



Environmental
& Statistical
Consultants

A Survey of Golden Eagles (*Aquila chrysaetos*) in the Western U.S. Mid-winter 2017

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ABSTRACT

We flew aerial line transect surveys using distance sampling and mark-recapture procedures to estimate Golden Eagle (*Aquila chrysaetos*) abundance in 4 Bird Conservation Regions (BCRs) in the western United States between 17 January and 17 February, 2017, on 206 transects totaling 16,483 km. The study area consisted of BCRs 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies). We observed 265 Golden Eagle groups within 1,000 m of 115 transects for a total of 325 individuals: 139 adults, 76 unknown immatures (not adults), 96 unknown adults (not juveniles), and 14 of unknown age. We did not classify observed Golden Eagles as either sub-adults or juveniles during the winter survey. We estimated that a total of 11,381 Golden Eagles (90% confidence interval: 8,698 to 14,906) were within the Great Basin (BCR 9) during the survey period, a total of 11,012 (90% confidence interval: 7,181 to 15,851) were within the Northern Rockies (BCR 10), a total of 3,248 (90% confidence interval: 2,063 to 4,709) were within the Southern Rockies / Colorado Plateau (BCR 16), and a total of 13,983 (90% confidence interval: 10,016 to 19,241) were within the Badlands and Prairies (BCR 17). These estimates do not include Golden Eagles that were potentially occupying military lands, elevations above 3,048 m (10,000 ft), large water bodies, or large urban areas.

INTRODUCTION

The Golden Eagle (*Aquila chrysaetos*) is one of North America's largest raptors and is currently protected under the Migratory Bird Treaty Act (16 United States Code 703–712) and the Bald and Golden Eagle Protection Act (16 United States Code 668–668d; hereafter Act). The Acts delegate to the Secretary of the Interior the ability to permit take of the eagle “necessary for the protection of other interests in any particular locality” if the take is “compatible with the preservation of the bald eagle or golden eagle,” which is defined as no net-decrease in the number of breeding pairs within regional geographic management units (Bird Conservation Regions; BCRs; U.S. Fish and Wildlife Service 2009). In 2016, the United States (U.S.) Fish and Wildlife Service (Service) issued updated regulations under the Act that refined conditions under which the Service could permit lethal take and disturbance of eagles. Take of an eagle is permitted if it is “consistent with the goals of maintaining stable or increasing breeding populations in all eagle management units and the persistence of local populations throughout the geographic range of each species” (81 Fed. Reg. 242 [December 16, 2016]). For more discussion on permitting take of Golden Eagles and the need for accurate population trend and size data for Golden Eagles, see Millsap et al. (2013) and U.S Fish and Wildlife Service (2016).

Other than work conducted by researchers at the Snake River Birds of Prey Natural Area in Idaho (Steenhof et al. 1997, Kochert et al. 1999) and Denali National Park (McIntyre and Schmidt 2012), few long-term monitoring studies of Golden Eagle populations have been conducted in the western U.S. (for examples see Leslie 1992, McIntyre and Adams 1999,

McIntyre 2001, McIntyre and Schmidt 2012, Hunt et al. 2017), and those have been limited in geographic range. Thus, survey-based estimates of numbers of Golden Eagles in the western U.S. were unavailable until 2003, when we designed and conducted the first aerial line transect distance sampling (DS; Buckland et al. 2001) survey for Golden Eagles across 4 BCRs in the western U.S. (Good et al. 2007).

The goal of the 2003 western-wide survey was to develop and test methods for estimating population size and monitoring trends of Golden Eagles across the 4 BCRs during late-summer. The survey was originally designed, and then adjusted after 2003, to allow detection of an average 3% decline per year in the eagle population over a 20-year period with statistical power ≥ 0.8 , using a 90% confidence interval (CI; equivalent to $\alpha = 0.1$). Based on results of the 2003 survey (Good et al. 2007), a new, systematic sample of transects was generated to increase sample sizes (number of transects and number of observations) to levels necessary to meet our goal. This new sample comprising about 17,500 km of transects has been surveyed annually during late-summer in 2006–2016 (Table 1; Figure 1), with exception of transects in BCR 17 (Badlands and Prairies), which were not surveyed in 2011 (Nielson et al. 2012). In addition to generating a new sample of transects after the 2003 survey, we modified the survey protocol to improve safety and standardize criteria for aging Golden Eagles, and we developed new statistical methods for estimating abundance and detecting trends (Nielson et al. 2014).

In 2014 and 2015 we conducted the first mid-winter surveys for Golden Eagles along the same transects developed for the late-summer surveys. These efforts were intended to provide estimates of Golden Eagle abundance within the 4 BCRs during January and February. In 2017, we conducted a third mid-winter Golden Eagle survey using the same protocol and transects. Here we describe methods for surveys conducted during late-summer and mid-winter months (late-summer: August and September; mid-winter: January and February) 2006–2017 and report findings from our analysis of abundance of the Golden Eagle population, with particular emphasis on the results of the mid-winter surveys.

STUDY AREA

The study area consisted of BCRs 9 (Great Basin), 10 (Northern Rockies), 16 (Southern Rockies / Colorado Plateau), and 17 (Badlands and Prairies) within the U.S. (Figure 1). These regions collectively covered about 80% of the range of the Golden Eagle in the coterminous western U.S. (U. S. Fish and Wildlife Service 2009). Habitat types across these BCRs ranged from low-elevation sagebrush and grassland basins to high-elevation coniferous forests and mountain meadows. Areas within these regions containing Department of Defense (DOD) lands, urban areas, bodies of water greater than 30,000 ha, and terrain above 3,048 m (10,000 ft) were excluded from this study. These no-fly zones covered 6.7% of the total study area and were not surveyed for safety reasons or, in the case of DOD lands, because access was problematic. The total area in the sample frame for 2006–2010 and 2012–2017, containing all 4 BCRs, was 1,962,909 km² (Figure 1).

