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Research Article

Golden Eagle Population Trends in the Western United States: 1968–2010

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ABSTRACT In 2009, the United States Fish and Wildlife Service promulgated permit regulations for the unintentional lethal take (anthropogenic mortality) and disturbance of golden eagles (*Aquila chrysaetos*). Accurate population trend and size information for golden eagles are needed so agency biologists can make informed decisions when eagle take permits are requested. To address this need with available data, we used a log-linear hierarchical model to average data from a late-summer aerial-line-transect distance-sampling survey (WGES) of golden eagles in the United States portions of Bird Conservation Region (BCR) 9 (Great Basin), BCR 10 (Northern Rockies), BCR 16 (Southern Rockies/Colorado Plateau), and BCR 17 (Badlands and Prairies) from 2006 to 2010 with late-spring, early summer Breeding Bird Survey (BBS) data for the same BCRs and years to estimate summer golden eagle population size and trends in these BCRs. We used the ratio of the density estimates from the WGES to the BBS index to calculate a BCR-specific adjustment factor that scaled the BBS index (i.e., birds per route) to a density estimate. Our results indicated golden eagle populations were generally stable from 2006 to 2010 in the 4 BCRs, with an estimated average rate of population change of −0.41% (95% credible interval [CI]: −4.17% to 3.40%) per year. For the 4 BCRs and years, we estimated annual golden eagle population size to range from 28,220 (95% CI: 23,250–35,110) in 2007 to 26,490 (95% CI: 21,760–32,680) in 2008. We found a general correspondence in trends between WGES and BBS data for these 4 BCRs, which suggested BBS data were providing useful trend information. We used the overall adjustment factor calculated from the 4 BCRs and years to scale BBS golden eagle counts from 1968 to 2005 for the 4 BCRs and for 1968 to 2010 for the 8 other BCRs (without WGES data) to estimate golden eagle population size and trends across the western United States for the period 1968 to 2010. In general, we noted slightly declining trends in southern BCRs and slightly increasing trends in northern BCRs. However, we estimated the average rate of golden eagle population change across all 12 BCRs for the period 1968–2010 as +0.40% per year (95% CI = −0.27% to 1.00%), suggesting a stable population. We also estimated the average rate of population change for the period 1990–2010 was +0.5% per year (95% CI = −0.33% to 1.3%). Our annual estimates of population size for the most recent decade range from 31,370 (95% CI: 25,450–39,310) in 2004 to 33,460 (95% CI: 27,380–41,710) in 2007. Our results clarify that golden eagles are not declining widely in the western United States.

KEY WORDS *Aquila chrysaetos*, Breeding Bird Survey, golden eagle, hierarchical model, populations, trend, United States.

In 2009, the United States Fish and Wildlife Service (Service) published regulations under the Bald and Golden Eagle Protection Act (16 United States Code 668–668d; hereafter Act) that established conditions under which the Service could permit lethal take and disturbance of bald (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*). The Act delegates to the Secretary of the Interior the ability to permit take of the eagles "necessary for the protection of other interests in any particular locality" after determining the take is "compatible with the preservation of the bald eagle or golden eagle." The regulations define take to mean pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, destroy, molest, or disturb. In the 2009

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regulations, the Service established that compatibility with mandates of the Act are accomplished if permitting activities do not result in a net decrease in the number of breeding pairs of either species of eagle (using 2009 as the baseline) within regional geographic management units, which in the case of the golden eagle are Bird Conservation Regions (BCR; U.S. North American Bird Conservation Initiative Monitoring Subcommittee 2007, U.S. Fish and Wildlife Service 2009). Direct counts of the number of golden eagle breeding pairs are not available and the number varies annually with environmental conditions (Kochert et al. 2002); therefore, the Service relies on trends in estimates of total golden eagle population size and demographic models that use those population estimates to assess whether the management objective of a stable breeding population is being achieved (U.S. Fish and Wildlife Service 2009).

This permitting threshold created a need for accurate population trend and size data for both species of eagle so Service and other agency biologists could make informed decisions when eagle take permits were requested. This had been problematic in the case of the golden eagle because available data had been sufficient for only coarse estimates of population size with no measure of uncertainty. The lack of robust population data was 1 factor that led the Service to conclude it could not authorize additional take above that existing at the time the eagle take regulations were published without potentially violating the preservation standard in the Act (U.S. Fish and Wildlife Service 2009). This decision has been controversial, particularly in the western United States where permits to unintentionally take golden eagles in association with renewable energy development are needed.

We integrated data from golden eagle population surveys conducted by Western Ecosystems Technology (WEST) and the Service (hereafter the western United States summer golden eagle survey, or WGES; Good et al. 2007, Nielson et al. 2012) and the North American Breeding Bird Survey (hereafter BBS) using a log-linear hierarchical model (Sauer and Link 2011, Zimmerman et al. 2012). Our broad objectives were to help clarify our understanding of the status of the golden eagle in the conterminous western United States. We studied the summer golden eagle population in the conterminous western United States roughly west of the 100th meridian; we stratified this population by BCR for analyses (Fig. 1). The BBS is a well-known survey intended to provide early-summer population change information for over 420 species of birds from the late 1960s to the present over much of North America (Sauer and Link 2011). Given its timing, the BBS provides information on golden eagles before young have fledged from nests over most of the western United States, hence it is a pre-recruitment survey. Population estimates from the BBS are controversial because they lack estimates of detection (Thogmartin et al. 2006), and the BBS is considered to have deficiencies because of low precision and low abundances with respect to assessing trends of golden eagle populations (http://www.mbr-pwrc.usgs.gov/cgi-bin/atlasa10.pl?03490&1&10, accessed 4 Nov 2012). The WGES was initiated in 2003 as a pilot study, and was designed to estimate population size of golden eagles. Adjustments were made following the pilot study and the survey has been conducted annually using a consistent protocol and sample of survey transects since 2006 by WEST with funding from the Service (Good et al. 2007, Nielson et al. 2012). This aerial transect-based survey focuses on late summer, post-breeding golden eagles in the Great Basin (BCR 9), Northern Rockies (BCR 10), Southern Rockies/Colorado Plateau (BCR 16), and Badlands and Prairies (BCR 17) BCRs, which collectively cover about 80% of the golden eagle's range in the conterminous western United States (U.S. Fish and Wildlife Service 2009).

Both WGES and BBS counts of golden eagles exist for BCRs 9, 10, 16, and 17 for the years 2006–2010; we refer to these BCRs as the overlap BCRs. The WGES has produced estimates of golden eagle density for the overlap BCRS for the years 2006–2010 (Nielson et al. 2012), and the BBS has generated estimates of golden eagle population trends for the period 1968–2008 (Sauer and Link 2011). Our specific objectives in integrating data from the WGES and BBS were to 1) collectively apply all available survey data to inform regional trend estimates; 2) assess whether the BBS and WGES were providing similar golden eagle population trend estimates for the time periods and BCRs of overlap; and if so, 3) develop an adjustment factor to scale the BBS counts of birds per route in the spring to density estimates post-breeding, which would allow us to estimate golden eagle population size and trend over the time series of the BBS (1968–2010) or for parts of that interval for both the overlap BCRs and other BCRs in the conterminous United States west of the 100th meridian.

We present the methods and results from the composite analysis of WGES and BBS golden eagle population data, and compare those findings with those from other recent golden eagle population analyses and assessments. In that context we also consider recent published estimates of golden eagle population trends from regression analyses of autumn western United States golden eagle migration counts (Bildstein et al. 2008). The original analysis of those data suggested migratory populations of golden eagles over much of the western United States have declined since the mid-1980s, and in particular from 1995 to 2005 (Farmer et al. 2008). However, recent analyses suggest migratory behavior of some North American raptors may be changing in response to climate change (Rosenfield et al. 2011, Buskirk 2012), and we wanted to assess whether this might be a factor in the golden eagle trends reported by Farmer et al. (2008). In addition to providing insights into golden eagle population change over the analysis period, our results also extend the utility of the hierarchical model developed by Sauer and Link (2011) in generating estimates of population numbers through the incorporation of estimated detection probabilities from the WGES.

