RESULTS

We flew 148 transects and observed 172 golden eagles, for an average of 1.15 golden eagles per transect. Of the 172 eagles, 34 were juvenile, 12 older immature, 54 adult, 4 unknown immature, 48 unknown adult, and 20 unknown age classes. Group sizes were generally small with little variation. There were 115 observations of individual golden eagles, 22 observations of groups of 2, 3 observations of groups of 3, and 1 observed group of 4 golden eagles. The expected group size for flying golden eagles was 1.2. The expected group sizes for perched golden eagles observed from either AGL was 1.1.

We made 20 observations of perched golden eagle groups detected by the front-seat observer from 107 m AGL during the double-observer trials. The estimated probability of detection at $W_1 = 25$ m for perched eagle groups was 0.865 (95% CI: 0.503–0.978), based on a logistic regression model with distance from transect as the only predictor variable. We made only 5 observations of perched golden eagles by the front-seat observer from 150 m AGL. We combined this small sample with the 20 double-observer trials for perched groups seen from 107 m AGL that were within 40–1,000 m from the transect line in order to estimate the logistic regression models for the probability of detection of perched golden eagles from 150 m AGL. The final logistic regression model for the probability of detection of perched golden eagle groups by the rear-seat observers at 150 m AGL contained distance from transect as the predictor variable and estimated detection at $W_2 = 40$ m to be 0.857 (95% CI: 0.525–0.974). Fifteen double-observer trials were available for estimating the probability that a group of flying golden eagles was detected by the rear-seat observer. Of these 15 trials, the rear-seat observer saw 14 of the groups. With only one failure out of 15 trials, the computer software (SAS) failed to converge and find a maximum likelihood estimate of a logistic regression function. In this case, the approximate maximum likelihood estimate of the probability of detection was the ratio of success to trials (detection = 14/15 = 0.933) for detection of flying groups by the rear-seat observers.

Only 11 observations of perched golden eagle groups observed from 150 m AGL were available for estimating $\hat{P}$, so we combined these observations with 68 observations of perched groups seen from 107 m AGL that were within 40 to 1,000 m from the transect line and then used to estimate $\hat{P}$ for observations from 150 m AGL.

We found that a uniform model with 3 cosine expansion terms was the best model (lowest AIC$_c$) for the detection of flying golden eagles, relative to detection on or near the transect. Based on this model, the average probability of detection of flying golden eagles within the search area was $\hat{P} = 0.293$, relative to detection at the minimum available sighting distance. We found half-normal models with no expansion terms to be the best models for the detection of perched golden eagle groups, relative to detection of groups at the minimum available sighting distance, observed from 107 m and 150 m AGL. The estimates of $\hat{P}$ for perched golden eagle groups observed from 107 m and 150 m AGL were 0.548 and 0.567, respectively. We labeled the intercept of the final models at the origin as $\hat{g}(0)$ in Figs. 2–4 to indicate that the estimated probability of detection of golden eagles at the minimum available sighting distance was <100%. The shaded area, labeled $1 - \hat{P} \times \hat{g}(0)$, is the estimate of the proportion golden eagles missed in the interval from W_1 to 1,000 m (Figs. 2–4).

We calculated the total area searched for golden eagles by determining the length of transects flown at each AGL within each BCR and thus the amount of search area associated with each search width. We estimated densities of golden eagles within each BCR (Table 1), and applied our density estimates to the entire study area (excluding military and Department of Energy lands, large water bodies, and urban areas), assuming our transect locations were representative of the study area. We estimated a total of 27,392 golden eagles (90% CI: 21,352–35,140) were present in the study area during the late summer and early fall of 2003 (Table 1). There was no evidence of mathematical bias in $\log_{10}(\hat{N})$ (Table 1). We estimated 5,042 juvenile golden eagles were present in the entire study area (90% CI: 3,723–6,839).