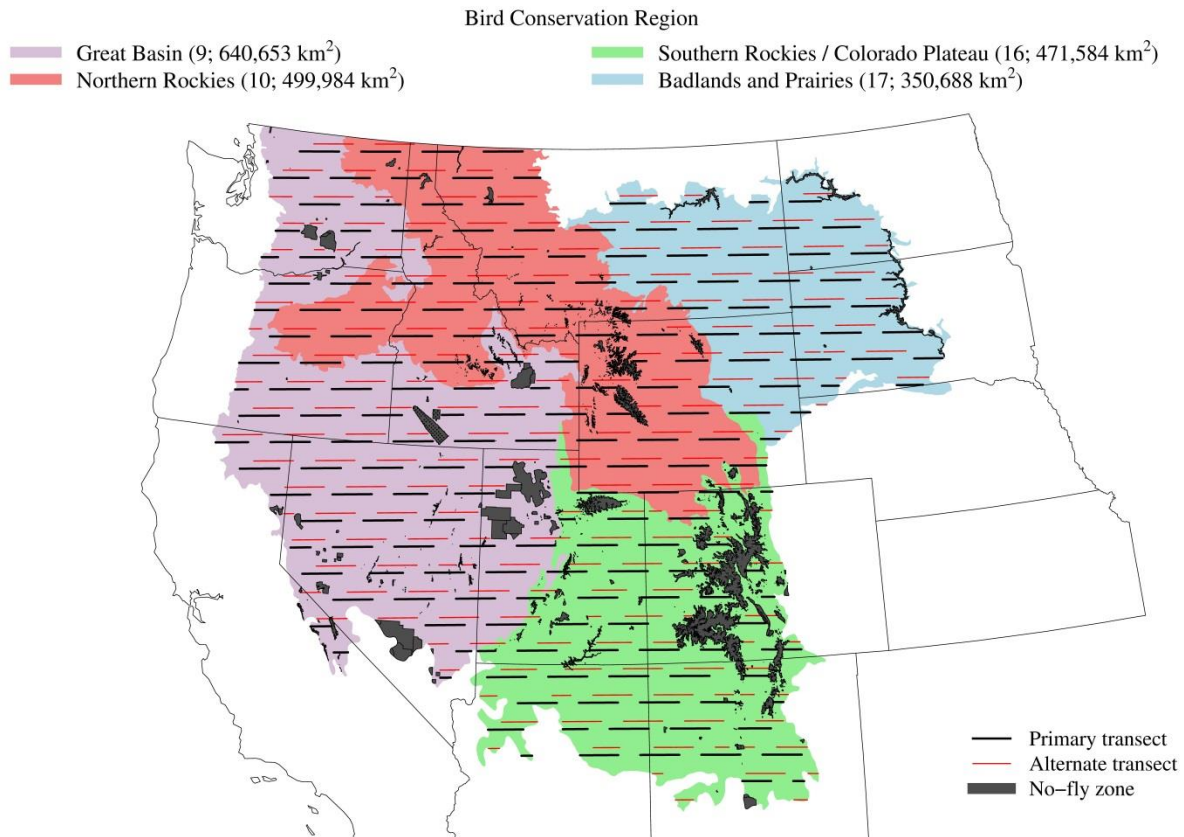


Figure 1. Study area and survey transects for the western-wide Golden Eagle survey.

METHODS

Surveys

We conducted Distance Sampling (DS, Buckland et al. 2001) surveys from 17 January to 17 February in 2017 on transects surveyed for Golden Eagles since 2006. Transects were established by randomly overlaying the study area with 2 systematic sets of 100-km long, east-west transects (systematic sample with a random start). The first systematic set contained the primary transects. The second set contained alternate transects to be surveyed to recoup lengths of primary transects that could not be flown due to a forest fire or localized weather event. After removing portions of transects extending outside the study area or over no-fly zones, the systematic set comprised about 17,500 km of transects. We attempted to survey all primary transects using 2 crews in Kodiak fixed-wing aircraft.

Surveys began at sunrise and were terminated at or before 1400 hours. Surveys were flown at about 160 km/hr. We flew at 107 m above ground level (AGL) over open, level to rolling terrain, and at 150 m AGL over forested, rugged, or mountainous terrain. The general survey sequence for flying transects was fairly consistent during the 2017 mid-winter survey compared with previous surveys (late-summer or mid-winter) conducted 2006–2010, and 2012–2017.

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

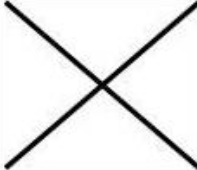
Tawny bar	?	Unknown immature	Adult	Unknown
	No	Juvenile		Juvenile
	Yes	Sub-adult	Adult	Unknown adult
Aging		Yes	No	?
		White on tail or wings		

Figure 2. Golden Eagle age classification decision matrix used during surveys conducted 2006–2017. Due to timing of the mid-winter survey we were unable to accurately distinguish between juveniles (1st year) and sub-adults, so non-adults were classified as unknown immature.

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

We conducted mark-recapture trials on the right side of the aircraft during all mid-winter surveys. Transects surveyed by only 2 observers in 2008 were surveyed from the front-right and back-left positions. Mark-recapture trials required observers on the aircraft's right side to search for and detect Golden Eagles independently of one another, so we installed a cardboard wall as a visual barrier between the 2 observers. In addition, when a Golden Eagle group was detected by an observer on the right side, several seconds were allowed to pass before the observation was communicated to the other observers. This allowed time for both observers to independently detect or not detect each group.

Statistical Analysis

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

Lower detection probabilities at the nearest available sighting distance compared to longer distances farther from the transect line have been documented for surveys from fast moving aircraft (Becker and Quang 2009). Given the speed at which the aircraft moves, objects closer to the transect line can be in an observer's field of view for less time, and thus, more difficult to detect. Indeed, some detection functions estimated from survey data collected during 2006–2017 had a substantial peak around 300 m from the transect line. For this reason, we used a non-monotonic, non-parametric, Gaussian kernel estimator (Wand and Jones 1995) to model shapes of detection functions (step 1; Chen 1999, 2000) as a function of distance from the transect line, rather than the less flexible detection functions available in the program Distance (v6.0; Thomas et al. 2006). The kernel density estimator used was of the form

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

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

Perpendicular distances have a boundary at the minimum available sighting distance. The kernel density estimator does not perform well near discontinuities such as sharp boundaries (Wand and Jones 1995), so we reflected the observed distances to both sides of 0 along the number line for density estimation (Chen 1996, 1999, 2000) after subtracting the minimum sighting distance (W_1) from the observed distances. Following kernel estimation, we only used

the portion of the detection function to the right of 0. Analyses of historic data beginning in 2006 have not indicated that shapes of detection functions differ between front and back seat observers, so all observations from the 3 observer positions in the aircraft were used to estimate detection functions using equation [1].

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

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

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

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

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

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

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

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

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

Analysis of the late-summer and mid-winter survey data from 2006–2017 did not show evidence that detection rates are trending (e.g., that observers are improving), or that detection rates differed by season (late-summer vs mid-winter). Given consistent survey methods since 2006, we pooled all data from 2006–2017 (late-summer and mid-winter) surveys to estimate the shapes of the detection functions (step 1; equation [1]) and to scale those detection functions (step 2; equations [2] – [3]). Pooling data across surveys reduced year-to-year variability in

detection functions due to small sample sizes within a given survey period and reduced our reliance on using only 3 years of mid-winter surveys for estimating probabilities of detection. We updated both the 2014 and 2015 mid-winter estimates (Nielson and McManus 2014, Nielson et al. 2015) upon inclusion of 2017 survey data for estimation of average probabilities of detection.

We calculated density estimates for all Golden Eagles using a standard distance formula (Buckland et al. 2001),

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

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

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

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

We bootstrapped (Manly 2006) individual transects flown to estimate 90% CIs for projected Golden Eagle abundance within each BCR and the entire study area. This process involved taking 10,000 random samples with replacement and re-running the analysis steps 1–4 to produce new estimates of Golden Eagle abundance. We calculated CIs based on the central 90% of the bootstrap distribution (the percentile method). We used the R language and environment for statistical computing (v3.3.1; R Development Core Team 2016) to estimate yearly densities and population totals in each BCR and the entire study area. We appended those mid-winter estimates with the estimated numbers from past late-summer surveys (Nielson et al. 2017).