STUDY AREA

The WGES was conducted in the United States portions of BCRs 9, 10, 16, and 17, which collectively cover the majority of the interior conterminous western United States (Fig. 1). Military lands, elevations >3,048 m, water bodies

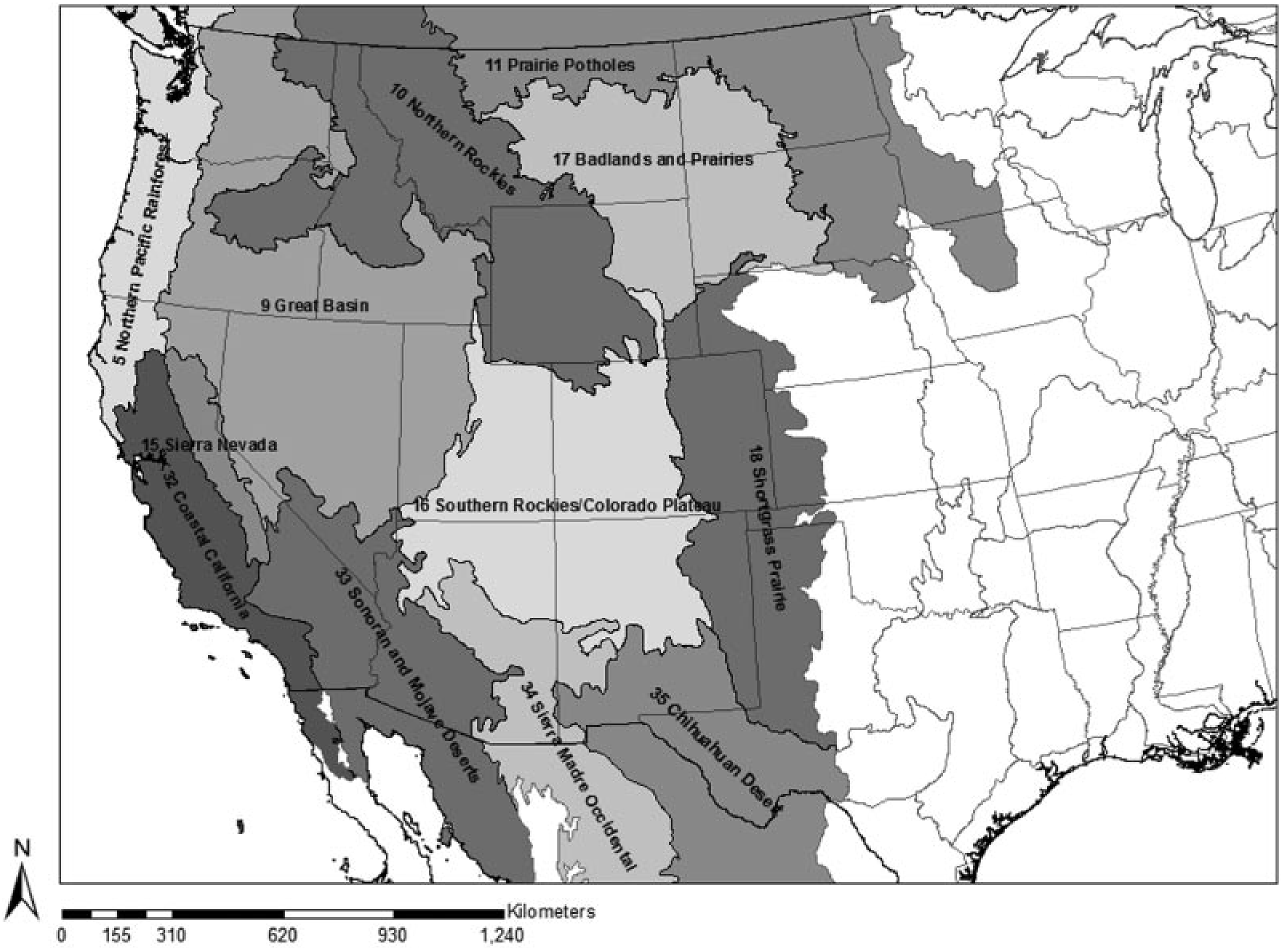

Figure 1. Map of our study area showing Bird Conservation Regions (BCRs), the geographic regions by which we stratified our analyses of golden eagle surveys. Shaded BCRs were included in our study.

>30,000 ha, and large urban areas accounting for 6.03% of these BCRs were not sampled in the WGES. The BBS provides information for the entire western United States; we used BBS data for each BCR west of the 100th meridian in the conterminous United States (Table 1). Thus, we used both WGES and BBS data from overlap BCRs 9, 10, 16, and 17, and BBS data only from the non-overlap BCR 5 (Northern Pacific Rainforest), BCR 11 (Prairie Potholes), BCR 15 (Sierra Nevada), BCR 18 (Shortgrass Prairie), BCR 32 (Coastal California), BCR 33 (Sonoran and Mojave deserts), BCR 34 (Sierra Madre Occidental), and BCR 35 (Chihuahuan Desert).

Table 1. Bird Conservation Region (BCRs) areas used in our analysis of golden eagle surveys, 2006–2010.

BCR[a]	Area (km^2)[b]
9—Great Basin	671,710
10—Northern Rockies	504,133
16—Southern Rockies/Colorado Plateau	477,753
17—Badlands and Prairies	360,113
5—Northern Pacific Rainforest	175,866
11—Prairie Potholes	414,819
33—Sonoran and Mojave Deserts	216,255
34—Sierra Madre Occidental	123,571
32—Coastal California	155,169
15—Sierra Nevada	48,340
18—Shortgrass Prairie	381,839
35—Chihuahuan Desert	176,139

[a] Analysis used only United States portions of BCRs.
[b] We filtered BCR areas to exclude military lands, elevations >3,048 m, water bodies >30,000 ha, and large urban areas to be compatible with the areas used by Nielson et al. (2012). Overall, this resulted in a 6.03% reduction in area compared to the unfiltered BCR areas.

METHODS

We used a log-linear hierarchical model (Sauer and Link 2011) to estimate population sizes and trends, and to integrate data from the WGES and the BBS. The WGES was conducted by WEST, flying fixed-wing aircraft along transects at a speed of about 161 km/hr. For complete details on the design of the WGES, see Good et al. (2007) and Nielson et al. (2012). We used WGES data from 2006 through 2010 in these analyses; we did not use data from the pilot year of 2003 as it may not be comparable, following the recommendation of Nielson et al. (2012). In each year, WEST flew between 203 and 216 standardized transects (Table 2). Transect length was typically 100 km, but differences in the number and length of transects occurred for various reasons (e.g., in some years forest fires precluded flying all or portions of some transects). These variations

Table 2. Length (km) of transects flown by year on the western United States summer golden eagle survey (WGES) in Bird Conservation Regions (BCRs) 9, 10, 16, and 17.

BCR	2006	2007	2008	2009	2010	Total
9	6,016	5,857	5,770	5,915	5,911	29,469
10	4,606	4,570	4,546	4,728	4,557	23,007
16	3,966	3,998	3,975	3,807	3,939	19,685
17	3,143	3,245	3,129	3,147	3,201	15,865
Total	17,731	17,670	17,420	17,597	17,608	88,026

were accommodated by treating transects as sampling units in the log-linear hierarchical models. These surveys were conducted from 15 August to 15 September, after juvenile golden eagles had fledged but before autumn migration (Fuller et al. 2001).

