BioOne COMPLETE

Population Size of Snowy Plovers Breeding in North America

Authors: Thomas, Susan M., Lyons, James E., Andres, Brad A., T-Smith, Elise Elliot, Palacios, Eduardo, et al.

Source: Waterbirds, 35(1) : 1-14

Published By: The Waterbird Society

URL: https://doi.org/10.1675/063.035.0101

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

WATERBIRDS

JOURNAL OF THE WATERBIRD SOCIETY

VOL. 35, NO. 1 | 2012 | PAGES 1-184

Population Size of Snowy Plovers Breeding in North America

SUSAN M. THOMAS[1,12], JAMES E. LYONS[2], BRAD A. ANDRES[3,*], ELISE ELLIOTT-SMITH[4], EDUARDO PALACIOS[5], JOHN F. CAVITT[6], J. ANDREW ROYLE[7], SUZANNE D. FELLOWS[8], KENDRA MATY[1], WILLIAM H. HOWE[9], ERIC MELLINK[10], STEFANI MELVIN[11,13] AND TARA ZIMMERMAN[1,14]

[1]U.S. Fish and Wildlife Service, Division of Migratory Birds and Habitat Programs, 911 NE 11th Avenue, Portland, OR, 97232, USA

[2]U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Patuxent Wildlife Research Center, 11510 American Holly Drive, Laurel, MD, 20708, USA

[3]U.S. Fish and Wildlife Service, Division of Migratory Bird Management, PO Box 25486, DFC, Denver, CO, 80225, USA

[4]U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 3200 SW Jefferson Way, Corvallis, OR, 97331, USA

[5]Departamento de Biología de la Conservación. Centro de Investigación Científica y de Educación Superior de Ensenada, B.C. (Unidad La Paz), Miraflores # 334, Fracc. Bella Vista, La Paz, Baja California Sur, 23050, México

[6]Department of Zoology, Weber State University, 2505 University Circle, Ogden, UT, 84408-2505, USA

[7]U.S. Geological Survey, Patuxent Wildlife Research Center, 12100 Beech Forest Road, Laurel, MD, 20708, USA

[8]U.S. Fish and Wildlife Service, Region 6 Migratory Bird Management Program, P.O. Box 25486, DFC, Denver, CO, 80225, USA

[9]U.S. Fish and Wildlife Service, Region 2 Nongame Migratory Bird Program,Albuquerque, NM, 87103, USA

[10]Departamento de Biología de la Conservación, Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California, Carretera Tijuana-Ensenada 3918, 22860 Ensenada, BC, México

[11]U.S. Fish and Wildlife Service, Migratory Bird Office, 1875 Century Blvd., Suite 420, Atlanta, GA, 30345, USA

[12]Current Address: Washington Maritime National Wildlife Refuge, 715 Holgerson Road, Sequim, WA, 98368, USA

[13]Current Address: Salmon-Challis National Forest, 1206 S. Challis St., Salmon, ID, 83467, USA

[14]Current Address: Kinglet Consulting, 36803 SE 25th St., Washougal, WA, 98671, USA

*Corresponding author; E-mail: brad_andres@fws.gov

Abstract.—Snowy Plovers (*Charadrius nivosus*) may be one of the rarest shorebirds in North America yet a comprehensive assessment of their abundance and distribution has not been completed. During 2007 and 2008, 557 discrete wetlands were surveyed and nine additional large wetland complexes sampled in México and the USA. From these surveys, a population of 23,555 (95% CI = 17,299 - 29,859) breeding Snowy Plovers was estimated. Combining the estimate with information from areas not surveyed, the total North American population was assessed at 25,869 (95% CI = 18,917 - 32,173). Approximately 42% of all breeding Snowy Plovers in North America resided at two sites (Great Salt Lake, Utah, and Salt Plains National Wildlife Refuge, Oklahoma), and 33% of all these were on wetlands in the Great Basin (including Great Salt Lake). Also, coastal habitats in central and southern Texas supported large numbers of breeding plovers. New breeding sites were discovered in interior deserts and highlands and along the Pacific coast of México; approximately 9% of the North American breeding population occurred in México. Because of uncertainties about effects of climate change and current stresses to breeding habitats, the spe-

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

cies should be a management and conservation priority. Periodic monitoring should be undertaken at important sites to ensure high quality habitat is available to support the Snowy Plover population. *Received 22 July 2011, accepted 18 October 2011.*

Key words.—breeding, *Charadrius nivosus*, North America, population, Snowy Plover, survey.

Waterbirds 35(1): 1-14, 2012

The Snowy Plover (*Charadrius nivosus*) is one of the least numerous shorebirds in North America (Morrison *et al.* 2006). The species is found along the Pacific coasts of México, the USA and southern Canada, along the Gulf of México coast, and in the deserts, plains and highlands of the western and central USA and central México (Gorman and Haig 2002; Shuford *et al.* 2008; Page *et al.* 2009). Wherever they occur, Snowy Plovers most often use unvegetated shorelines of brackish or saline waters throughout their annual cycle (Page *et al.* 2009). Despite a broad but discontinuous distribution of Snowy Plovers in North America (*C. nivosus nivosus*; Funk *et al.* 2007; Küpper *et al.* 2009), their dependence on shorelines have made them vulnerable to negative effects of habitat loss or degradation and increased human disturbance (Page *et al.* 2009). Suspected population declines, small population size, negative effects of invasive plant species and predators, and conflicts with human development and recreation have all contributed to an elevated conservation status for the species (Page *et al.* 2009). The USA Pacific coast population is listed as a threatened Distinct Population Segment under the Endangered Species Act (U.S. Fish and Wildlife Service 1988), and remaining geographic populations are considered conservation priorities in the U.S. Shorebird Conservation Plan (2004), the U.S. Fish and Wildlife Service's (2008a) Birds of Conservation Concern, and appropriate State Wildlife Action Plans. Recently, the Snowy Plover was designated as a threatened species in México (Secretaría de Medio Ambiente y Recursos Naturales 2010).

Despite high conservation concern for Snowy Plovers and pervasive threats to their habitats, a comprehensive assessment of abundance and distribution in North America has not been completed. Assessing the population status of the Snowy Plover is required for: 1) determining and implementing management actions tailored to regional conservation needs for the species; 2) providing a reliable North American context to determine the vulnerability of the Pacific coast population; and 3) evaluating, at a population level, the results of any conservation actions that are undertaken for the species. Past efforts to assess population status of North American Snowy Plovers have either not considered the full range of the species or have integrated information across a broad time period (Page *et al.* 1991; Gorman and Haig 2002; U.S. Fish and Wildlife Service 2006; Page *et al.* 2009). Recent attempts to summarize population status of Snowy Plovers (Morrison *et al.* 2006) acknowledge that estimates have a high degree of uncertainty and are thought to be only within 50% of the suggested value. Therefore, we designed and implemented a series of regional surveys and used existing, concurrent monitoring information to index the population size of Snowy Plovers in North America.