RESULTS

Abundance

We flew 206 (partial and complete) transects totaling 16,483 km in the study area (Tables 1 and 2). Approximately 1,000 km of transects in the northwest, which included portions of BCRs 9 and 10, were not surveyed because of persistent weather that created unsafe flying conditions. To account for this, we applied observations made in surveyed areas to the entire BCR(s) to estimate Golden Eagle density and abundance in areas not surveyed.

We observed 265 Golden Eagle groups within 1,000 m of the transect line along 115 transects (Figure 3) for a total of 325 individuals (Figure 4): 139 adults, 76 unknown immatures (including sub-adults), 96 unknown adults, and 14 of unknown age (Figure 5). Average Golden Eagle group size did not increase with perpendicular distance from the aircraft for observed Golden Eagle groups within 1,000 m of the transect line in the mid-winter 2017 survey. Mean group size in 2017 was 1.23 ($SE = 0.03$) and was the same as mean group size observed during the previous (2015) mid-winter survey (1.23, $SE = 0.03$) but slightly larger than in the 2014 mid-winter survey (1.17, $SE = 0.03$).

Table 1. Total length (km) of transects flown in each Bird Conservation Region 2006–2017, during late-summer (S) and mid-winter (W) surveys.

Year (Season)	Great Basin (9)	Northern Rockies (10)	Southern Rockies / Colorado Plateau (16)	Badlands and Prairies (17)	Total
2006(S)	6,016	4,606	3,966	3,143	17,731
2007(S)	5,861	4,572	3,998	3,245	17,676
2008(S)	5,773	4,563	3,958	3,124	17,418
2009(S)	5,934	4,728	3,807	3,147	17,616
2010(S)	5,911	4,557	3,939	3,201	17,608
2011(S)	5,820	4,585	3,880	— ^a	14,285
2012(S)	5,868	4,531	3,919	3,169	17,487
2013(S)	6,001	4,587	3,898	3,164	17,650
2014(S)	5,893	4,527	3,956	3,177	17,553
2015(S)	5,898	4,515	4,014	3,159	17,586
2016(S)	5,941	4,510	4,004	3,154	17,609
2014(W)	5,863	4,583	3,977	3,162	17,585
2015(W)	6,024	4,536	4,036	3,264	17,860
2017(W)	5,217	4,148	3,953	3,165	16,483

^aBCR 17 was not surveyed in 2011.

Table 2. Number of primary (Prm.) and alternate (Alt.) transects surveyed in each Bird Conservation Region each year 2006–2017, during late-summer (S) and mid-winter (W) surveys.

Year (Season)	Great Basin (9)		Northern Rockies (10)		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)	
	Prm.	Alt.	Prm.	Alt.	Prm.	Alt.	Prm.	Alt.
2006(S)	71	10	58	9	54	4	39	1
2007(S)	72	3	59	5	52	3	39	1
2008(S)	76	2	63	5	58	3	38	0
2009(S)	79	2	64	4	56	5	39	0
2010(S)	79	1	65	2	58	4	38	1
2011(S)	78	1	63	1	57	2	— ^a	— ^a
2012(S)	78	3	62	4	59	3	39	0
2013(S)	76	4	64	2	59	2	38	0
2014(S)	79	0	64	1	59	3	37	1
2015(S)	78	4	64	6	59	4	39	0
2016(S)	77	3	64	3	58	5	38	0
2014(W)	75	7	62	5	58	4	38	0
2015(W)	78	7	63	6	54	10	39	0
2017(W)	66	5	56	4	56	10	39	0

^aBCR 17 was not surveyed in 2011.

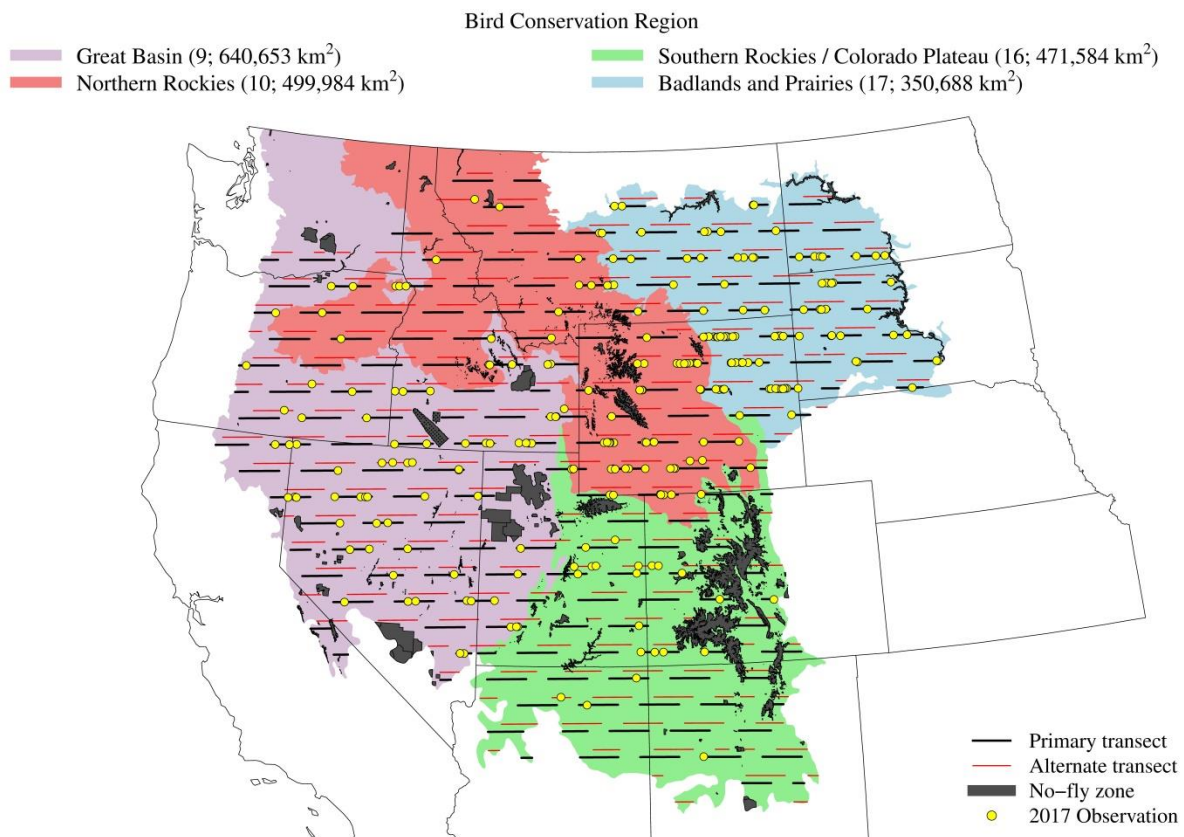


Figure 3. Study area for the annual Golden Eagle survey, with observations of Golden Eagle groups observed during the 2017 mid-winter survey. The northwestern corner of the study area (BCRs 9 and 10) was not surveyed due to persistent poor weather conditions. Transects from that region not surveyed were removed from this figure.