Surveys were flown at different altitudes because of topography. Specifically, rugged portions of transects were flown at a higher altitude (150 m above-ground level; AGL) compared to relatively level portions (107 m AGL). During 2006, 2007, 2009, and 2010, 2 observers were situated on the right side of the aircraft (1 in the front seat and 1 in the rear) and 1 observer in the rear left side of the aircraft. During 2008, only 1 observer occupied the right side of the aircraft (in the front) on 68 of 213 transects. Observers counted all golden eagles, attempted to place each eagle in an age class, estimated the perpendicular distance of observed eagles from the transect, and recorded whether eagles were perched or flying. Using these data and a combination of distance sampling (Buckland et al. 2001) and mark-recapture methods (Borchers et al. 2006), Nielson et al. (2012) estimated population sizes and detection functions for golden eagles in each of the 4 BCRs covered by the WGES. Considering the various combinations of observer position (back-left, front and back-right, and front-right only), flight height (AGL), and eagle behavior (flying vs. perched), we recognized 9 different detection categories for our analysis of WGES data. In our analysis, we used the estimated average probability of detection within 1,000 m of the aircraft for each detection category to relate counts of golden eagle groups during the WGES to density estimates.

The BBS was conducted from the ground at points along road transects (different from WGES transects) from April through June. Each route was 39.4 km long and survey points were placed at 0.8-km intervals. Protocol dictated that observers counted every bird that was not a dependent juvenile heard or seen within 400 m for a 3-minute period at each point. However, we were not confident that observers consistently followed protocol with respect to the distance, so we did not incorporate the area sampled in analysis of the BBS data. We used BBS data from 1968 to 2010 for this analysis, but calculated trend estimates for 2 time periods: 1968–2010 and 1990–2010. We included the former period to present our best estimate of trend for the complete range of years for which we have data. We present the limited trend because early years of the BBS provided relatively small sample sizes for analysis, and these small sample sizes can lead to imprecise results and to an inability to distinguish patterns within the period. The years 1990–2010 had much greater BBS coverage and commensurately larger golden eagle sample sizes, and the estimates of annual change over this period were unaffected by the imprecise estimates from the earlier years. Past analyses of BBS data have assigned routes to strata defined by BCR and state or province. To maintain consistency with the design of the WGES, we defined strata based on BCR only, except that we split out British Columbia and Alberta from BCRs 10 and 11 because the WGES did not survey areas outside the United States.

Many juvenile golden eagles encountered during the WGES in a given year were not available to be sampled during the BBS survey in that year, as the BBS primarily occurred before juvenile golden eagles fledged. Initially we considered analyzing the juvenile and non-juvenile age class data separately, but uncertainty over how to treat golden eagles classified as an unknown age in the WGES precluded this approach. Therefore, we combined all golden eagles observed during the WGES to a single age class.

The hierarchical models we used to derive population indices accommodate the stratification and the repeated sampling (i.e., counts are conducted along the same transects each year for the respective surveys) design of both surveys (Sauer and Link 2011, Nielson et al. 2012). The model used for the BBS was

$$\log(\lambda_{i,j,t}) = S_i + \beta_i T_t{}^* + \gamma_{i,t} + \omega_j + \eta E_{j,t} + \varepsilon_{i,j,t}$$

where we assumed that counts of eagles from each transect were samples from an overdispersed Poisson distribution with expected value λ that was specific for each BCR (i), route-observer combination (j), and year (t). The S and β represent BCR-specific intercept and slope parameters for underlying trends over the entire time series. Following Sauer and Link (2011), we centered years on the median value (i.e., $T_t^* = t -$ median year). We also included BCR- and year-specific random effects (γ) to model annual indices as offsets from the underlying trends, a random effect for observer and BBS route combinations (ω) to account for repeated sampling along the same routes by the same observers each year, and a fixed effect of first-year observers (η) to account for inexperience and learning by observers during the survey. The $E_{j,t}$ was an indicator variable that was assigned a 1 if an observer conducted a BBS route j for the first time (in year t) and a 0 otherwise (e.g., observer experience). We included an overdispersion parameter (ε) to account for extra Poisson variation. Following Sauer and Link (2011), we weighted BBS indices for each BCR by the proportion of routes that recorded ≥1 golden eagle since the survey's inception. Because we did not have an estimate of detection probability or area sampled, the model for the BBS data yields an annual index to population size quantified as the number of birds per route (Sauer and Link 2011).

Although the model structure for the WGES was similar to the BBS model, the WGES model statement accommodated differences in survey design. For the WGES, WEST 1) employed observers that were carefully trained and had a year of pilot surveys, which allowed us to ignore the first-year observer effect; 2) estimated detection probability, which allowed us to adjust the counts for undetected individuals; and 3) surveyed a defined area along a systematic sample of transects across the overlap area, which enabled us to estimate an actual density (see Table S1, available online at www.onlinelibrary.wiley.com). Our modeling approach was similar to Zimmerman et al. (2012), except that we included detection rate directly in the main model, whereas they used a visibility correction factor when calculating derived statistics. Specifically, the structure of our model for the WGES data was

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

where A represented the area sampled for each detection class along transects and P represented the detection probability. Area sampled was based on the assumption of a 1,000-m buffer on each side of the aircraft minus the area underneath the plane where vision was blocked, which was 25 m over flat terrain and 40 m over rugged terrain for each side of the aircraft (i.e., total buffer width was 1,950 m and 1,920 m over flat and rugged terrain, respectively). The indexing for the WGES data was slightly different than the model for the BBS data. Although i still indexed BCR, j represented individual transects for the WGES data (i.e., our sampling unit). The indices a, b, and c are associated with detection classes. Detection probabilities varied by 1) for perched golden eagles, gentle terrain flown at 107 m versus rugged terrain flown at 150 m, indexed by a above; 2) side of the airplane (left side had 1 observer in the rear, the right side had 2 observers most years, and 1 observer in the front for some transects in 2008) indexed by b above; and 3) behavior (flying vs. perching birds) indexed by c above. Although the detection probability of perched birds varied by altitude flown, we found no effect of altitude on detection of flying birds (Table 3). Separate linear regressions ($S_{i,c} + \beta_{i,c} T_t^* + \gamma_{i,c,t}$) of the trend and separate random transect effects ($\omega_{j,c}$) were estimated for perched and flying birds.

We used Bayesian methods to make inferences about unknown parameters in the models. We used the Markov chain Monte Carlo (MCMC) method implemented in program WinBUGS (Lunn et al. 2000) to estimate posterior distributions of unknown parameters (Table S1, available online at www.onlinelibrary.wiley.com, which also provides prior distributions for each of the unknown parameters). We incorporated uncertainty associated with the detection probabilities by sampling a P (detection probability) from a normal distribution with means and variances estimated by Nielson et al. (2012; see Table 3). We ran 3 chains for 40,000 iterations and used the first 36,000 iterations for a burn-in period and made inferences using the final 4,000 iterations for each of the chains. Therefore, our final summary statistics are based on a total of 12,000 iterations. We inspected history plots and used $\hat{R}$ to estimate convergence. $\hat{R}$ convergence measures <1.1 suggested convergence (Gelman and Hill 2007), and all model results reported here had $\hat{R}$ values ≤1.03.

We used the MCMC procedure to estimate the posterior distributions of several derived parameters. We computed annual indices of golden eagles from each survey in each BCR as functions of the model parameters. For the BBS, we derived annual indices (I) of birds per route from parameters and variance components as

$$I_{i,t} = z_i \exp(S_i + \beta_i T_t^* + \gamma_{i,t} + 0.5\sigma_{\omega}^2 + 0.5\sigma_{\varepsilon}^2)$$

where z represented a weighting factor based on the proportion of routes in that strata (Sauer and Link 2011). We estimated annual estimates of birds per km^2 from the WGES as

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

Note that perched birds were indexed as $c = 1$ and flying as $c = 2$, and we summed these 2 densities to estimate a total density for eagles in each BCR for each year based on the WGES data ($n_{it.}$).