METHODS

General Sampling Approach

Known and potential breeding sites of Snowy Plovers were identified by searching literature, electronic databases and historical records; reviewing topographic, satellite image and hydrographic maps; and inquiring with local biologists across the plovers' breeding range (Koopman *et al.* 2006). From this extensive review, survey sites were identified along the Pacific coast of the Baja California peninsula and mainland México, along the Gulf of México coast and in the following Bird Conservation Regions (BCR): Coastal California's Central Valley, Colorado Plateau, Great Basin, Shortgrass/Mixed-grass Prairies, Sonoran and Mojave Deserts, Chihuahuan Desert, Gulf Coastal Prairie, Tamaulipan Brushlands, Mexican Altiplano and Mexican Transverse Volcanic Belt (see http://www.nabci-us.org/map.html for a map and definitions). Suitable habitat in the interior of western North America was defined as the shorelines and flats of (predominantly) alkali playas, lakes, ponds, seeps, reservoirs and braided river channels. Sandy shorelines, barrier beaches, salt flats and saltworks along the Gulf of México and the Pacific coast of México were also defined as suitable habitat. For most sites, suitable habitat was delineated on a map prior to field surveys. At the time of the survey, field observers determined that many

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

of the potential sites on the USA list, mainly in the Colorado Plateau, Great Basin and Shortgrass/Mixed-grass Prairies, were unsuitable for breeding ($n = 102$), primarily due to dry conditions, filled basins or excessive human disturbance. Unsuitable sites were not used in the analysis. All site descriptions and delineation of suitable habitat are archived with the U.S. Fish and Wildlife Service, Division of Migratory Birds and Habitat Programs, Portland, Oregon.

We developed a dual strategy to 1) survey all available habitat at the small, discrete wetlands and defined beach segments that could generally be surveyed within ≤ 1 day (hereafter "list sites") and 2) sample large wetland complexes (hereafter "spatial sampling sites") using finite population sampling methods (Thompson 2002). Spatial sampling sites were characterized by extensive areas of suitable habitat that would be difficult to survey completely in a reasonable amount of time (to minimize under-counting and double-counting due to bird movement within the site). The strategy is similar to the dual frame approach of Haines and Pollock (1998) and has been used to assess other shorebird populations (Brown *et al.* 2005; Andres *et al.* 2009).

Our general approach at spatial sampling sites required several steps. Together with local area experts, we first delineated suitable habitat at each site that was to be randomly sampled rather than searched completely. We then used a geographic information system to superimpose a regular grid on all suitable habitat and asked local area experts to stratify each grid cell according to expected plover abundance (i.e. the probability of encountering plovers). We used two or three levels of expected plover abundance (strata) depending on prior survey information available for each site and expert opinion on habitat heterogeneity. Because of the dynamic nature of habitat quality and water levels, there was often uncertainty about stratum assignments for some cells at each site. Nevertheless, the mean numbers of birds per cell was greatest in high density stratum, and smallest in low density stratum, at all sites. Grid size at most sites was 300 m on a side, resulting in 9-ha cells (plots) that could be quickly and thoroughly searched by two observers. When the entire grid at a site had been stratified, we made a random selection of grid cells from each stratum; allocation of survey effort among strata (number of cells chosen from each) was designed to place more effort where plovers were expected and reduce time in areas that we expected to have a small number of plovers (e.g. allocation 70:20:10 for high, medium, and low strata). Because we had no information on count means and variances from plots at any of the sites, it was not possible to design an optimal allocation of effort (for minimum variance of estimates). Observers then visited each randomly selected plot and made a complete count of birds found in the plot (see specific methods for each site or region below). From the plot counts, we used standard stratified random sampling estimators to derive a population total and variance for each site (Thompson 2002:119). We created a 95% confidence interval for the population total at each site (τ) using $\hat{\tau} + 1.96\sqrt{\hat{\text{var}}(\hat{\tau})}$ (Thompson 2002).

Surveys at list sites and spatial sampling sites were conducted when most individuals were nesting so that movement of birds between sites was minimal (within a three- to six-week period). Surveys occurred generally between 1 April and 30 June and varied with nesting chronology among geographic regions (U.S. Fish and Wildlife Service 2009). Surveys in the southern part of the Snowy Plover's range began in early April, whereas surveys in the most northern portions did not commence until late May. Surveys were generally conducted during the morning or early evening to maximize visibility by reducing glare and heat waves and were not made on days of excessive rain, fog or wind (>25 km/h). Although most surveys were accomplished on foot, motorized vehicles (all-terrain vehicles [ATVs], boats, trucks) were used in some regions and/or at some large sites.

Under the assumption that our list sites and spatial sampling sites represent independent sampling frames, we estimated overall Snowy Plover population size by aggregating regional totals. Regional totals (e.g. Great Basin BCR) were derived in two steps. First, we summed population totals and variances across sites and used methods described above to estimate a 95% confidence interval for spatial sampling sites aggregated by region. Second, totals and 95% credible intervals for list sites were derived directly from the Markov chain Monte Carlo simulations of the N-mixture model (see below). To derive overall regional totals and 95% confidence intervals, we summed regional totals and confidence limits for both spatial sampling and list sites.

To provide the most comprehensive assessment of the current population size of North American Snowy Plovers, we also included information on Snowy Plover abundance from the periodic USA Pacific coast surveys and published accounts and personal communications on presence of plovers in areas not surveyed by us during 2007 or 2008.

Detection Rates

Snowy Plovers are small cryptic birds and difficult to detect in many survey situations. Nevertheless, sample units (i.e. plots) at our spatial sampling sites were small enough to assume that all birds present on the sample unit were detected, so it was not necessary to adjust plot counts for imperfect detection. However, at list sites where we searched the entire site as opposed to searching small sample units, it was unlikely that all birds were detected because observers could easily overlook birds ("perception bias"), and resident birds may not be present at the time of the survey ("temporary emigration"). To correct counts from list sites for bias resulting from imperfect detection, we used repeated counts and N-mixture models (Royle 2004). N-mixture models require that sites are visited on multiple occasions, and that the local population at each site is closed during the time of the repeated counts (no immigration, emigration, deaths, or births not distinguishable from adults). Repeated counts (c) were modeled as a binomial random variable

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

$$c_{i,t} \sim Bin(N_t \cdot p_{i,t})$$

where N_i are the unobserved, site-specific population sizes and $p_{i,t}$ is the proportion detected at site i on visit t. Site-specific abundances were modeled as a zero-inflated Poisson random variable to accommodate the large number of zeros in the dataset (Kéry *et al.* 2005; Royle *et al.* 2005):

$N_i \sim Posisson\ (\lambda)$ *with Probabiltiy* ψ
$N_t = 0$ *with probability* $(1 - \psi)$.

With the N-mixture model, it is straightforward to model detection (p) as a function of covariates thought to influence detection probability using the logit link function (Royle 2004; Kéry 2008). We fit six *a priori* models of detection and used a model selection criterion (Deviance Information Criterion; Spiegelhalter *et al.* 2002) to identify the model with the most support in the data. One model evaluated detection as a function of site, year, and the interaction of site and year (Site + Year + Site × Year). Four models were used to evaluate detection as a function of survey duration (person-hours) and site area (ha): survey duration alone, site area alone, an additive model for duration and area, and an interaction model for duration and area (with main effects). Finally, we also included a null model without any covariates (intercept only). We conducted a Bayesian analysis of the N-mixture model using WinBUGS software (Spiegelhalter *et al.* 2003). We used uninformative priors for all parameters and assessed convergence with the Gelman-Rubin Statistic (Brooks and Gelman 1998). We used the top model in the model selection procedure to make inference about detection and abundance at list sites. We used the median of the posterior distribution for total abundance (i.e. sum of site-specific abundance estimates [*Ni*]) to describe overall abundance at list sites. We used the 2.5th and 97.5th percentiles of the posterior distribution as a 95% credible interval.