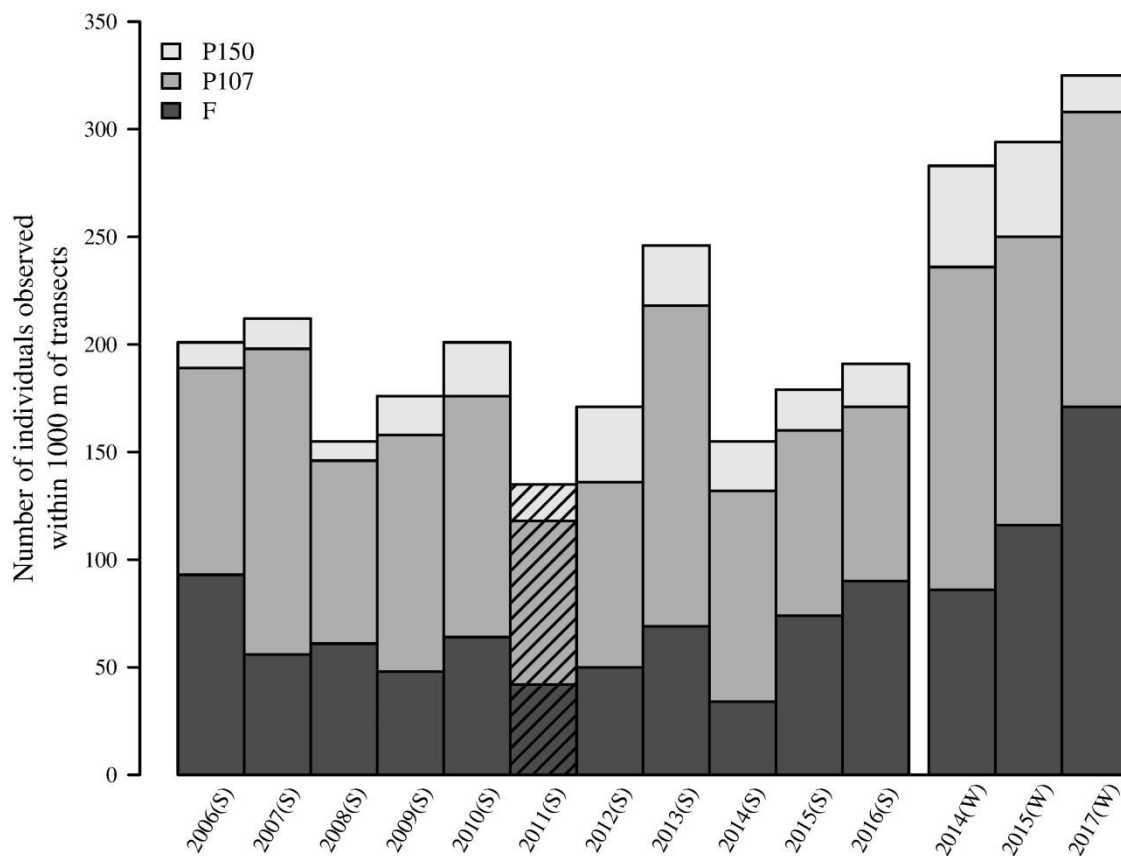


Figure 4. Number of Golden Eagles observed within 1,000 m of transect lines surveyed in 2006–2017, during late-summer (S) and mid-winter (W) surveys. Observation types (detection classes) are perched and observed from 150 m AGL (P150), perched and observed from 107 m AGL (P107), and flying (F).

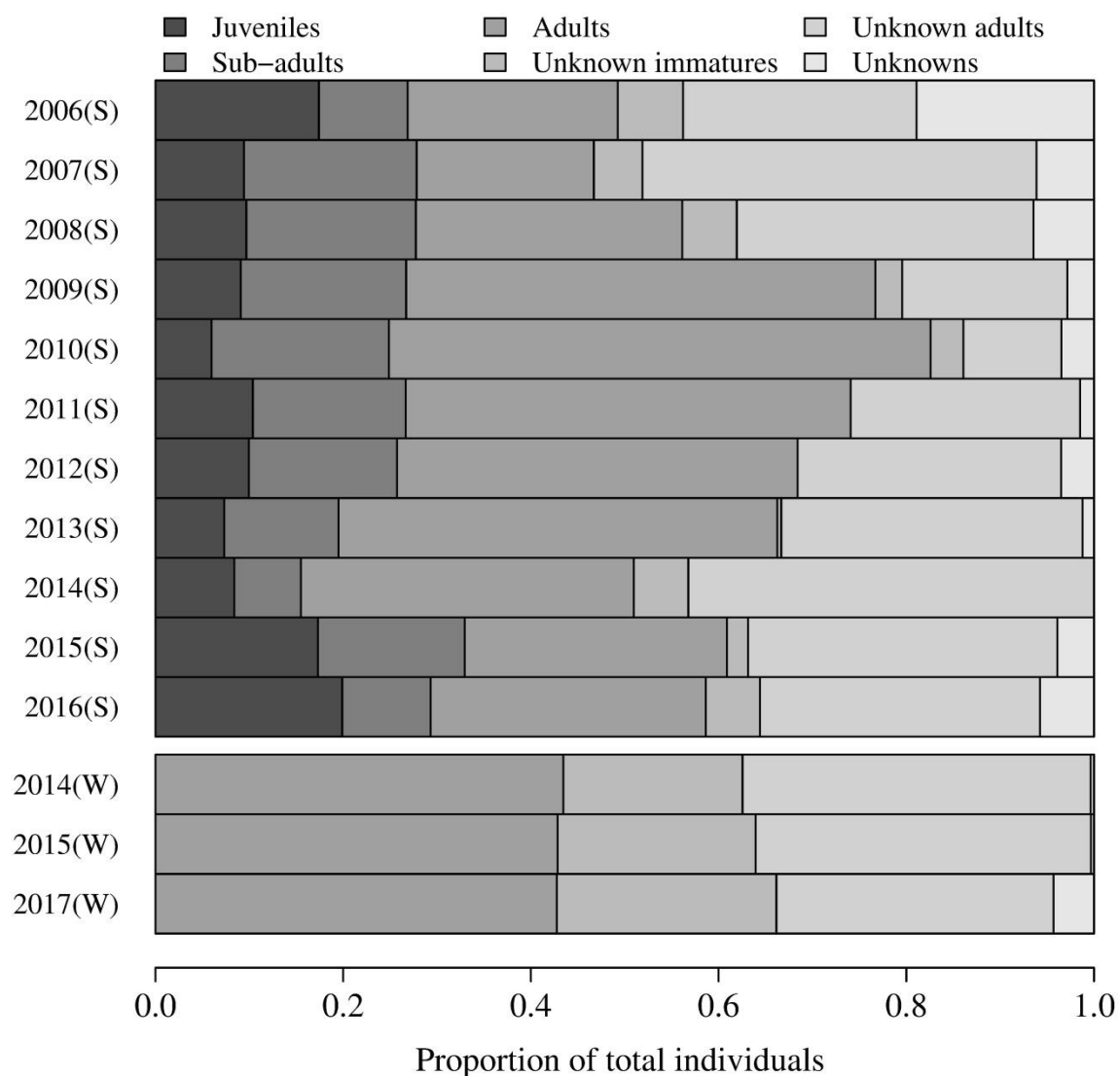


Figure 5. Age classifications of all Golden Eagles observed within 1,000 m of transect lines surveyed in 2006–2017, during late-summer (S) and mid-winter (W) surveys. For mid-winter surveys, the juvenile and sub-adult Golden Eagles were combined with unknown immatures due to difficulty aging young birds during winter.