Similar to Zimmerman et al. (2012), we needed to scale data from 1 survey to the level of the other to integrate results from the 2 surveys. We chose to scale the BBS data to the

Table 3. Detection probabilities and standard errors (SE) for the different observation categories in the western United States summer golden eagle survey (WGES) in Bird Conservation Regions (BCRs) 9, 10, 16, and 17 from 2006 to 2010.

	Detection probability (SE)[a]		
	Eagle flying	Eagle perched	
Observer position in aircraft	All terrain[b]	Gentle[c]	Rugged[c]
Left (rear)	0.437 (0.071)	0.443 (0.033)	0.325 (0.010)
Right (front and rear)	0.511 (0.060)	0.556 (0.033)	0.419 (0.091)
Right (front only; 2008)	0.304 (0.059)	0.426 (0.032)	0.283 (0.090)

[a] Detection probabilities were estimated as the mean of detection functions from distance sampling over a 1-km range.
[b] Terrain and altitude did not influence detection probabilities for flying golden eagles.
[c] Flight altitude was 150 m above-ground level over rugged terrain compared to 107 m above-ground level over gentle terrain.

level of the WGES because the goal of this analysis was to derive a population estimate. To transform the BBS indices of birds per route during the breeding season to estimates of density post-fledging, we adjusted the BBS levels for the overlap BCRs to the WGES for all years using the ratio of the sum of WGES densities over all overlap years (*nDen* in Table S1, available online at www.onlinelibrary.wiley.com) to the sum of the BBS indices over all overlap years (*n* in Table S1, available online at www.onlinelibrary.wiley.com) for each BCR ($i = 9$, 10, 16, and 17):

$$\text{Scale}_i = \frac{n_{i,..}}{I_i}$$

The purpose of the scale factor is to adjust the results of the 2 surveys to a common level to enable results to be combined during years of overlap. In addition to combined inference for overlap years, historical BBS results should be scaled to be consistent with combined results to make inferences regarding population size and trends for years prior to implementation of the WGES. More complicated models for aggregation could be considered, with parameters to control for 1) differences in units (i.e., BBS population index and WGES density) and approach (road counts vs. aerial counts); 2) mortality of birds throughout the summer; and 3) movements of birds to and from the conterminous western United States during the summer. These factors are accounted for implicitly by the scale factor in our analyses, but even with data and a model to directly account for these added features we would still need to estimate a constant scale factor to adjust the BBS index to the density scale of the WGES. We adjusted the BBS indices in the non-overlap BCRs using an overall scaling factor averaging the overlap BCR-specific scaling factors, and based variability in these estimates on the MCMC simulations. These constant scale factors maintained the trend information in the BBS data and were the best available for adjusting BBS indices for the years prior to the WGES.

After scaling the BBS data to represent densities, we calculated composite estimates as the means of scaled BBS and WGES densities for each year and BCR. The WGES did not begin until 2006, so the composite BBS densities for years prior to 2006 were only the BBS estimates scaled by the adjustment for the respective BCR in the overlap regions (i.e., prior to 2006, we had no WGES estimate to average with the scaled BBS index). We then calculated the population estimate by expanding the composite density estimates by the total area in each BCR. We generated area estimates that excluded military lands, elevations >3,048 m, water bodies >30,000 ha, and large urban areas. Overall, we excluded 6.03% of the total area.

We calculated trends by BCR and for all BCRs combined as the average population change from 1968 to 2010 and 1990 to 2010 based on the composite population index as suggested by Sauer and Link (2011):

$$B_i = \left(\frac{N_{i,2010}}{N_{i,\text{year1}}}\right)^{1/(2010-\text{year1})}$$

where i indexes BCR, year1 represents the first year (i.e., 1968 or 1990), and N is the composite population size for each year, reported as a percent relative change.

We compared our results relative to population size and trends for golden eagles in the western United States to prior published assessments, including the previous analyses of the WGES by Nielson et al. (2012). With respect to trends in numbers of autumn migrant golden eagles, we hypothesized that if migration behavior was changing in response to climate change that negative trends in autumn counts of golden eagles would be greater at southern than more northern hawk watch sites. A complete assessment of this hypothesis was not possible as we were unable to obtain raw data from all pertinent hawk watch sites for analysis in this paper. Given this, we were not able to separate the location-specific trends from the overall trend, but we were able to evaluate this hypothesis in a preliminary context by plotting the summary trend results from Smith et al. (2008: 226–227) against latitude, and fitting a locally weighted scatterplot smoothing (LOWESS) line to the trend data and to upper and lower 95% confidence limits for each site. We used the locfit package and scb function (http://CRAN.R-project.org/package=locfit, accessed 18 Jun 2012) in R (version 2.15.0, http://www.r-project.org/, accessed 18 Jun 2012) for this analysis.

RESULTS

From 2006 to 2010, 780 golden eagles were detected on approximately 88,000 km of transects that were surveyed in the 4 BCRs covered by the WGES (Table 2). Golden eagle detection probabilities on the WGES across the 9 detection classes ranged from 0.28 to 0.56 (Table 3). Hierarchical model estimates from the WGES for the total population of golden eagles in all BCRs tended to be slightly larger than distance sampling estimates, but broad overlap occurred in the credible intervals (Fig. 2).

Golden eagles are generally seen at low abundances throughout their range on BBS routes, though our analysis included 3,977 golden eagle detections on BBS routes over all 12 BCRs over the study period (Tables S2 and S3). As BBS data only index trends, the scaling factors derived from the WGES analysis for each BCR allowed us to adjust the scale of BBS estimates from golden eagles per route to golden eagles per km^2 (Table 4). The scaling factors were similar among BCRs 9, 10, and 16. The scaling factor in BCR 17 was approximately 3 times greater than the other BCRs, which resulted from a relatively high density of eagles observed in that BCR by the WGES ($\bar{x} = 0.009$, 0.015, 0.008, 0.027 birds/km^2 in BCRs 9, 10, 16, and 17, respectively) compared to the BBS index of birds per route ($\bar{x} = 0.322$, 0.362, 0.225, 0.253 in BCRs 9, 10, 16, and 17, respectively). In other words, the WGES estimated almost double the density of golden eagles in BCR 17 compared to any of the other BCRs, whereas the BBS survey counted more birds per route in BCRs 9 and 10 than BCR 17. We plotted the scaled BBS data against the densities estimated from the WGES to compare trends between the 2 surveys (Fig. 3). Credible intervals of yearly estimates and patterns of