We estimated detection rates for 130 list sites in 2007 and 2008. Sites were distributed among BCRs as follows: Great Basin (N = 47 sites), Shortgrass/Mixed-grass Prairies (N = 43), Colorado Plateau (N = 7), Central Valley of California (N = 11), Sonoran and Mojave and Chihuahuan Deserts (N = 17), and Gulf Coastal Prairie and Tamaulipan Brushlands (N = 5 sites). Repeated counts were conducted at 60 of these sites using the same technique and number of observers as initial counts. The period between repeated counts averaged 4.7 days (SD = 6.5 days) among sites. At 92% of sites, repeated counts were conducted within 14 days after the initial count (range = 0-31 days). With such a short amount of time between repeated counts at most sites, it is reasonable to assume closure for local populations under the N-mixture model.

Because we were unsuccessful in implementing a double-observer method (Nichols *et al.* 2000) to estimate detectability in Florida, count totals from each of the two observers at each site were treated as repeated counts and analyzed using N-mixture models described above (Riddle *et al.* 2010). In our analysis of repeated counts from Florida sites, we modeled detection rate as a function of survey type (ATV vs. foot).

Great Basin Surveys

All list sites in the Great Basin were surveyed in 2007. Each list site was surveyed in its entirety, at least once, by a single surveyor or team who walked parallel to the shoreline and used a binocular or spotting scope to scan for adult plovers. At each site, observers were deployed so that each observer surveyed suitable habitat, which was delineated on a field map prior to the survey, within 100 m of each side of her/him. Observers indicated the actual area sampled on the field map and proofed the delineation of suitable habitat, which was digitized after the survey was completed. If multiple observers were required, they surveyed in unison to avoid double-counting; all observers moved steadily through the area to avoid double-counting plovers. At some large or hard-to-access sites, boats and ATVs were used for surveys. Vehicles were driven slowly (≤15 km/h) through the area or along the shoreline. If suitable habitat patches were >20 m wide, observers stopped the vehicle every 100 m to scan the suitable habitat. In a few cases, multiple transects were driven to cover large areas.

Besides enumerating adults, ancillary information was collected on sex, behavior and evidence of breeding activity of plovers; breeding habitat characteristics; survey duration; and weather conditions. Observers were trained in field methods, practiced estimating distances before undertaking surveys, and were provided standard data forms and detailed field methods (U.S. Fish and Wildlife Service 2009).

For the seven spatial sampling sites within the Great Basin (Table 2), we delineated three spatial sampling strata that were based generally on the expected probability of encountering a Snowy Plover as ascertained by local experts: high (>30% chance), medium (10-29%), and low (<10%). Using a GIS, we superimposed a grid on each site and categorized grid cells as into high, medium and low strata. All spatial sampling sites in the region used a grid of 9-ha plots, with the exception of Great Salt Lake, Utah, where plot sizes (i.e. grid cells) were 100 ha. From the stratified grid, we selected a random sample at each site with an approximate allocation of 70:20:10 (high to low) among strata. Spatial sampling sites in the Great Basin were surveyed in either 2007 or 2008, although surveys were conducted in both years at the Great Salt Lake. Because of differences in sampling and improvements in stratification, we present information only from the 2008 Great Salt Lake survey.

Plots were searched systematically so that no point in the plot was ever >75 m from the observer. We assumed that observers would detect all plovers at this distance, so no adjustments for imperfect detection were necessary at spatial sampling sites. Protocols were modified to reduce observer distances in plots that had more vegetation or greater topographical relief. Ancillary information (e.g. weather, survey duration) collected at spatial sampling sites was the same as at list sites.

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Shortgrass/Mixed-grass Prairies Surveys

All list sites in the Shortgrass/Mixed-grass Prairies were surveyed in 2007, and field protocols followed those described above for list sites in the Great Basin; most sites were surveyed on foot and a few by ATV. Surveys were conducted in both 2007 and 2008 at Salt Plains National Wildlife Refuge (NWR), Oklahoma, which was the only spatial sampling site in this region. Similar to spatial sampling sites in the Great Basin, we stratified available habitat according to probability of encountering plovers, but we used only two strata (high and low) and made a random selection of 9-ha plots in each stratum at Salt Plains NWR. Because water levels varied greatly between years in this region, we present survey results only from 2007, when list sites in the region also were surveyed. Due to logistical constraints, we were unable to conduct comprehensive surveys along rivers in the southern Great Plains.

Colorado Plateau and Central Valley Surveys

Lists sites on the Colorado Plateau and the Central Valley, California, were surveyed during 2007. All list sites were surveyed on foot as described for the Great Basin. Detection rates were used to adjust counts from all list sites these regions.

Sonoran and Mojave/Chihuahuan Deserts and México Highlands Surveys

List sites in the Sonoran/Mojave and the USA portion of Chihuahuan Desert BCRs were surveyed in 2007. Detection rates were used to adjust counts from list sites in Arizona, California, Nevada and New Mexico, except for Salton Sea and Owens Lake (California). At Salton Sea and Owens Lake, observers used traditional, site-specific protocols that did not provide information on detectability, so for these two sites we present unadjusted count totals and assume these figures are minimum estimates. List sites in the Mexican Altiplano, Mexican Transverse Volcanic Belt, and Mexican portion of the Chihuahuan Desert BCR were surveyed in 2008. Most sites were searched by foot, although vehicles were occasionally used as a survey platform at a few larger sites. At the Salton Sea, surveys were made by slowly driving a boat along the shoreline. Because repeated counts were not conducted at list sites surveyed in México, we had no information on detection rate in these BCRs and therefore were not able to adjust counts for imperfect detection. We present unadjusted count totals and assume these figures are minimum estimates.

Gulf of México Surveys

List sites along the Gulf of México coastlines of Tamaulipas, Veracruz, Tabasco and Yucatán were surveyed in 2007. Sites were surveyed either by foot or slowly driving vehicles along the beach. Because repeated counts were not conducted at list sites in Tamaulipas, Veracruz, Tabasco or Yucatán, we had no information on detection rate in these Gulf of México shorelines and therefore were not able to adjust counts for imperfect detection. We present unadjusted count totals and assume these figures are minimum estimates.

From previous survey information, the Florida Gulf coastline was divided into a series of list sites that were surveyed either on foot or ATV. We were able to adjust counts for imperfect detection as described above, accounting for differences in survey type.