The total number of observations of perched Golden Eagle groups when the aircraft was 107 m AGL, perched groups when the aircraft was 150 m AGL, and flying groups are presented in Table 3 and Figure 4. Scaled detections functions, along with estimated average probabilities of detection ($\bar{P}$), are shown in Figure 6.

Table 3. Numbers of Golden Eagle groups observed within 1,000 m of survey transects in 2006–2017, during late-summer (S) and mid-winter (W) surveys, categorized by observation type: perched and observed from 107 m above ground level (AGL), perched and observed from 150 m AGL, and flying.

Year (Season)	Observed perched from 107 m AGL	Observed perched from 150 m AGL	Observed flying	Total
2006(S)	74	9	74	157
2007(S)	115	11	46	172
2008(S)	73	8	52	133
2009(S)	90	15	43	148
2010(S)	97	21	50	168
2011(S) ^a	67	17	33	117
2012(S)	74	25	42	141
2013(S)	123	22	62	207
2014(S)	81	19	31	131
2015(S)	67	15	62	144
2016(S)	65	18	70	153
2014(W)	128	40	73	241
2015(W)	112	35	93	240
2017(W)	120	16	129	265

^aBCR 17 was not surveyed in 2011.

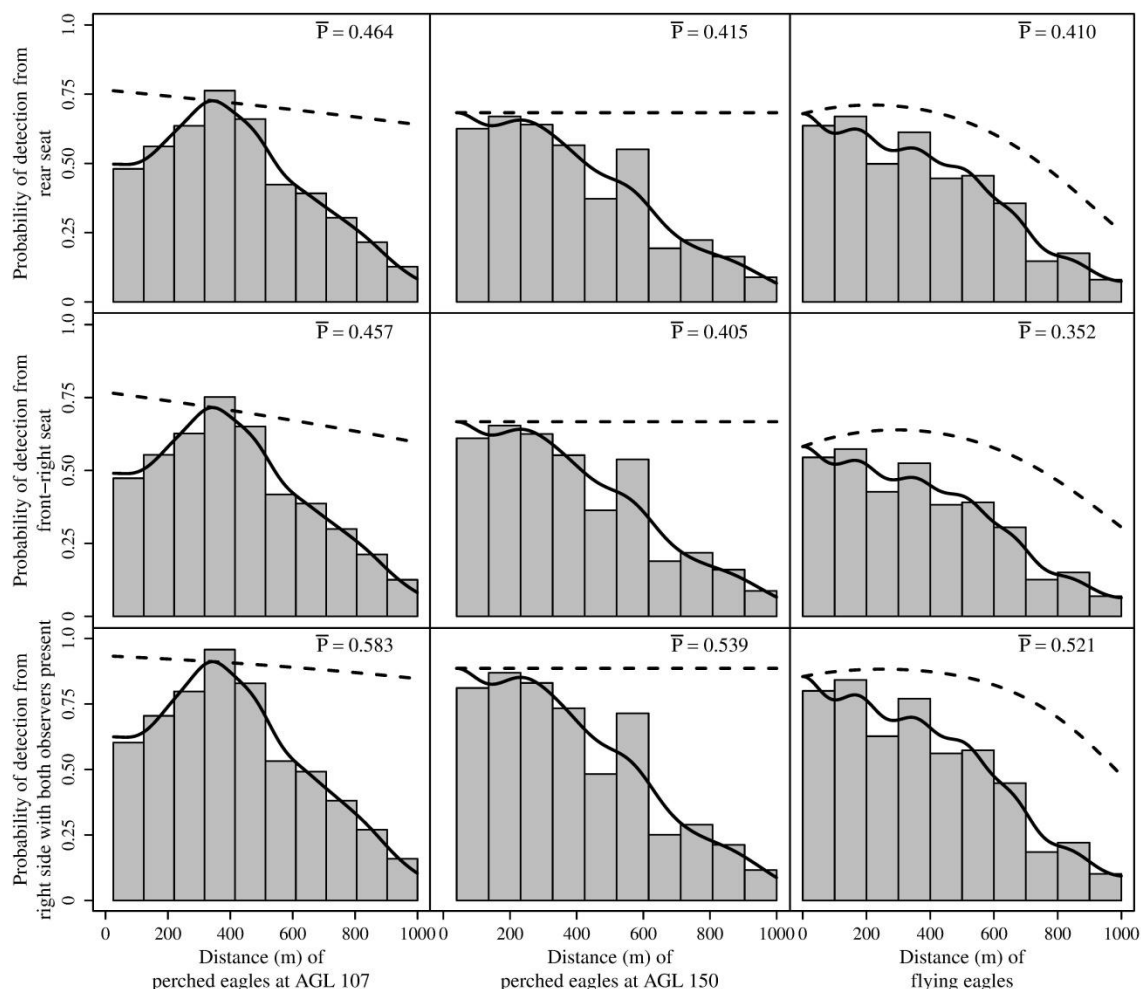


Figure 6. Probability of detection of perched Golden Eagle groups from 107 and 150 m AGL and probability of detection of flying Golden Eagle groups. Dashed lines represent probabilities of detection estimated from mark-recapture sampling. Solid lines represent scaled detection functions that were integrated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

Based on estimated densities of Golden Eagles within each BCR (Table 4), during mid-winter of 2017 we projected a total of 11,381 Golden Eagles (90% CI: 8,698–14,906) in BCR 9, 11,012 (90% CI: 7,181–15,851) in BCR 10, 3,248 (90% CI: 2,063–4,709) in BCR 16, and 13,983 (90% CI: 10,016–19,241) in BCR 17 (excluding military lands, elevations above 3,048 m [10,000 ft], large water bodies, and large urban areas) (Table 5, Figure 7). Estimated abundance across the entire survey area in mid-winter 2017 was 39,625 (90% CI: 32,860–48,897), a 17% increase from the last mid-winter survey and a 24% increase from the first mid-winter survey (Table 5, Figure 8).

Table 4. Estimated mean densities of Golden Eagles (#/km²) of all ages in each Bird Conservation Region (excluding no-fly zones) in 2006–2017^a, during late-summer (S) and mid-winter (W) surveys. Upper and lower limits for 90% confidence intervals are to the right of each estimate.