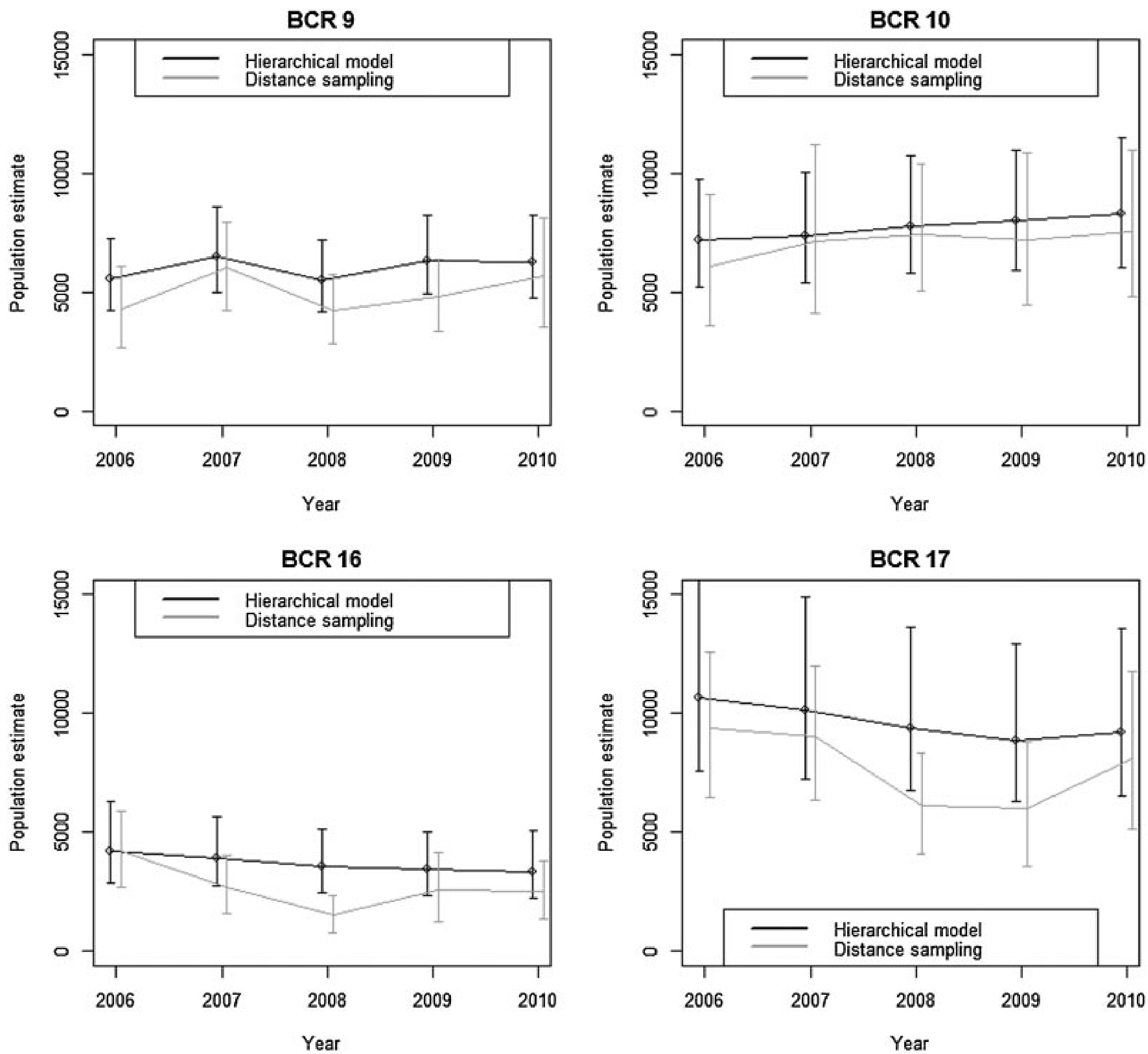

Figure 2. Comparison of population estimates from our hierarchical model to those derived from distance sampling (Nielson et al. 2012) from the western United States summer golden eagle survey in Bird Conservation Regions (BCRs) 9, 10, 16, and 17, 2006–2010. Error bars represent the 90% credible intervals.

population change of overlap BCRs were generally consistent between surveys. Declines in WGES results in BCR 17 over the period 2006–2009 were not significantly different from the no-change indicated by BBS results, and more positive trends from WGES results in BCR 10 were likewise not significantly different from the less positive BBS results.

We expanded the 4 overlap BCR density estimates to provide estimates of composite population size and credible intervals for these BCRs (Fig. 4). As in the non-combined estimates, credible intervals of the composite population index were larger for BCR 17. However, average coefficients of variation for BCRs 9, 10, 16, and 17 were 21%, 21%, 25%, and 25%, respectively, indicating that the variability of BCR 17 scaled with the higher index of golden eagles there (i.e., indices were 2–4 times higher in BCR 17 than in the other 3 BCRs).

Population estimates for BCRs other than 9, 10, 16, and 17 were based solely on BBS data, which were scaled to the level of the WGES using the overall scaling factor (Fig. 5, Table S4). Our analysis indicates some support for population increases in the Northern Rockies and Prairie

Table 4. Factors used to scale the Breeding Bird Survey (BBS) counts of golden eagles per route to the level of golden eagles per km^2 as estimated from the western United States summer golden eagle survey (WGES), for the 4 Bird Conservation Regions (BCRs) and years of overlap (2006–2010) for the 2 surveys.

BCR	Median scaling factor (95% CI)
9	0.028 (0.020, 0.039)
10	0.042 (0.029, 0.062)
16	0.034 (0.023, 0.052)
17	0.106 (0.069, 0.168)
Overall	0.053 (0.041, 0.071)

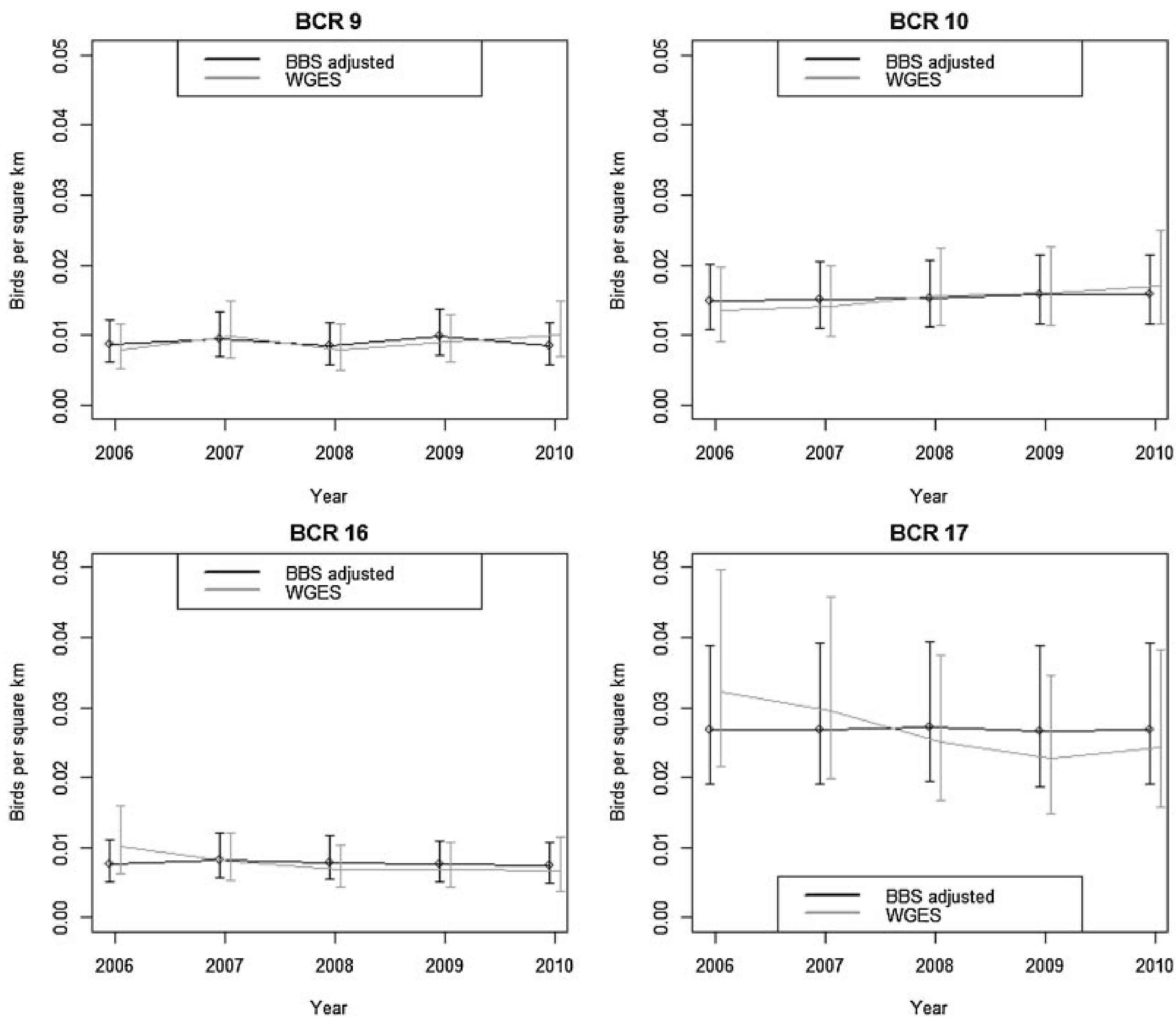

Figure 3. Comparison of trends in golden eagle density for years and Bird Conservation Regions (BCRs) of survey overlap by the Breeding Bird Survey (BBS) and Western Golden Eagle Survey (WGES). Error bars represent the 95% credible intervals.