In Texas, we used stratified random sampling to sample coastal habitats south of Port Lavaca; coastal areas north of Port Lavaca were not sampled because prior surveys indicated few or no birds breeding in this area (Zdravkovic 2004). South of Port Lavaca, coastal areas were divided into two geographic zones: central and southern. The central zone extended from Port Lavaca south to Corpus Christi (Nueces, Aransas and Calhoun counties), whereas the southern zone extended from Corpus Christi south to the Brownsville area (Cameron, Willacy, Kenedy and Kleberg counties). Central and southern zones were further divided using three habitat classes (Gulf beach, bayside beach/island and mainland) for a total of six sampling strata. A 500-m grid, encompassing a total of 322,575 ha, was superimposed on the study area. Historical information on Snowy Plover abundance was used to allocate survey effort among the six geographic/habitat strata. From the stratified grid, a random selection of 25-ha plots (N = 600) was selected to be surveyed. Most of the sample (67%) was allocated to bayside beach habitat (46% of randomly selected cells were south zone bayside beach and 21% were central zone bayside beach). Field observers followed procedures developed for surveying spatial sampling sites in the Great Basin. As in the Great Basin, we assumed that all birds in sample units (plots) were detected, and we used unadjusted counts to estimate a population total for coastal Texas with the stratified random sample estimator (Thompson 2002: 119). We also surveyed five list sites in Texas: two on the north coast (Gulf Coastal Prairie BCR) and three at inland saline lakes in the southeast (Tamaulipan Brushlands BCR). Count data from Texas list sites were analyzed with data from 2007 list sites because methods were identical, and Texas list site totals were adjusted for imperfect detection using analysis for repeated counts described above (see Detection Rates).

México Pacific Coast Surveys

The Baja Peninsula and mainland Pacific coast of México were divided into a set of list sites that were surveyed in 2007. Environmental characteristics varied greatly among sites in the region, and surveys were therefore accomplished by foot, slowly driving a vehicle along the beach, or occasionally by boat. Because of the interest in the status of Pacific Coast Snowy Plovers, we surveyed the Baja California peninsula again in 2008; herein, we present the mean of both years' surveys. Repeated counts (within season) were not conducted at list sites surveyed in México, and totals from these sites were not adjusted for imperfect detection. Unadjusted totals are considered minimum population estimates.

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

RESULTS

Detection at List Sites

Detection was a function of survey duration (person-hours) and site area (ha). The interaction model (Hours + Area + Hours × Area) received more support than simpler models (Table 1) and was therefore used to estimate abundance at list sites in the Great Basin, Shortgrass/Mixed-grass Prairies, Colorado Plateau, Central Valley, Sonoran and Mojave/Chihuahuan Deserts, Gulf Coastal Prairie and Tamaulipan Brushlands. Detection rate increased with survey duration and was greater at larger sites (Fig. 1), which might be explained by a higher rate of temporary emigration at smaller sites. Detection rate using repeated counts was relatively high (77%). Using parameter estimates from the interaction model, the 95% CI for the probability of detection was 75-79% for a survey of average duration (6.2 person-hours) at a site of average size (226 ha). Our adjustment for imperfect detection is very close to the ratio (1.3) used to adjust Snowy Plover counts along the Pacific Coast (U.S. Fish and Wildlife Service 2008b).

In Florida, detection was higher during ATV surveys (63%, 95% CI = 57-69%) than during foot surveys (27%, 95% CI = 15-49%). During ATV surveys, two independent observers often detected similar numbers of birds, especially when the total number of birds detected at the site was small (<20 birds). Florida observers conducting surveys on foot had much lower detection than observers conducting surveys on foot at list sites in the Great Basin and Shortgrass/Mixed-grass Prairies. At several sites in Florida, one observer detected almost twice as many plovers as the second observer.

Great Basin

We surveyed 40 list sites in the Great Basin, where suitable habitat ranged from 1 to 2,415 ha among sites. We detected 631 plovers in all at list sites in the Great Basin, and from these counts our estimated total population size was 785 (95% CI = 734-836; Table 2). In addition, there were seven spatial sampling sites in the Great Basin region. We sampled five sites in Oregon and California, where sampling fractions (habitat units sampled/those available × 100) ranged from 9 to 31%. Two spatial sampling sites were in Utah: Great Salt Lake and Dugway Proving Ground. We surveyed 387 plots (100 ha each) at Great Salt Lake in 2008, which represented 10% of available habitat. We present the 2008 population estimate from Great Salt Lake because we believe improved stratification produced a more reliable estimate than in 2007. Our Dugway Proving Ground sample in 2008 included 81 plots (9 ha each), but we did not detect any plovers within sampled plots. Using the combined totals from list sites and spatial sampling sites, we estimated 8,545 Snowy Plovers (95% CI = 5,319-11,773) for Great Basin wetlands, the highest total for any region in our survey (Table 2). The seven large wetland complexes supported the majority of plovers in the Great Basin (91%). We estimated that 5,511 (95% CI = 2,391-8,631)

Table 1. Model selection results for hierarchical models of repeated counts at Snowy Plover list sites. Abundance and detection were estimated using Poisson-binomial mixture models. Each model in the table represents a hypothesis about detection rate as a function of particular covariates, including site, year, survey duration (person hours) and site area (ha). Model with lowest Deviance Information Criterion (DIC = mean deviance + pD) is the most parsimonious model for the data.

	Mean deviance	Effective no. parameters (p_D)[1]	DIC
Hours + Area + Hours × Area	1045	192	1237
Hours + area	1070	199	1269
Area	1094	197	1292
Hours	1100	219	1319
Site + Year + Site × year	1081	295	1377
Null (intercept only)	1192	221	1413

[1]p_D = Var(Deviance)/2

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

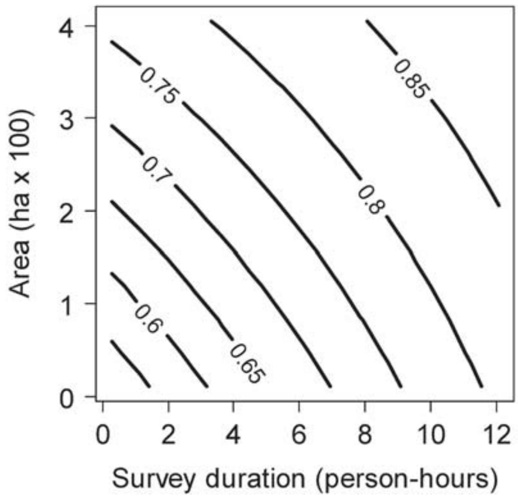

Figure 1. Probability of detecting Snowy Plovers when using area search methods at list sites. Detection rate is plotted to show the interaction of survey duration (person hours) and area being searched (ha). Contour lines indicate predicted values from the interaction model (Hours + Area + Hours × Area) in Table 1.

plovers occupied Great Salt Lake, more than any other single site in our survey.

Shortgrass/Mixed-grass Prairies

Within the Shortgrass/Mixed-grass Prairies, Snowy Plover abundance at Salt Plains NWR in 2007 (5,280 individuals, 95% CI = 3,692 - 6,868) was comparable to the Great Salt Lake, despite Salt Plains NWR having only 2% of the amount of suitable habitat available at Great Salt Lake. We used our 2007 estimate for Salt Plains NWR because we surveyed list sites in the region in 2007, which was a high water year. We sampled 11% of the suitable habitat at Salt Plains NWR. An additional 48 list sites in five states contributed another 1,644 individuals for a regional estimate of 6,924 plovers (95% CI = 5,297-8,560). Suitable habitat at list sites in the prairies ranged from 2.4 to 970 ha.

COLORADO PLATEAU AND CENTRAL VALLEY

We detected 135 birds in the Colorado Plateau (all at one site in south-central Colorado) and 102 birds at eleven sites in the Central Valley. From these counts, we estimated population totals of 147 plovers for the Colorado Plateau (95% CI = 140 - 156) and 147 plovers for the Central Valley (95% CI = 132 - 166). Suitable habitat at list sites on the Colorado Plateau ranged from 0.2 to 247 ha and 25 to 971 ha in the Central Valley.