Year	Great Basin (9)		Northern Rockies (10)		Southern Rockies / Colorado Plateau (16)		Badlands and Prairies (17)	
2006(S)	0.0066	0.0096 0.0040	0.0117	0.0183 0.0067	0.0086	0.0125 0.0057	0.0263	0.0374 0.0181
2007(S)	0.0090	0.0124 0.0064	0.0137	0.0219 0.0077	0.0056	0.0087 0.0033	0.0246	0.0340 0.0174
2008(S)	0.0065	0.0094 0.0043	0.0139	0.0198 0.0092	0.0031	0.0050 0.0017	0.0171	0.0242 0.0115
2009(S)	0.0072	0.0100 0.0051	0.0136	0.0209 0.0082	0.0052	0.0086 0.0026	0.0166	0.0248 0.0101
2010(S)	0.0084	0.0127 0.0054	0.0145	0.0216 0.0090	0.0050	0.0081 0.0028	0.0228	0.0329 0.0149
2011(S)	0.0096	0.0129 0.0070	0.0134	0.0188 0.0093	0.0060	0.0084 0.0041	— ^b	— ^b — ^b
2012(S)	0.0092	0.0138 0.0062	0.0124	0.0181 0.0081	0.0079	0.0118 0.0050	0.0137	0.0197 0.0094
2013(S)	0.0113	0.0156 0.0081	0.0164	0.0249 0.0098	0.0086	0.0139 0.0052	0.0257	0.0349 0.0184
2014(S)	0.0090	0.0129 0.0060	0.0065	0.0100 0.0039	0.0062	0.0092 0.0039	0.0176	0.0258 0.0114
2015(S)	0.0100	0.0144 0.0067	0.0098	0.0149 0.0058	0.0054	0.0083 0.0032	0.0197	0.0288 0.0127
2016(S)	0.0113	0.0158 0.0080	0.0109	0.0152 0.0076	0.0070	0.0114 0.0037	0.0179	0.0284 0.0103
2014(W)	0.0169	0.0223 0.0128	0.0127	0.0187 0.0080	0.0091	0.0133 0.0057	0.0303	0.0406 0.0224
2015(W)	0.0145	0.0188 0.0112	0.0150	0.0212 0.0102	0.0111	0.0155 0.0077	0.0340	0.0468 0.0244
2017(W)	0.0178	0.0233 0.0136	0.0220	0.0317 0.0144	0.0069	0.0100 0.0044	0.0400	0.0549 0.0286

^aEstimates for 2006–2016 late-summer surveys were taken from Nielson et al. (2017). For 2014, 2015, and 2017 mid-winter surveys, densities are calculated based on detection probabilities from pooled survey data. Thus, estimates for 2014 and 2015(W) have been updated and are slightly different than those presented in Nielson et al. (2015).

^bBCR 17 was not surveyed in 2011.

Table 5. Estimated numbers of Golden Eagles of all ages in each Bird Conservation Region (excluding no-fly zones) in 2006–2017^a, during late-summer (S) and mid-winter (W) surveys. Upper and lower limits for 90% confidence intervals are to the right of each estimate.

Year	Great Basin (9)	Northern Rockies (10)	Southern Rockies / Colorado Plateau (16)	Badlands and Prairies (17)	Total
2006					
(S)	4,222	6,177 2,577	5,855 9,164 3,368	4,068 5,891 2,682	9,221 13,102 6,346
2007					
(S)	5,783	7,942 4,090	6,855 10,933 3,836	2,657 4,093 1,565	8,619 11,928 6,095
2008					
(S)	4,153	6,002 2,751	6,956 9,903 4,576	1,479 2,362 791	5,983 8,491 4,038
2009					
(S)	4,630	6,399 3,294	6,786 10,474 4,098	2,449 4,056 1,212	5,806 8,714 3,557
2010					
(S)	5,405	8,129 3,455	7,247 10,787 4,495	2,357 3,822 1,339	8,006 11,545 5,217
2011					
(S)	6,129	8,251 4,515	6,701 9,410 4,650	2,850 3,984 1,963	— ^b — ^b — ^b
2012					
(S)	5,906	8,859 3,951	6,186 9,034 4,053	3,708 5,565 2,341	4,822 6,906 3,292
2013					
(S)	7,233	9,986 5,220	8,218 12,470 4,919	4,069 6,545 2,449	8,998 12,253 6,461
2014					
(S)	5,771	8,289 3,824	3,272 5,006 1,934	2,908 4,349 1,855	6,156 9,031 3,983
2015					
(S)	6,436	9,243 4,262	4,889 7,474 2,906	2,538 3,929 1,506	6,898 10,083 4,446
2016					
(S)	7,232	10,152 5,148	5,445 7,585 3,824	3,314 5,357 1,732	6,265 9,961 3,623
2014					
(W)	10,803	14,261 8,208	6,337 9,326 3,981	4,284 6,272 2,676	10,637 14,232 7,855
2015					
(W)	9,303	12,047 7,203	7,492 10,607 5,106	5,221 7,333 3,621	11,906 16,417 8,569
2017					
(W)	11,381	14,906 8,698	11,012 15,851 7,181	3,248 4,709 2,063	13,983 19,241 10,016

^aEstimates for 2006–2016 late-summer surveys were taken from Nielson et al. (2017). For 2014, 2015, and 2017 mid-winter surveys, densities are calculated based on detection probabilities from pooled survey data. Thus, estimates for 2014 and 2015(W) have been updated and are slightly different than those presented in Nielson et al. (2015).

^bBCR 17 was not surveyed in 2011.