Pothole BCRs (10 and 11, respectively), and slight declines in some of the southern BCRs (15, 16, 32, 33). However, in nearly all cases credible intervals included 0, indicating limited support for decreasing or increasing populations in these BCRs. The overall trend estimate from 1968 to 2010 for all BCRs combined (including both the combined results from the 4 overlap strata and the BBS-only strata) was +0.4% per year (95% CI = −0.27% to 1.00%), suggesting the population was stable over the period (Figs. 5 and 6). Our estimate of overall trend for the period 1990–2010 was +0.5% per year (95% CI = −0.33% to 1.3%).

Our LOWESS-fit plot of trends in counts of autumn migrant golden eagles by latitude showed stronger negative trends from 1995 to 2008 at hawk watch sites south of 40° north latitude than a sites further north (Fig. 7).

DISCUSSION

These data represent the first comprehensive, integrated analysis of the 2 most appropriate existing datasets to assess the golden eagle's status in the western United States and are therefore of interest for comparison with previous findings. Kochert and Steenhof (2002) provided a broad overview of migration count, BBS, Christmas Bird Count, and local population study data for golden eagles throughout North America. They concluded that golden eagle populations in Alaska and Canada were likely stable, but that some breeding populations in the western United States were evidencing declines. Nielson et al. (2012) analyzed the WGES trend data from 2006 to 2010 and concluded those data showed no evidence of a trend in overall numbers of golden eagles in BCRs 9, 10, 16, and 17. Our findings from the composite analysis of BBS and WGES data for the overlap BCRs parallel those of Nielson et al. (2012) for the period of the WGES, but also suggest the study population has been generally stable in those BCRs since the late 1960s. Moreover, our analysis of BBS data for the other BCRs in western North America suggests golden eagle populations are generally stable there as well. Our overall estimates of

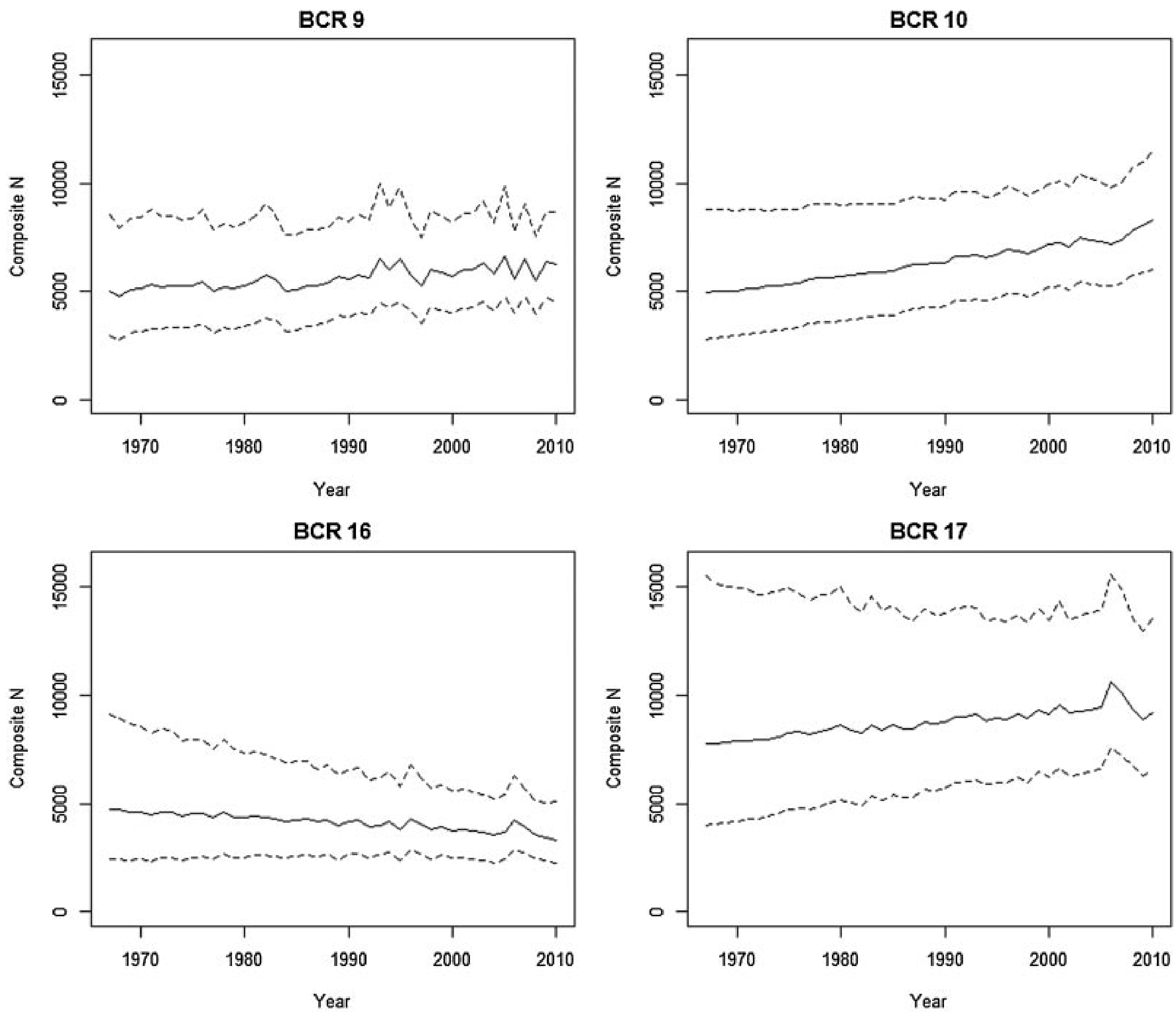

Figure 4. Integrated Breeding Bird Survey and Western Golden Eagle Survey estimates of golden eagle population size in Bird Conservation Regions (BCRs) 9, 10, 16, and 17. Dashed lines represent the 95% credible interval.

golden eagle population trends were similar for the 2 time periods of analysis, so these findings were not an artifact of the relatively imprecise estimates over the early years of the BBS.

The level of imprecision and scale of our estimates certainly leaves room for the local declines described by Kochert and Steenhof (2002), and point estimates of trend for BCRs 15, 16, and 34 were <0 in our analysis. However, point estimates of trend from our analysis were above 0 for BCRs 5, 9, 10, 11, 17, and 18. Thus, although our results overall suggest golden eagle populations are and have been stable for the past 43 years in the western United States, the direction of golden eagle population change may differ at the BCR level. In addition, the amount of annual change estimated in some BCRs is greater than what might be expected from mortality and fecundity alone. This suggests that other factors, such as geographic shifts in the summer distribution of golden eagles from southern to northern BCRs among years, may be contributing to the population change estimates at the BCR level.

Our composite estimates for BCRs 9, 10, 16, and 17, both in terms of golden eagle population trends and size, compare favorably with prior distance sampling analyses of the WGES data (Nielson et al. 2012). We note that our estimates were slightly greater than those based on distance sampling alone because of transformation to the log scale and the addition of variance components for calculating derived parameters for our log-linear model, the inclusion of a sample unit random effect in our repeated measures analysis, and the slightly larger expansion areas used in our analysis. However, credible intervals for the 2 approaches greatly overlapped and inferences were consistent.