The Monte Carlo simulation indicated that power of the test for trend in the data was near 99% following survey year 20 and 80% following year 15, for all 3 sample sizes

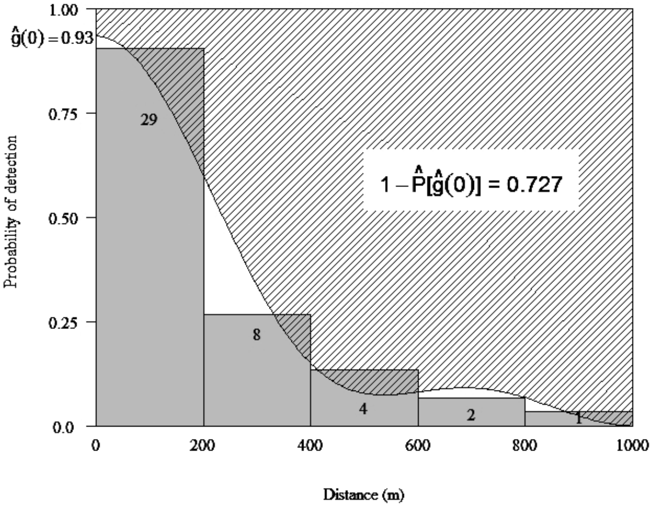

Figure 2. Uniform model with 3 cosine expansion terms fit to the distance data for golden eagle groups observed flying, with the number of golden eagle groups observed in each distance bin by the rear-seat observers. $\hat{P}$ is the estimated probability of detection of flying golden eagle groups observed in each distance bin by the rear-seat observers. $\hat{g}(0)$ is the estimated probability of detection of golden eagles "on the transect line." The shaded area, labeled $1 - \hat{P} \times \hat{g}(0)$, is the estimate of the proportion of golden eagles missed in the interval from 0 m to 1,000 m. Note that distance bin sizes do not correspond with the *y*-axis; rather relative size of each bin equals the number of eagles observed in each distance category. The survey data displayed are from golden eagle surveys conducted during 2003 in bird conservation regions 9, 10, 16, and 17.

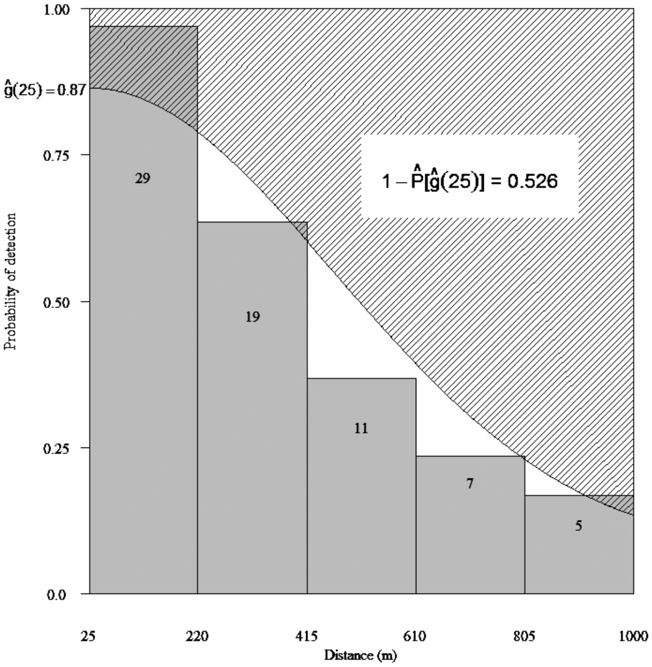

Figure 3. Half-normal model fit to the distance data for perched golden eagle groups observed from 107 m above ground level, with the number of golden eagle groups observed in each distance bin by the rear-seat observers. $\hat{P}$ is the estimated probability of detection of golden eagle groups observed in each distance bin by the rear-seat observers. $\hat{g}(25)$ is the estimated probability of detection of golden eagles at the minimum available sighting distance. The shaded area, labeled $1 - \hat{P} \times \hat{g}(25)$, is the estimate of the proportion of golden eagles missed in the interval from 25 m to 1,000 m. Note that distance bin sizes do not correspond with the *y*-axis; rather relative size of each bin equals the number of eagles observed in each distance category. The survey data displayed are from golden eagle surveys conducted during 2003 in bird conservation regions 9, 10, 16, and 17.

investigated. However, statistical size of the test for trend was slightly larger by 1–5% than the expected 10% for all sample sizes after 5 years, 10 years, 15 years, and 20 years of surveys. Power of the test for net change was only 33% to 35% following year 20, and 10.5% to 11.5% following year 15.

DISCUSSION

We estimated there were 27,392 golden eagles within the 4 BCRs surveyed. This is the first attempt to estimate the golden eagle population size across most of the species range using a uniform set of methods, and the method gives wildlife managers a valuable tool for assessing potential threats to golden eagles and their habitat. Because we were not able to survey some habitats such as military-owned lands and large water bodies, this estimate should be considered conservative.