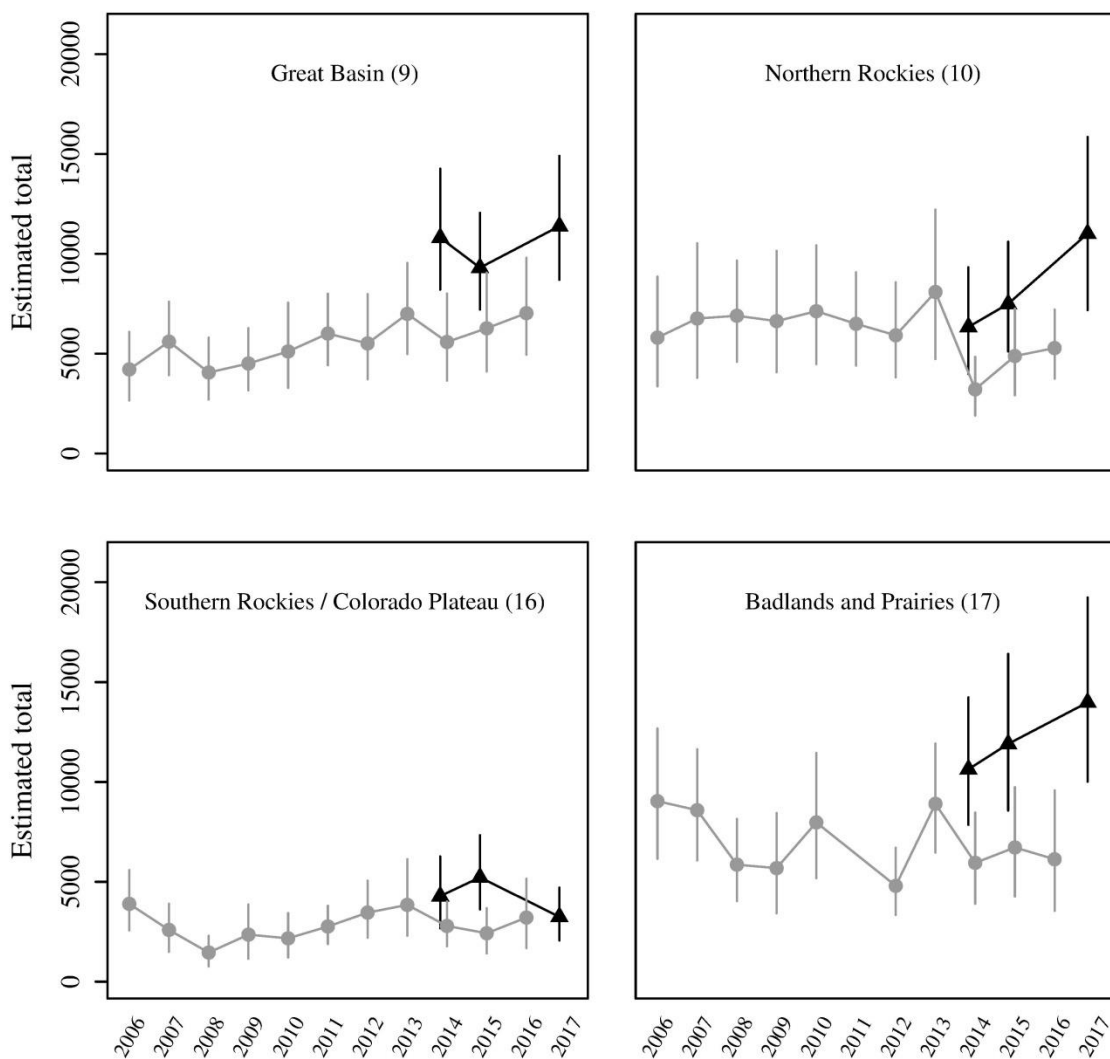


Figure 7. Estimates with 90% confidence intervals (vertical lines) of the total number of Golden Eagles (all ages) within each Bird Conservation Region (BCR) (excluding no-fly zones) in late summer (15 August–15 September) and mid-winter (15 January–15 February) 2006–2017. Late summer is in gray; mid-winter is in black. Bird Conservation Region 17 was not surveyed in 2011, so estimates for BCR 17 are not presented for that year.

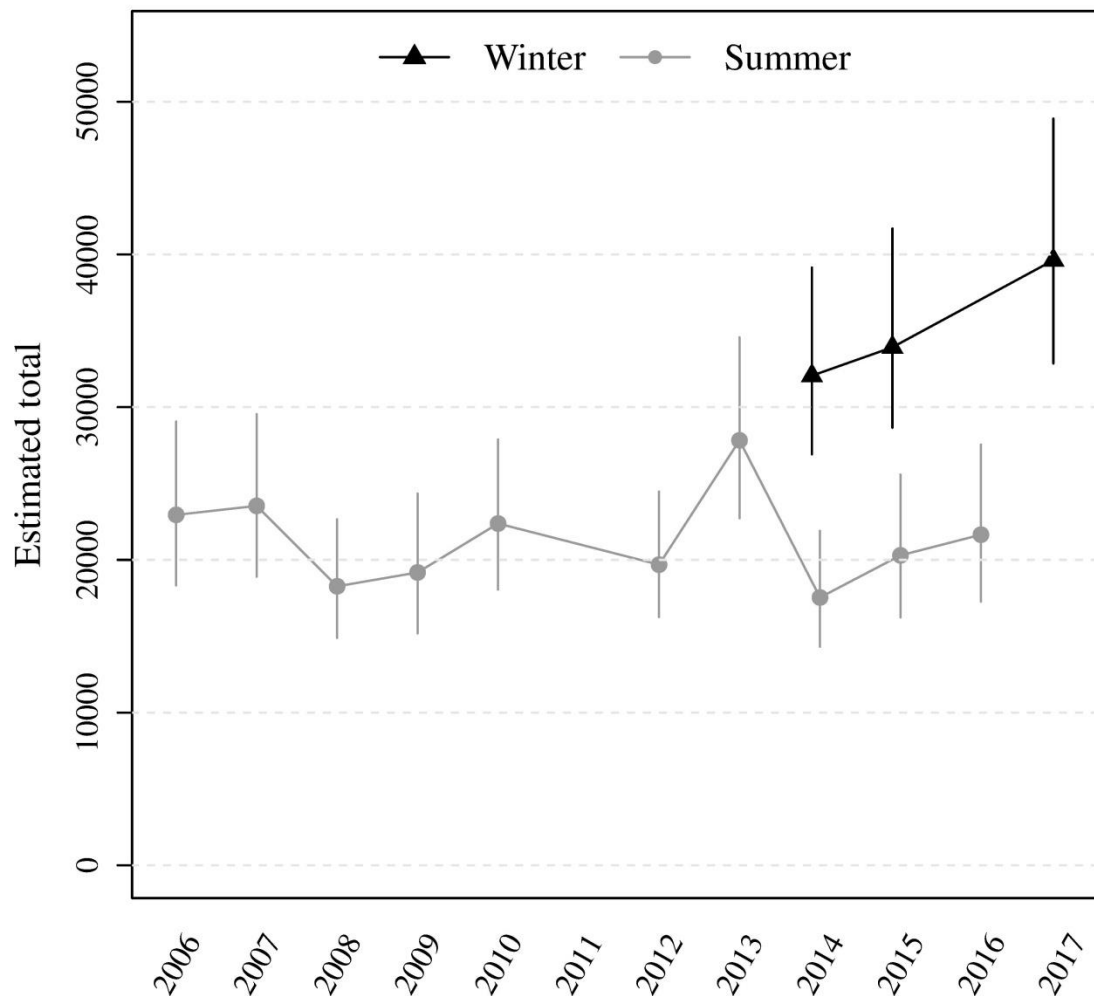


Figure 8. Estimates with 90% confidence intervals (vertical lines) of the total number of Golden Eagles (all ages) across the entire study area (excluding no-fly zones) in late summer (15 August–15 September) and mid-winter (15 January–15 February) 2006–2017. Bird Conservation Region 17 was not surveyed in 2011, so estimates for the entire study area are not presented for that year.