Our inferences regarding trend in all cases are based on BCR-specific information. The scaling factor, which we derived from the overlap BCRs only, merely scaled results from 1 survey to the other and had no affect on the trend

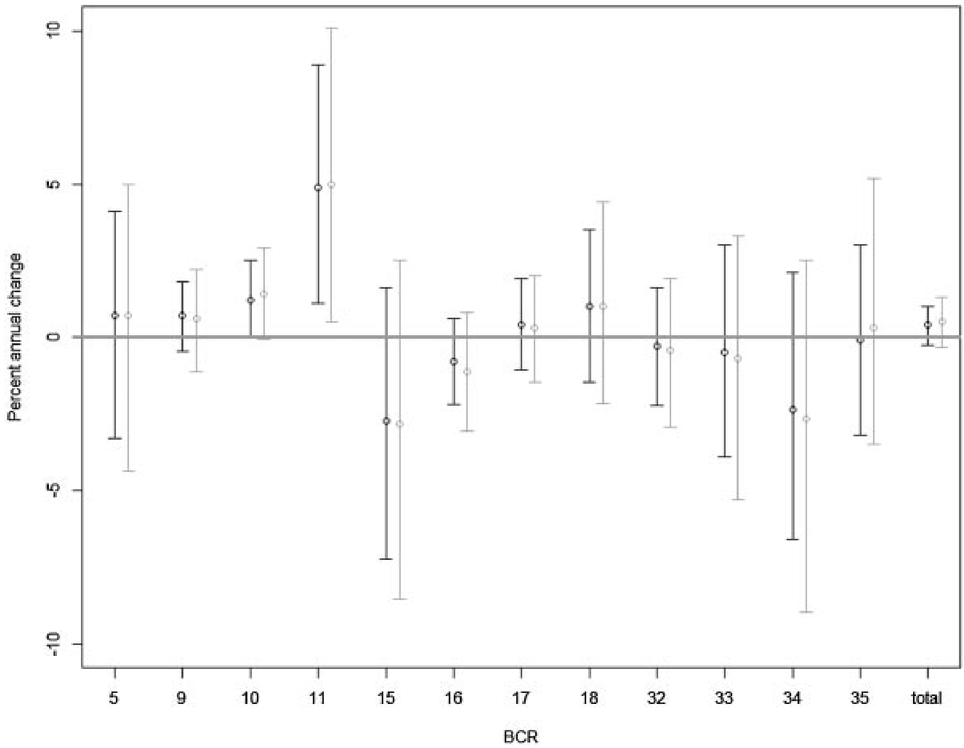

Figure 5. Trend estimates by Bird Conservation Region (BCR) and total survey area for golden eagles based on Breeding Bird Survey indices (BCRs 5, 11, 15, 18, 32, 33, 34, and 35) and integrated population estimates (BCRs 9, 10, 16, and 17). The black lines represent trends for the 1968–2010 period and the gray lines represent the trend from 1990 to 2010. Error bars represent 95% credible intervals.

estimate. Scaling permitted the conversion of golden eagles observed per BBS route to golden eagles per km^2, and controlled for population differences due to timing of surveys (i.e., the BBS survey was largely a pre-fledging survey whereas the WGES was a post-fledging survey). Inclusion of the BBS data allowed us to extend the time series trend beyond the years of the WGES in the overlap BCRs and make predictions about population size in BCRs outside of

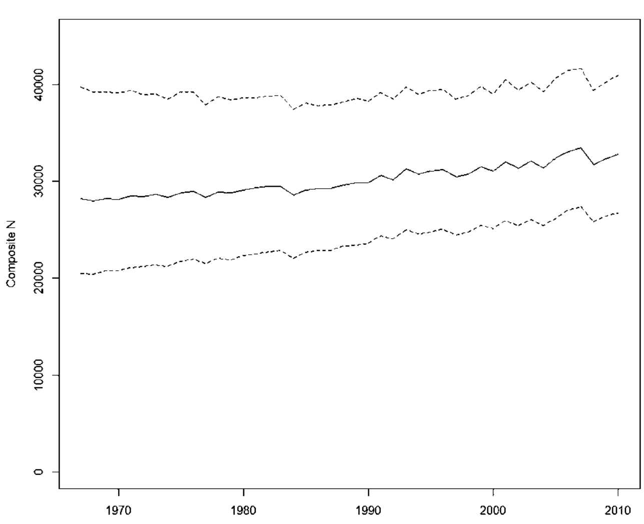

Figure 6. Trend in golden eagle population estimates for all western United States Bird Conservation Regions (BCRs) combined, 1968–2010. Estimates for all BCRs from 1968 to 2005 are from the Breeding Bird Survey (BBS), as are estimates for all BCRs but 9, 10, 16, and 17 from 2006 to 2010. Estimates for BCRs 9, 10, 16, and 17 for 2006–2010 are composite estimates using both BBS and western United States summer golden eagle survey data. The middle line is the median, and upper and lower dotted lines represent the 95% credible intervals.

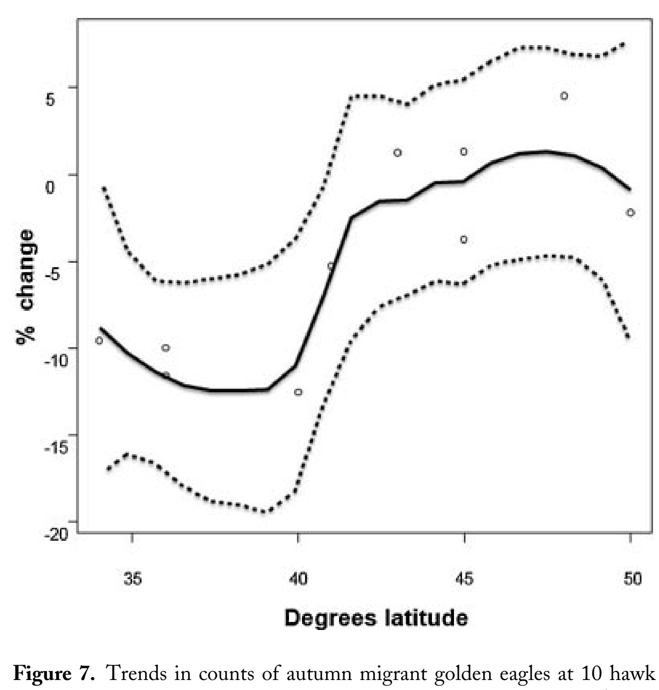

Figure 7. Trends in counts of autumn migrant golden eagles at 10 hawk watch sites in the western United States, as reported in Smith et al. (2008; Table 3). Periods of observation vary by site, but range from 1985 to 2005. The middle line is the mean, and the upper and lower dotted lines represent the 95% confidence intervals reported in Smith et al. (2008).

the overlap area. We have advanced our understanding of golden eagle populations in these BCRs, and implemented a method for incorporating detection rates into the Sauer and Link (2011) hierarchical model. The close correspondence in direction and magnitude between BBS and WGES trends in BCRs 9, 10, 16, and to a lesser degree, 17, for the overlap years of 2006–2010 suggest the BBS may provide more useful information on golden eagle population change than previously thought (Kochert and Steenhof 2002). This also lends support for our use of BBS data to provisionally estimate golden eagle trends in other BCRs in the western United States.

Smith et al. (2008) and Farmer et al. (2008) reviewed migration count data from autumn hawk watch sites in western North America, and reported negative count trends over the most recent decade at many count sites and concluded migratory golden eagle populations in western North America were undergoing recent declines. Our reassessment of their results suggests a latitudinal pattern may exist in the trends in counts of autumn migrant golden eagles in western North America. Such a pattern implies that factors other than, or in addition to, population change may be operating to affect autumn counts of migrant golden eagles. We hypothesize that this pattern may be a consequence of changes in migratory behavior that result in fewer golden eagles arriving at southern hawk watch sites during the time those sites are operating. This could occur if fewer golden eagles left northern breeding areas, if they migrated shorter distances, or if migration were delayed in time, such as has been reported for the sharp-shinned hawk (*Accipiter striatus*; Rosenfield et al. 2011) and other raptors in eastern North America (Buskirk 2012). This hypothesis should be explored further with full data from these hawk watch sites. Counts of migrant golden eagles also represent a larger area than is covered by the WGES or our BBS samples (e.g., golden eagles from breeding areas across all of Canada and Alaska), and population trends in the portion of the migrant population not included in our analyses were possibly different from those of golden eagles summering in the western United States.