Our survey methods were successful for detecting golden eagles from the aerial transects. We detected 1.15 golden eagles per transect, consistent with the number of eagles Fuller et al. (2001) predicted would be detected. Few other population estimates were available from other studies (Hammerstrom et al. 1975, Olendorff et al. 1981, Watson 1997) for comparison. All of these estimates are based on few data collected under varying methods and include estimates of birds breeding in Canada and Alaska, making direct comparisons problematic.

Factors Affecting Precision and Bias of the Survey

Not all target transects within BCR 10 were sampled due to large forest fires, resulting in a relatively smaller sample size in the rugged and mountainous terrain of BCR 10. Because our survey period coincides with the peak forest fire season, preclusion of some transects should be expected every year and some transects will not be sampled for safety reasons.

In a year when forest fires are more frequent and more transects in forested areas are not sampled, population estimates may be less precise and biased in the rugged and mountainous terrain. If flight time and resources are shifted to the open habitats with gentle topography, then precision would be increased in those areas. The overall effects will be unknown, but we would expect that precision for the combined areas would be about the same as if all planned transects are flown, with some positive bias because forested areas are expected to have lower density than other rugged and mountainous terrain. Our ability to detect trends will be decreased if the frequency and duration of forest fires varies greatly from year to year because the variation over time about the true trend is increased.

Due to small numbers of golden eagle groups observed from 150 m AGL, we pooled the observations with those from 107 m AGL to estimate probabilities of detection. If golden eagles were more easily detected from 107 m AGL over gentle terrain versus 150 m AGL over rugged and mountainous terrain, then estimates of probability of detection from 150 m AGL were likely biased high, and thus we may have underestimated the number of golden eagles in the rugged and mountainous habitat.

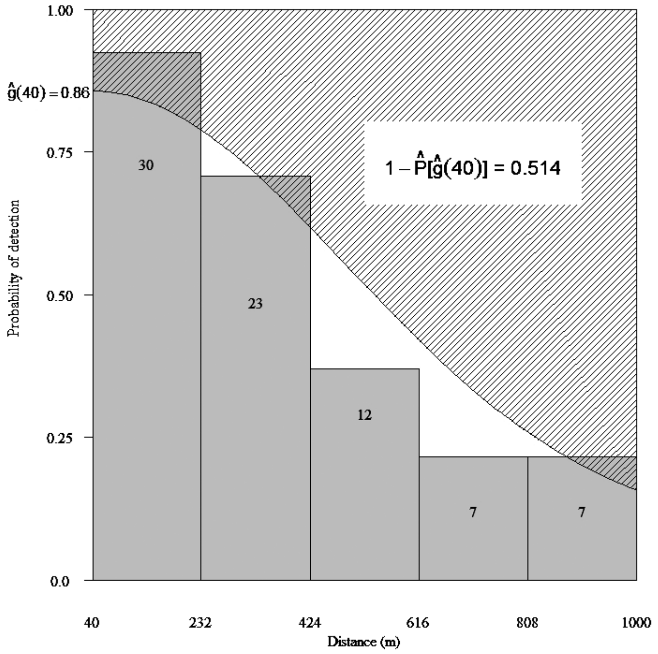

Figure 4. Half-normal model fit to the distance data for perched golden eagle groups observed from 150 m above ground level (AGL) with the number of golden eagle groups observed in each distance bin by the rear-seat observers. $\hat{P}$ is the estimated probability of detection of flying golden eagle groups observed in each distance bin by the rear-seat observers. $\hat{g}(40)$ is the estimated probability of detection of golden eagles at the minimum available sighting distance. The shaded area, labeled $1 - \hat{P} \times \hat{g}(40)$, is the estimate of the proportion of golden eagles missed in the interval from 40 m to 1,000 m. Note that distance bin sizes do not correspond with the *y*-axis; rather relative size of each bin equals the number of eagles observed in each distance category. The survey data displayed are from golden eagle surveys conducted during 2003 in bird conservation regions 9, 10, 16, and 17.

Table 1. Estimated densities, standard deviations, and population totals of golden eagles with 90% confidence intervals for bird conservation regions (BCR) 9, 10, 16, and 17 from 16 August to 8 September 2003.