Sonoran and Mojave/Chihuahuan Deserts

We detected 311 plovers at 17 sites in Arizona, California, Nevada and New Mexico and estimated a population total of 400 birds for these sites, which ranged in size from 2.5 to 807 ha. Surveys along the entire shoreline of the Salton Sea (approximately 150 km) yielded 306 plovers in 2007 (unadjusted count), and an entire shoreline survey of Owens Lake, California, in 2007 produced 421 plovers (unadjusted count). Snowy Plovers were much rarer at inland sites in northern and central México. Eighteen alkaline wetlands were surveyed in the Mexican portion of the Chihuahuan Desert, and 62 plovers (unadjusted count) were located at six sites in Chihuahua; no plovers were detected in Coahuila.

México Highlands

Thirty-two sites in four states were surveyed on the Mexican Altiplano, and 15 Snowy Plovers (unadjusted count) were found. Eighty-five Snowy Plovers (unadjusted count) were found at two of the 38 sites surveyed in the Mexican Central Volcanic Belt (Table 2); 77 plovers were observed at Lago Texcoco in the state of México.

Gulf of México Coast

In coastal Texas, we surveyed only 319 of 600 randomly selected plots due to logistic and time constraints. Nevertheless, we surveyed 7,975 ha (2.5%) of the 322,575 ha delineated for the sample frame along the central and south coastline of Texas. Our estimated total for coastal Texas was 3,223 plovers (95% CI = 2,039 - 4,407), 71% of the estimated total for the entire Gulf of México region. The sampling fraction was highest

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Table 2. Regional and site-based abundance estimates and 95% confidence limits/credible intervals for Snowy Plovers surveyed during the breeding seasons of 2007 and 2008. For spatial sampling sites, number of plots (sample units) is indicated in parentheses. Population estimates are for 2007 unless otherwise indicated.

	No. of surveyed sites	Population estimate	Confidence limits	
			Lower	Upper
Great Basin BCR (subtotal)	47	8,545	5,319	11,773
Spatial sampling sites (all)	7	7,760	4,585	10,937
Honey Lake, CA	(281)	226	123	330
Surprise Valley, CA	(281)	793	442	1,144
Harney Lake, OR (2008)	(119)	242	76	408
Lake Abert, OR (2008)	(58)	333	118	548
Summer Lake, OR (2008)	(123)	655	282	1,029
Great Salt Lake, UT (2008)	(387)	5,511	2,391	8,631
Dugway Proving Ground, UT (2008)	(81)	0	0	0
List sites (all)	40	785	734	836
California	7	226	183	264
Nevada	23	333	319	351
Oregon	9	117	111	126
Utah	1	109	94	127
Shortgrass/Mixed-grass Prairies BCRs (Subtotal)	43	6,924	5,297	8,560
Spatial sampling site	1	5,280	3,692	6,868
Salt Plains National Wildlife Refuge, OK	(92)	5,280	3,692	6,868
List sites (all)	42	1,644	1,605	1,692
Colorado	5	294	274	317
Kansas	12	364	352	379
Nebraska	1	0	0	0
New Mexico	9	50	40	64
Oklahoma	2	518	508	530
Texas	13	418	399	442
Coastal California/Central Valley BCRs (subtotal, all list sites)	11	147	132	166
Colorado Plateau BCR (subtotal, all list sites)	7	147	140	156
Colorado	6	147	140	155
Utah	1	0	0	1
Sonoran and Mojave/Chihuahuan Deserts BCRs (subtotal, all list sites)	37	1,189	1,166	1,216
Arizona	1	14	9	23
California	7	59	52	68
California, Owens Lake[1]	1	421	421	421
California, Salton Sea[1]	1	306	306	306
Chihuahua (2008)[1]	15	62	62	62
Coahuila (2008)[1]	3	0	0	0
Nevada	3	88	76	102
New Mexico	6	239	225	256
Mexican Altiplano BCR (subtotal, all list sites, 2008)[1]	32	15	15	15
Aguascalientes	1	0	0	0
Jalisco	8	0	0	0
Zacatecas	10	1	1	1
San Luís Potosí	13	14	14	14
Mexican Transverse Volcanic Belt BCR [1](subtotal, all list sites, 2008)[1]	38	85	85	85
México	18	77	77	77
Oaxaca	6	0	0	0
Puebla	6	8	8	8
Guerrero	5	0	0	0
Morelos	3	0	0	0

[1]Confidence limits or credible intervals are not available; unadjusted count used as upper and lower confidence limits.

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Table 2. (Continured) Regional and site-based abundance estimates and 95% confidence limits/credible intervals for Snowy Plovers surveyed during the breeding seasons of 2007 and 2008. For spatial sampling sites, number of plots (sample units) is indicated in parentheses. Population estimates are for 2007 unless otherwise indicated.

	No. of surveyed sites	Population estimate	Confidence limits	
			Lower	Upper
Gulf of México Coast (subtotal)	130	4,515	3,157	5,900
Spatial sampling	1	3,223	2,039	4,407
Central and southern Texas (2008)	(319)	3,223	2,039	4,407
List sites (all)	129	1,292	1,118	1,493
Florida (2008)	81	841	683	1,022
Texas (2008)	5	189	173	209
Tamaulipas[1]	13	82	82	82
Veracruz and Tabasco[1]	19	0	0	0
Yucatán[1]	11	180	180	180
Baja Peninsula (subtotal, all list sites, 2007-2008) 1	67	730	730	730
Baja California Pacific Coast	14	326	326	326
Baja California Sur Pacific Coast	52	387	387	387
Bahía La Paz	1	17	17	17
Mainland México, Gulf of California and Pacific Coast (subtotal, list sites)[1]	154	1,258	1,258	1,258
Sonora	26	458	458	458
Sinaloa	47	645	645	645
Nayarit	5	8	8	8
Jalisco	21	63	63	63
Colima	6	31	31	31
Michoacán	6	1	1	1
Guerrero	19	15	15	15
Oaxaca	9	23	23	23
Chiapas	15	14	14	14
All Regions (Total)	566	23,555	17,299	29,859

[1]Confidence limits or credible intervals are not available; unadjusted count used as upper and lower confidence limits.

for Gulf beaches in the south zone (12.4% of delineated habitat) and lowest for mainland habitat in the central zone (1%). The bay-side beaches in the south zone had the highest density of Snowy Plovers (0.03 birds/ha) of the six geographic-habitat strata surveyed.

Fewer plovers were found at the five list sites in northern and southeast Texas and 13 sites in Tamaulipas (Table 2); all observations in Tamaulipas came from Laguna Madre. No Snowy Plovers were observed at the 19 sites surveyed in Veracruz and Tabasco. On the Yucatán peninsula, surveys were conducted in Yucatán but were not conducted in Quintana Roo or Campeche. Yucatán had 180 Snowy Plovers (unadjusted count) at eleven sites; plovers were detected at small salt ponds along the northern (81%) and northwestern (19%) coast of the state.

In Florida, we estimated 841 Snowy Plovers from observations made at 81 sites; >80% of the birds occurred along beaches in the northwestern part of the state.