DISCUSSION AND CONCLUSIONS

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

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

We pooled data across all late-summer and all mid-winter surveys to generate detection functions for estimating mid-winter population totals in 2017 and retroactively for mid-winter 2014 and 2015 surveys. We justified pooling based on the consistency of the survey across years (e.g., protocol, observer training, and experience). Pooling data across years reduced year-to-year variability in detection functions, which we believe was primarily due to small sample sizes within any particular survey period. As reported in Nielson et al. (2015), using both the mid-winter and late-summer data, the pooled detection probability for perched Golden Eagles observed from 150 m AGL was higher after including the winter data compared to the summer data alone (Nielson et al. 2017). Detection probabilities for flying eagles and perched eagles observed from 107 m AGL were very similar during the late-summer and mid-winter surveys. Figure 3 shows that the number of perched eagles observed from 150 m AGL was higher in the first two mid-winter surveys than in late-summer (and consistent between both mid-winter surveys) but this mid-winter survey did not observe as many perched eagles in general. This might indicate that observing perched eagles from that height is somehow easier in mid-winter, or there is some behavioral change (e.g., perching in different, more visible locations) exhibited by Golden Eagles during the winter months. Or this could simply be a random occurrence. Further study during the winter months should help elucidate the factors affecting the detection probabilities.

We used the same protocol for the mid-winter survey as the late-summer surveys conducted since 2006, with the exception of allowing crews to survey later into the day and fly either east-west or west-east during the morning hours. Golden Eagles tend to soar, sometimes to great heights AGL, in the afternoon during the summer to thermoregulate. We did not expect to see much evidence of this behavior during the mid-winter surveys, although we did see a substantial number of Golden Eagles in flight during all winter surveys (Table 3). This,

combined with trying to complete the full survey in approximately the same number of days (~30), but with shorter day lengths (later sunrise) in which to work, prompted us to survey transects up to 1400 hours, rather than only 1300 hours as conducted during late-summer surveys. We flew early morning transects in either direction, as the mid-winter sun was sufficiently south in the sky to not cause glare or difficulty observing Golden Eagles when flying west to east during early morning.

The estimated abundance of Golden Eagles found in the mid-winter 2017 survey was greater than the estimated numbers from the previous mid-winter surveys (Table 5, Figure 8). In 2014, the overall estimate was 32,060 (90% CI: 26,912–39,145), and the overall estimate was 33,923 (90% CI: 28,656–41,703) in 2015. In 2017, the overall estimate was 39,625 (90% CI: 32,860–48,897), representing a 24% and a 17% increase in estimated eagle abundance since the 2014 and 2015 mid-winter surveys, respectively. While the year-to-year differences suggest interannual variation, the confidence intervals from these overall estimates show great overlap and imply consistent estimates across these three mid-winter surveys.

The mid-winter estimates from all three surveys are greater than the late-summer estimates (Table 5, Figure 8) during that timeframe. All mid-winter estimates were 44% to 78% greater than the most recent late-summer survey estimate (22,256; Nielson et al. 2017). The data suggest that this comes from more eagle observations, not a change in the number of eagles per observation (i.e., group size). Average group size of Golden Eagles in 2017 was 1.23 ($SE = 0.03$), the same as in 2015, and was similar to mean group size observed during the previous mid-winter survey (1.17, $SE = 0.03$). Group sizes across all mid-winter surveys (1.21, $SE = 0.01$) have been consistent with those observed in late-summer across all surveyed years (1.21, $SE = 0.01$).

Eagle abundances within the individual BCRs observed during the mid-winter survey indicate that the overall eagle population is primarily from 3 BCRs: the Great Basin (9), the Northern Rockies (10), and the Badlands and Prairies (17), and the large estimates from the 2017 mid-winter survey could reflect population changes occurring in these three BCRs. High population numbers in the Great Basin mirror the significant increasing trend in late-summer Golden Eagle numbers within that BCR reported in Nielson et al. (2017). The winter estimates from the Northern Rockies and the Badlands and Prairies, however, seem to indicate different trajectories than those observed during summer surveys (Figure 7). The increased Golden Eagle winter abundance in the Northern Rockies and the Badlands and Prairies, and perhaps portions of the Great Basin, could indicate an influx of eagles from more northern latitudes. McIntyre et al. (2008) and McIntyre (2012) document the movement of tagged Golden Eagles from interior Alaska southward along the Rocky Mountains in late autumn and then back to Alaska in the spring. Non-resident Golden Eagles are likely contributing to our abundance estimates, although the proportion of that contribution is unknown. In the Southern Rockies / Colorado Plateau BCR, though, the numbers in winter are similar to those observed in summer (Figure 7).

Weather had an effect on the pace and efficiency of the mid-winter surveys compared to the late-summer surveys. During the 2017 mid-winter survey, there were 16 days that crews

could not fly any transects because of weather. Due to persistent weather delays and concerns about changes in behaviors and eagle migration, we did not survey the upper northwestern area of the survey region (Figure 3). While our survey effort (km flown) was lower in 2017 compared to the other 2 mid-winter surveys (Table 1), we do not think that missing this part of the study area impacted our estimates. Previous winter surveys did not detect many Golden Eagles on the missed transects (<0.2% of all observations in previous winter surveys were made on the missed transects in that region).

We began to use an age classification matrix (Figure 2) in 2006, and this classification matrix provides a valuable framework for classifying Golden Eagles observed along aerial transects during late-summer surveys. In winter, however, the matrix does not provide an unambiguous framework for distinguishing and classifying both juvenile and sub-adult Golden Eagles. We recognized the difficulty in aging sub-adults during mid-winter, when plumage characteristics have changed and the aging matrix (Figure 2) is no longer appropriate, so we binned the mid-winter 2015 observations of juvenile/sub-adult eagles with unknown immatures (Figure 5). While we initially reported juvenile and sub-adult numbers from the 2014 mid-winter survey (Nielson and McManus 2014), we retroactively binned the mid-winter 2014 observations of juvenile/sub-adult eagles with unknown immature (Figure 5), and have done this for all subsequent mid-winter surveys.

The late-summer (post-fledging) monitoring program has already proven to be of additional value beyond estimating the size and trends of Golden Eagle populations in the four BCRs surveyed. Millsap et al. (2013) used the survey data to determine that Breeding Bird Survey (BBS) data were in fact providing useful trend information even though the BBS ignores probability of detection and occurs along roadsides, prior to juvenile Golden Eagles fledging from nests. They also developed adjustment factors that were used to scale BBS counts in other regions not covered in the western-wide estimates of Golden Eagle densities. In addition, we used Golden Eagle observations from our survey to develop a landscape-scale resource selection function that relates Golden Eagle densities to habitat characteristics (Nielson et al. 2016). At this time, the three years of mid-winter data have not provided enough data to develop a similar habitat model for Golden Eagles during the mid-winter period, but additional survey data during the winter months may provide sufficient data to develop a stand-alone Golden Eagle winter habitat use model.

During the 2017 mid-winter survey we also collected line transect DS data on Bald Eagles (*Haliaeetus leucocephalus*). We observed 64 Bald Eagle groups while flying transects in mid-winter 2017, for a total of 92 individual eagles. Although we collected DS information for these observations, we have not analyzed these data or included them in this report; however, our database of bald eagle observations may yield interesting insights after formal analysis.

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