Estimates	BCR 9	BCR 10	BCR 16	BCR 17	
Density (birds/km^2)	0.017	0.009	0.010	0.018	
SD	0.004	0.004	0.003	0.004	
CV = SD/density	0.218	0.383	0.256	0.208	
Estimated total in entire BCR	**BCR 9**	**BCR 10**	**BCR 16**	**BCR 17**	**Total**[a]
$\hat{N}$	10,939	4,831	4,998	6,624	27,392
$\log_{10}(\hat{N})$	4.04	3.68	3.70	3.82	4.44
$\log_{10}(\hat{N})$ mean	4.04	3.66	3.69	3.82	4.44
SD	0.10	0.18	0.11	0.09	0.07
Bias	0.00	−0.02	0.00	0.00	0.01
Percentile 90% CI low (N)	7,522	2,262	3,199	4,611	21,556
Percentile 90% CI high (N)	15,754	8,580	7,275	9,207	35,369

[a] Totals do not include birds in military lands, large bodies of water, or urban areas.

Another complicating factor is the ability of the pilot to maintain constant airspeeds and AGL when flying over rugged terrain. In order to maintain safety of the aircraft and crew, constant airspeeds and AGLs are not always maintained over rugged terrain. Assumptions of minimum sighting distances were sometimes compromised when flying in rugged terrain, especially in areas above 3,048 m.

Two basic types of bias potentially existed in estimation of the probability of detection during the aerial surveys: availability and perception bias (Manly et al. 1996). Availability bias is defined as bias introduced if golden eagles were in the survey strip but not visible to the observers. Perception bias is defined as bias introduced if golden eagles were available to be seen, but the observers failed to detect them. Conventional line transect or distance sampling methods account for a combination of perception and availability bias with the assumption that all individuals close to and on the inside edge of the survey strip were available to be seen and were detected.

The extent to which availability bias may affect our population estimates is uncertain. Using radiotelemetry, Bowman and Schempf (1999) estimated that 21% of nesting adult bald eagles (*Haliaeetus leucocephalus*) were unavailable to be seen within the entire survey strip during aerial surveys in Prince William Sound, Alaska, USA. We are not aware of any published studies describing estimated availability biases for golden eagles. Availability bias likely varied throughout the survey area and we expect more golden eagles were hidden from view in areas with greater topographical relief or tree cover compared to more open grassland habitats. This factor is expected to introduce a negative bias in the estimated abundance of golden eagles in the rugged and mountainous terrain.

We simulated power under the assumption that biases and precision in the 2003 survey remain representative of the future. Golden eagle populations in portions of the United States are thought to cycle on a 10-year basis with jackrabbit (*Lepus* spp.) populations (Kochert and Steenhof 2002). Our estimates of power to detect population trends are based on linear population trends (log scale). Thus, a cycling golden eagle population may compromise our predictions of sample sizes required to detect population trends within power and precision requirements. Jackrabbit and golden eagle populations may fluctuate on a regional basis in our study area. If the scale of cycling populations matches that of individual BCRs, then our esimates of trend and power estimates may be impacted.

Aging Golden Eagles from the Air

A certain number of unknown adults will always be present in future surveys. This complicates interpretation of age ratios as a tool for assessing population productivity. It is possible to age juvenile golden eagles from the perched position based on the lack of a tawny bar on the wing and overall uniform, darker plumage (W. S. Clark, Raptours Inc., personal communication). We felt confident in our ability to correctly age juvenile golden eagles from an airplane and our results should accurately reflect the number of juvenile golden eagles observed. The number of juvenile golden eagles observed through annual surveys may provide a useful index of golden eagle productivity across BCRs.

Suggestions for Future Surveys

Although our sample sizes were sufficient to meet our power and precision requirements, we suggest a few modifications to our protocol in order to better estimate population size and trend detection in future surveys. Our number of double-observer detections was low for some strata. In order to adequately assess total population size and population trends, we recommend $\geq$175 transects be surveyed annually and a double observer be present on every flight in order to obtain greater samples sizes for estimating perception bias on the transect line. A set of alternate transects should also be generated to utilize when fires prevent surveying primary transects. Future surveys should also not be conducted in areas above 3,048 m in order to minimize the effects of variable terrain on maintaining constant airspeeds and AGL.

MANAGEMENT IMPLICATIONS

Rigorous population estimates for avian species are rarely available to wildlife managers. Our estimates of golden eagle population size in the western United States may improve the ability of agencies to manage golden eagles. A reliable population estimate allows managers to make informed decisions and assess potential threats to golden eagle populations and their habitats. Perhaps more importantly than knowing how many golden eagles occur in the western United States is determining if the population is increasing, decreasing, or stable. The methods outlined in this paper provide wildlife managers with a relatively low cost method that can reliably detect decreasing or increasing golden eagle populations over a 20-year period. Additionally, the non-breeding segment of the population is accounted for.

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