México Pacific Coast

On the west coast of México, Snowy Plovers were most abundant along the Pacific coast of the Baja California peninsula (713 birds at 66 sites, unadjusted count) and the Sonoran and Sinaloan shorelines of the Gulf of California (Table 2). Counts from these four northwestern states represented 76% of all Snowy Plovers recorded in México (a total of 2,412 breeding-season individuals). Plovers were much less abundant south of Sinaloa (8% of the Mexican Pacific coast total), but individuals were recorded at sites in every state south to the Chiapas-Guatemala border (Table 2).

All Regions

For all areas surveyed in 2007 and 2008 (557 list sites, eight spatial sampling sites, and coastal Texas), we estimated a total breeding population of 23,555 Snowy Plovers (95% CI

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

= 17,299 - 29,859). When other sources of information from the same time period are included, we suggest a total North American population of 25,869 Snowy Plovers (95% CI = 18,917 - 32,173; Table 3). If we assumed a similar imperfect detection rate at list sites where detection rates were not estimated, the North American population of Snowy Plovers may be close to 27,000 individuals.

Based on our composite estimate of 25,869 individuals, 42% of all North American Snowy Plovers resided at just two sites—the Great Salt Lake and Salt Plains NWR. Important sites for breeding Snowy Plovers (≥1% of the total population, ≈ 250 individuals) included San Quintin Bay, Baja California; the Colorado River Delta, Sonora; San Ignacio Lagoon, Baja California Sur; Ceuta Bay, Sinaloa; Quivira NWR, Kansas; Salton Sea, California; Owens Lake, California; and Cargill Salt Flat, Oklahoma. All of the five spatial sampling sites in the western Great Basin (Honey Lake and Surprise Valley, California; and Harney Lake, Summer Lake, and Lake Abert, Oregon) supported, or nearly supported, ≥1% of the total population. Coastal habitats in central and South Texas supported 12% of the total North American population of Snowy Plovers (Table 2).

DISCUSSION

Our point estimate of the total population size of North American Snowy Plovers exceeds previously published estimates of 18,500 individuals by about 40% (Morrison *et al.* 2006; Page *et al.* 2009). Because spatial coverage was limited in past assessments and imperfect detection was not accounted for in most areas, we suspect previously published estimates were likely population minima, and our estimate does not reflect an increase in the population. Our survey provides an index to the North American Snowy Plover population and resulted in a continental assessment made in a relatively short amount of time. We documented apparent declines and shifts in distribution, new breeding locations in México, and contemporary breeding sites in the USA.

Despite variations in methods among prior population assessments and our study, there were some apparent differences in current and past population estimates for particular sites and regions: similar numbers at the Great Salt Lake, but a decrease of 1,500 plovers at other sites in the Great Basin; a halving of the population residing on the Baja California peninsula; an

Table 3. Total population size of North American Snowy Plovers, 2007-2008.

Region	Total number	Confidence Limits	
		Lower	Upper
Interior USA and México			
This study	16,905	12,002	21,805
South Dakota, North Dakota, and Saskatchewan[1,2]	31	31	31
Gulf of México Coast (USA and México)			
This study	4,515	3,157	5,900
Mississippi and Alabama[2,3]	68	68	68
Pacific Coast			
Washington to California[4,5]	2,001	1,539	2,001
Baja Peninsula (this study)[4,5]	927	713	927
Central Valley (this study)	147	132	166
Bahia La Paz (this study)[2]	17	17	17
Sonora to Chiapas (this study)[2]	1,258	1,258	1,258
All regions	25,869	18,917	32,173

[1]Martin 2007; S. Westworth, personal communication.
[2]Confidence limits not available; unadjusted count used as lower and upper confidence limit.
[3]Zdravkovic 2008; M. Zdravkovic, personal communication.
[4]Listed population, U.S. Fish and Wildlife Service 2008b.
[5]Counts are multiplied by 1.3 to get total population size and upper confidence limit per current practice for the U.S. listed population. The lower confidence limit is the unadjusted count.

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

increase of 1,100 individuals on the mainland México Pacific coast and interior México (largely unsurveyed in the past); and large increases for the Shortgrass/Mixed-grass Prairies (5,000 individuals) and the southern Texas coast (2,200 plovers).

Distribution of breeding Snowy Plovers generally follows previously reported range maps (Gorman and Haig 2002; Page *et al.* 2009), and many of the important sites reported previously for the Shortgrass/Mixed-grass Prairies supported substantial numbers of breeding Snowy Plovers during our survey. However, our plover estimates for Salt Plains NWR were 250% greater than the number previously suspected. Our estimate for the Great Salt Lake, long known for large numbers of breeding Snowy Plovers, was about 30% higher than the previously reported estimate (see Morrison *et al.* 2006). Our estimate of Snowy Plovers at 26 sites in Nevada was about 50% lower than raw counts reported from twelve western Nevada sites in 1980 (Herman *et al.* 1988); however, this area experienced a low water year during our survey.

One of the strengths of our study was that we were able to conduct the survey during a narrow time period, thereby minimizing shifts among sites due to variation in annual weather patterns and water levels. In 2007, high water levels in the Great Plains likely made many small wetlands unsuitable to plovers and concentrated breeding birds at larger, often managed, sites, which may have reduced the number of birds in areas we did not sample. The appearance of Snowy Plovers north of their "normal" range provides some evidence of unsuitable habitat conditions in the southern central plains (Martin 2007). More Snowy Plovers may also occur along rivers of the southern Great Plains, but high water may have prevented their use in 2007. Because of the ephemeral and variable nature of their habitat, Snowy Plovers may be more transitory in interior North America than along the coast. Assessing the annual variation in plover use between riverine and lacustrine habitats in the southern Great Plains and understanding the scale of annual movements among interior sites would be useful for determining potential metapopulation dynamics and making conservation and management decisions.

Prior knowledge of variability in counts among sample units is critical for optimally allocating a stratified sample and for making precise inferences about the entire sampling frame. In designing this study, we had virtually no quantitative information on the variability of plover counts either within or among potential strata, so we attempted to allocate sampling effort based on the expert opinion of biologists familiar with the species. However, uncertainty associated with estimates from the spatial sampling of large wetlands was greater than that associated with regional population totals at list sites. In the future, results of this study may be used to design an optimal sample allocation (i.e. for minimum variance of population totals) at large wetland complexes, which could increase the precision of our estimates. In addition to an optimal sample allocation, increasing sampling intensity would also increase precision of population totals. Daily and seasonal variation in water levels, however, will always be a challenge in designing a survey for this species. Finally, given the semi-colonial nesting behavior of Snowy Plovers (Paton 1994), future surveys should consider adaptive sampling designs to increase precision (Thompson 2002).

Non-random implementation of stratified sampling was a potential source of bias at our spatial sampling sites. If observers were not able to survey all randomly selected plots (grid cells) that were chosen from the sample frame to be surveyed, it is possible that the plots that were actually surveyed are not representative of the sample frame. We suspect this was a problem in our survey of coastal Texas. We underestimated the amount of time necessary to access and survey plots in this area and were not able to complete the entire random sample of units for any stratum. For example, in the south zone bayside beach stratum, we actually surveyed only 107 of 273 randomly selected cells. The surveyed cells were clustered in the southern portion of the zone (Cameron and Willacy counties), an area of high plover density (Hood and Dinsmore 2007). Indeed, our estimate

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

of bird density for the south zone bayside beaches (0.03 birds/ha) was similar to the estimate of Hood and Dinsmore (2007; 0.02 birds/ha) who used a sample frame largely restricted to Cameron and Willacy counties. Had we been able to complete all 207 randomly selected units, it is likely that our mean number of birds per cell for this stratum would have been lower, leading to a lower population total for coastal Texas.