Historically, the golden eagle population in the conterminous United States was estimated at between 10,000 and 100,000 individuals (Hamerstrom et al. 1975), but this estimate was not based on actual surveys. Rich et al. (2004) estimated about 30,000 golden eagles occurred in parts of the United States and Canada sampled by BBS routes. Good et al. (2007) estimated 27,392 golden eagles (90% CI: 21,352–35,140) occurred in the WGES area in 2003. Nielson et al. (2012) updated the estimate of Good et al. (2007) for the WGES area for the years 2006–2010; annual estimates of total population size ranged from a low of 19,286 (90% CI: 15,802–23,349) in 2008 to a high of 24,933 (90% CI: 20,296–30,664) in 2007. The Service adopted an estimate of 30,193 golden eagles in the conterminous western United States in its final environmental assessment addressing unintentional take regulations under the Bald and Golden Eagle Protection Act; this estimate was derived from a combination of the WGES results through 2008 for BCRs 9, 10, 16, and 17, and estimates in Rich et al. (2004) for the other western BCRs (U.S. Fish and Wildlife Service 2009). Our population estimates from the composite model for the overlap BCRs for 2006–2010 range from a low of 26,490 (95% CI: 21,760–32,680) in 2008 to a high of 28,220 (95% CI: 23,250–35,110) in 2007, slightly greater than the estimates of Nielson et al. (2012). Our overall golden eagle population estimates for the western United States must be regarded cautiously in light of the underlying assumptions. However, our annual estimates since 2001 (31,370 [95% CI: 25,450–39,310] in 2004 to 33,460 [95% CI: 27,380–41,710] in 2007) compare favorably with the Service's 2009 estimate (U. S. Fish and Wildlife Service 2009) and the Partner's In Flight estimate, though the latter included parts of Canada not covered by our estimate (Rich et al. 2004), and our estimate excludes 6.03% of the area in the western United States.

Two issues with our approach warrant further discussion. First, for the years and BCRs where we had both BBS and WGES data, we were able to directly calculate scaling factors to scale the BBS data to estimate golden eagle density. Factors accounted for by the adjustment in these BCRs and years included 1) differences in units between the BBS and WGES due to a lack of detection probability and lack of a well-defined sampling area associated with BBS counts, 2) possible bias in the BBS estimates given the counts are conducted from roads, 3) addition of fledged young to and mortality of breeding birds from the golden eagle population of each BCR between the time of the BBS and WGES, and 4) immigration and emigration of birds between the 2 surveys. As noted previously, we considered omitting juvenile golden eagles counted on the WGES from the composite estimates, and then estimating trends and density of juveniles separately. However, we were uncertain how to treat unknown-age golden eagles seen on the WGES under that approach. In some years and in some BCRs the number of unknown-aged eagles was at the same level as the number of juveniles; therefore, the treatment of unknowns had influential consequences on estimates of juvenile population size and trend. After comparing various approaches, we decided that pooling age classes and thus incorporating the correction for the addition of juveniles to the population between the BBS and WGES into the scaling factor was the most defensible method.

The second issue involves application of the scaling factor used to scale the BBS counts to golden eagle density. The overall scaling factor was similar for BCRs 9, 10, and 16, but about 3 times greater in BCR 17. We are uncertain why BCR 17 was different, but this demonstrates that the adjustment can vary considerably among BCRs. However, the overall scaling factor reflects the differences among groups, as it has a large credible interval that overlaps the credible intervals of all the BCR estimates except BCR 9. The overall scaling factor allows us to scale BBS data for non-overlap years and BCRs to an abundance estimate, and that abundance estimate reflects the uncertainty in the scaling factor. Even though uncertainty reflected in the composite estimate reduces the precision, the population size estimates we calculated are based on survey data and have direct management relevance, as estimates of population size are essential for the Service's permitting of eagle take. The golden eagle population size estimates currently being used by the Service for the non-overlap BCRs are based on outdated estimates from biological data for which measures of uncertainty are lacking (Rich et al. 2004, U.S. Fish and Wildlife Service 2009). Accordingly, comparative population estimates using current data, for which explicit assumptions can be described, and which are amenable to testing are desirable for the non-overlap BCRs.

A fundamental assumption underlying our population estimates for the 8 non-overlap BCRs is that the overall adjustment factor for BCRs 9, 10, 16, and 17 is relevant for these BCRs and years. This assumption could be tested by independent surveys in these BCRs and generating additional BCR-specific adjustment factors for comparison. In the meantime, considering the variation in adjustment factors we found for the 4 overlap BCRs, the population estimates presented here for the non-overlap BCRs should be regarded cautiously and with due consideration of the wide confidence intervals surrounding the annual estimates and range in the adjustment factors for the 4 overlap BCRs. Improving population estimates for non-overlap BCRs may also be possible by using information presented in our supplemental tables in conjunction with other information (e.g., BCR-specific landscape-scale habitat information) to better match scaling factors for non-overlap BCRs to the most similar overlap BCR.

Hierarchical models provide a very general framework for modeling survey data, and we chose to use models that conformed as close as possible to present BBS analyses (Sauer and Link 2011) but used the information and results from analysis of WGES data (Nielson et al. 2012). During the development of the model, we considered alternative forms to assess whether we could improve performance. Alternatives we evaluated included approaches where we modeled the trend with a common linear regression or a common random walk (Durbin and Koopman 2001) for both surveys, estimated a single trend with random effects for perched and flying birds, and included a BCR-transect-year random effect and estimated BCR-specific variances. These alternative models resulted in only minor changes to our results and did not influence inferences from our study.

MANAGEMENT IMPLICATIONS

Our findings have potential implications for the issuance of golden eagle take permits under the Act by the Service. In 2009, the Service concluded that golden eagle populations might be declining and were not robust enough to support additional permitted take. Consequently, the Service severely restricted availability of such permits. Our results clarify that golden eagles are not declining, at least widely and at the present time, in the western United States, though we acknowledge occupied breeding areas may be declining locally or regionally as described by Kochert and Steenhof (2002). However, our findings do not address the question of whether golden eagles have the demographic resiliency to absorb additional mortality and maintain their stable population trajectory. Additional demographic research and modeling is needed to address this question. Our results also show promise relative to use of a combination of BBS and aerial surveys in generating credible population size estimates for golden eagles on a landscape scale. Population size estimates and an understanding of the uncertainty in those estimates are necessary to assess the population-level significance of any authorized take of golden eagles. An important next step is to conduct WGES-like aerial counts in 1 or more of the non-overlap BCRs to develop additional BCR-specific adjustment factors for comparison with those presented here for BCRs 9, 10, 16, and 17. Such an analysis would help clarify the applicability of an overall adjustment factor for BBS counts in other BCRs, and provide information useful in deciding whether aerial surveys comparable to the WGES are necessary in every BCR for which population estimates are needed.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Table S1. WinBUGS code used to integrate information from the Breeding Bird Survey (BBS) and western United States summer golden eagle survey (WGES).

Table S2. Number of golden eagles counted on Breeding Bird Survey (BBS) routes by Bird Conservation Region (BCR) from 1968 to 2010. Data from Canadian potions of BCRs that extend into Canada are excluded.

Table S3. Numbers of Breeding Bird Survey (BBS) routes for Bird Conservation Regions (BCRs) used in this analysis that have been surveyed from 1968 to current. Counts in Canadian portions of BCRs that extend into Canada are omitted.

Table S4. Golden eagle population estimates for all western United States Bird Conservation Regions (BCRs), 1967–2010. For the overlap BCRs (9, 10, 16, and 17) and years (2006–2010) the estimates are composites derived from the BBS and WGES. For other BCRs and years, estimates are derived from the BBS only, using the overall adjustment factor derived for the composite estimates to scale to density.