From previous studies (Zdravkovic 2004; Hood and Dinsmore 2007), the breeding population of Snowy Plovers along the southern Texas coast was thought to be 416-456 individuals, whereas we estimated 2,039 -4,407 plovers. We designated 150,050 ha of suitable habitat in the southern Texas coast stratum, but Hood and Dinsmore (2007) designated only 18,100 ha of suitable habitat in portions of the two most southern counties. Because plover density on sampled units was similar between the two studies, differences in total numbers are primarily due to the delineation of suitable habitat and the area of inference. Zdravkovic (2004) encountered a minimum of 947 Snowy Plovers on the entire Texas coast. Some areas suitable to Snowy Plovers were likely missed, and the estimate was considered low by the author.

Our estimate for the Gulf coast of Florida is much larger than that previously reported (Himes *et al.* 2006). However, previous surveys in Florida: 1) focused on breeding pairs and did not count birds showing no evidence of breeding, 2) did not include assessments of detectability, and 3) did not cover all suitable sites. If we apply the suggestion of one non-breeding bird for each encountered pair (Wetlands International 2006), the adjusted estimate for 2006 (666 plovers) is close to the lower bound of our estimate for Florida (683 plovers).

Both Page *et al.* (2009) and the U.S. Fish and Wildlife Service (2007) assumed that the population of the western Snowy Plover listed under the Endangered Species Act was evenly distributed between the Pacific coast of the Baja California peninsula and the USA. However, our results indicate a 40% decrease in the number of plovers counted between 1991-92 (Palacios *et al.* 1994) and 2007-2008 on the Baja California peninsula (assuming similar detection rates between time periods). Changes in detection did not appear to explain differences in plover numbers between the two time periods, as surveys were conducted at the same sites, during the same time of year, by the same methods, and in some cases by the same observer. Declines were distributed among all breeding sites on the peninsula and appear to be influenced by human disturbance on barrier beaches and management of salt ponds. Little is known about movements of Snowy Plovers among these sites, and plovers breeding along shorelines of the Gulf of California coast are thought to be interior Snowy Plovers, rather than part of the listed distinct population segment (U.S. Fish and Wildlife Service 2007).

Our estimate of Snowy Plovers inhabiting the Central Valley, California, is similar to the mean number of birds reported there between 1994 and 2001 (Shuford *et al.* 2008). In the San Luis Valley, Colorado, our estimate corresponded to counts made in 2004 and more recent years (Bureau of Land Management, unpublished data).

Surveys conducted along both coasts and in the interior highlands and deserts provide modern breeding records for Snowy Plovers in México and a more complete assessment of their Mexican range. Breeding sites in Chihuahua were previously unknown, and new breeding sites were found all along the Pacific Coast of México from the Colorado River mouth south to the Guatemalan border (Mellink and Riojas-López 2005; Mellink *et al.* 2009) and in interior Mexico (Luevano *et al.* 2010). Surveys in Yucatán produced the highest number of breeding-season Snowy Plovers ever reported there.

Our results confirm the importance of saline wetlands in the central Mixed-grass Prairie to breeding Snowy Plovers. Four sites in north-central Oklahoma and central Kansas supported 24% of all Snowy Plovers breeding in North America. Although Salt Plains NWR was previously suspected of supporting large numbers of Snowy Plovers (Gorman and Haig 2002; Page *et al.* 2009), the results indicate that its importance ranks on

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

the level of the Great Salt Lake. The high densities recorded at Salt Plains NWR clearly support the designation of the Snowy Plover as a management priority for the refuge.

Our study indicates that Snowy Plovers remain a relatively uncommon North American shorebird; only nine of 50 shorebird species regularly breeding in the USA and Canada have populations lower than the Snowy Plover (Morrison *et al.* 2006). The aggregation of breeding plovers at a relatively few inland sites and along coastal beaches heavily used by humans make them continually vulnerable to population declines. Changes in temperature and precipitation patterns and rises in sea-level, as a product of climate change, could also increase the vulnerability of Snowy Plovers. Maintaining or increasing Snowy Plover numbers should be a management priority at sites where they occur, particularly for sites that support ≥1% of the North American population, and periodic monitoring should be undertaken at important sites to ensure the management objective of population maintenance or improvement is being accomplished.

ACKNOWLEDGMENTS

Without the assistance of hundreds of observers in México, the USA and Canada this project could not have been accomplished. We thank all birders and biologists who provided information on Snowy Plover breeding sites. We appreciate the cooperation of the many land managers and land owners who allowed us access. Major funding for the project was provided by the U.S. Fish and Wildlife Service's national and regional Migratory Bird Management programs and the Neotropical Migratory Bird Conservation Act. Other funding and support was provided by Utah's Linking Communities project, Weber State University, the National Wildlife Refuge System, the U.S. Fish and Wildlife Service Ecological Services Field Offices and National Wildlife Refuges, Fort Hays State University, the Bureau of Land Management, Colorado Division of Wildlife, California Department of Fish and Game, Oregon Department of Fish and Wildlife, Nevada Department of Wildlife, PRBO Conservation Science, Great Basin Bird Observatory, Klamath Bird Observatory, Canadian Wildlife Service, Stephen F. Austin University, U.S. Geological Survey—Forest and Rangeland Ecosystems Science Center, Baker State University, Kansas Department of Wildlife and Parks, Nebraska Game and Parks Commission, Northern Oklahoma College, Oklahoma Department of Wildlife Conservation, Arizona Game and Fish Department, Department of Defense installations, the Army Corps of Engineers, National Park Service, New Mexico Department of Game and Fish, New Mexico State Lands Department, Texas Audubon Society, Texas Parks and Wildlife Department, Kennecott Utah Copper, U.S. Magnesium, University of Rhode Island, Utah Division of Wildlife Resources, Playa Lakes Joint Venture, and Texas Tech University. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service or the U.S. Geological Survey.

LITERATURE CITED

Andres, B. A., J. A. Johnson, J. Valenzuela, R. I. G. Morrison, L. A. Espinosa and R. K. Ross. 2009. Estimating eastern Pacific coast populations of Whimbrels and Hudsonian Godwits, with an emphasis on Chiloé Island, Chile. Waterbirds 32: 216-224.

Brooks, S. P. and A. Gelman. 1998. General methods for monitoring convergence of iterative simulations. Journal Computation and Graphical Statistics 7: 434-455.

Brown, S., S. Schulte, B. Harrington, B. Winn, J. Bart and M. Howe. 2005. Population size and winter distribution of eastern American Oystercatchers. Journal of Wildlife Management 69: 1538-1545.

Funk, W. C., T. D. Mullins and S. M. Haig. 2007. Conservation genetics of Snowy Plovers (*Charadrinus alexandrinus*) in the Western Hemisphere: Population genetic structure and delineation of subspecies. Conservation Genetics 8: 1287-1309.

Gorman, L. R. and S. M. Haig. 2002. Distribution and abundance of Snowy Plovers in eastern North America, the Caribbean, and the Bahamas. Journal of Field Ornithology 73: 38-52.

Haines, D. E. and K. H. Pollock. 1998. Estimating the number of active and successful Bald Eagle nests: An application of the dual-frame method. Environmental and Ecological Statistics 5: 245-256.

Herman, S. G., J. B. Bulger and J. B. Buchanan. 1988. The Snowy Plover in southeastern Oregon and western Nevada. Journal of Field Ornithology 59: 13-21.

Himes, J. G., N. J. Douglass, R. A. Pruner, A. M. Croft and E. M. Seckinger. 2006. Status and distribution of the Snowy Plover in Florida, 2006 study final report. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida.

Hood, S. L. and S. J. Dinsmore. 2007. Abundance of Snowy and Wilson's Plovers in the lower Laguna Madre region of Texas. Journal of Field Ornithology 78: 362-368.

Kéry, M., J. A. Royle and H. Schmid. 2005. Modeling avian abundance from replicated counts using binomial mixture models. Ecological Applications 15: 1450-1461.

Kéry, M. 2008. Estimating abundance from bird counts: Binomial mixture models uncover complex covariate relationships. Auk 125: 336-345.

Koopman, M., E. Elliot-Smith and S. Haig. 2006. Potential, surveyed, and historical breeding locations for Snowy Plovers (*Charadrius alexandrinus*) throughout their

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use

North American range, excluding the Pacific west coast of the United States. Unpublished Report, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon.

Küpper, C., J. Augustin, A. Kosztolányi, T. Burke, J. Figuerola and T. Székely. 2009. Kentish versus Snowy Plover: phenotypic and genetic analyses of *Charadrius alexandrinus* reveal divergence of Eurasian and American subspecies. Auk 126: 839-852.

Luevano, J., E. Mellink and M. Riojas-López. 2010. Plovers breeding in the highlands of Jalisco, Aguascalientes, Zacatecas and San Luis Potosí, Central Mexico. Western North American Naturalist 70: 121-125.

Martin, R. 2007. Northern Great Plains. North American Birds 61: 605-607.

Mellink, E. and M. Riojas-López. 2005. New breeding localities for the Snowy Plover in western Mexico. Western Birds 36: 141-143.

Mellink, E., M. E. Riojas-López and J. Luevano. 2009. Breeding locations of seven Charadriiformes in coastal southwestern México. Waterbirds 31: 44-53.

Morrison, R. I. G., B. J. McCaffery, R. E. Gill, S. K. Skagen, S. L. Jones, G. W. Page, C. L. Gratto-Trevor and B. A. Andres. 2006. Population estimates of North American shorebirds, 2006. Wader Study Group Bulletin 111: 66-84.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon and P. J. Heglund. 2000. A double observer approach for estimating detection probability and abundance form point counts. Auk 117: 393-408.

Page, G. W., S. E. Stenzel, W. D. Shuford and C. R. Bruce. 1991. Distribution and abundance of the Snowy Plover in its western North American breeding grounds. Journal of Field Ornithology 62: 245-255.

Page, G. W., L. E. Stenzel, J. S. Warriner, J. C. Warriner and P. W. Paton. 2009. Snowy Plover (*Charadrius alexandrinus*). The birds of North America online (A. Poole, Ed.). Cornell Lab of Ornithology, Ithaca, New York. http://bna.birds.cornell.edu/bna/species/154/, accessed 23 July 2010.

Palacios, E., L. Alfaro and G. W. Page. 1994. Distribution and abundance of breeding Snowy Plovers on the Pacific coast of Baja California. Journal of Field Ornithology 65: 490-497.

Paton, P. W. C. 1994. Breeding ecology of Snowy Plovers at Great Salt Lake, Utah. Unpublished Ph.D. Dissertation, Utah State University, Logan, Utah.

Riddle, J. D., K. H. Pollock and T. R. Simons. 2010. An unreconciled double-observer method for estimating detection probability and abundance. Auk 127: 841-849.

Royle, J. A. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60: 108-115.

Royle, J. A., J. D. Nichols and M. Kery. 2005. Modelling occurrence and abundance of species when detection is imperfect. Oikos 110: 353-359.

Secretaría de Medio Ambiente y Recursos Naturales. 2010. Protección ambiental—especies nativas de México de flora y fauna silvestres—categoría de riesgo y especificaciones para su inclusión, exclusión o cambio -lista de especies de riesgo. Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Diario Oficial de la Federación, Diciembre 30 de 2010, Tomo DCLXXXVII N° 23 (2ª Sección): 1-77.

Shuford, W. D., S. Abbott and T. D. Ruhlen. 2008. Snowy Plover (*Charadrius alexandrinus*) (interior population). Studies of Western Birds 1: 173-179.

Spiegelhalter D. J., N. G. Best, B. P. Carlin and A. van der Linde. 2002. Bayesian measures of model complexity and fit (with discussion). Journal of Royal Statistics Society B 64: 583-640.

Spiegelhalter, D. J., A. Thomas, N. G. Best, and D. Lunn. 2003. WinBUGS version 1.4 user manual. MCR Biostatistics Unit, Cambridge, UK. http://www.mrc-bsu.cam.ac.uk/bugs/, accessed 15 February 2010.

Thompson, S. K. 2002. Sampling. John Wiley and Sons, New York, New York.

U.S. Fish and Wildlife Service. 1988. Endangered and threatened wildlife and plants; findings on petitions to list populations of the western Snowy Plover and the California Mountain Lion. Federal Register 53(219): 45789.

U.S. Fish and Wildlife Service. 2006. Endangered and threatened wildlife and plants; 12-month finding on a petition to delist the Pacific coast population of the western Snowy Plover. Federal Register 71(77): 20607-20624.

U.S. Fish and Wildlife Service. 2007. Recovery plan for the Pacific coast population of the western Snowy Plover (*Charadrius alexandrinus nivosus*). Endangered Species Program, Sacramento, California.

U.S. Fish and Wildlife Service. 2008a. Birds of conservation concern 2008. Division of Migratory Bird Management, Arlington, Virginia. http://www.fws.gov/migratorybirds/, accessed 23 July 2010.

U.S. Fish and Wildlife Service. 2008b. 2008 summer window survey for Snowy Plovers on U.S. Pacific Coast with 2005-2008. Unpublished report, U.S. Fish and Wildlife Service, Arcata, California. http://www.fws.gov/arcata/es/birds/WSP/plover.html, accessed 23 July 2010.

U.S. Fish and Wildlife Service. 2009. Protocols for Snowy Plover (*Charadrius alexandrinus*) breeding season survey. U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Portland, Oregon.

U.S. Shorebird Conservation Plan. 2004. High priority shorebirds—2004. Unpublished Report, U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia. http://www.fws.gov/shorebirdplan/Conservation.htm, accessed 26 July 2010.

Wetlands International. 2006. Waterbird population estimates—fourth edition. Wetlands International, Wageningen, Netherlands.

Zdravkovic, M. 2004. Coastal Texas breeding Snowy and Wilson's Plover census and report. Coastal Bird Conservation Program, National Audubon Society, Science Department, New York, New York.

Zdravkovic, M. 2008. Beach-nesting bird breeding census and report for coastal Alabama - 2007 Report. Audubon Coastal Bird Conservation Program, Science Department, National Audubon Society, New York, New York.

Downloaded From: https://complete.bioone.org/journals/Waterbirds on 25 Apr 2024
Terms of Use: https://complete.bioone.org/terms-of-use