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Abundance of Snowy and Wilson's Plovers in the lower Laguna Madre region of Texas

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ABSTRACT. Snowy Plovers (*Charadrius alexandrinus*) and Wilson's Plovers (*C. wilsonia*) are shorebird species of increasing conservation concern, with populations apparently declining in North America. However, estimates of current populations are needed before initiating long-term monitoring or planning. In 2004, we estimated abundance of breeding Snowy and Wilson's plovers in the lower Laguna Madre region of Texas using occupancy abundance estimation. We made repeated visits to survey plots from April to June, recording the number of adults of both species observed and the amount of suitable breeding habitat within each plot. We considered Bayesian occupancy abundance models with and without habitat covariates to explain the abundance of both species. For both Snowy and Wilson's plovers, the number of birds counted in each plot was influenced by the amount of suitable breeding habitat within the plot (Snowy Plover $\alpha_{habitat} = 0.52$, SD = 0.10, 95% CI = 0.33–0.71; Wilson's Plover $\alpha_{habitat} = 0.48$, SD = 0.12, 95% CI = 0.24–0.71). Using the habitat covariate models for each species, we estimated that 416 adult Snowy Plovers (95% CI = 394–438) and 279 adult Wilson's Plovers (95% CI = 262–296) were present in our study area. Our results illustrate the use of a relatively new method for abundance estimation, and indicate that the lower Laguna Madre region of Texas is an important breeding area for both Snowy and Wilson's plovers. Given the documented and suspected population declines for Snowy and Wilson's plovers, we recommend protection of their breeding habitats along the coast of Texas from development and degradation resulting from unregulated use.

SINOPSIS. **Abundancia de individuos de *Charadrius alexandrinus* y *C. wilsonia* en la parte baja de la Laguna Madre de Texas**

Charadrius alexandrinus y *C. wilsonia* son dos especies de playeros que son objeto de preocupación porque sus poblaciones parecen estar disminuyendo en Norte América. Sin embargo, se necesitan estimados poblacionales antes de se comience con su monitoreos a largo alcance o la planificación de su conservación. En el 2004, estimamos la abundancia de ambas especies en la parte baja de la Laguna Madre en Texas utilizando estimados de abundancia. Hicimos visitas repetidas para hacer encuestas en parcelas de abril a junio, contando el número de adultos de ambas especies y la cantidad de hábitat adecuado para cada especie entre cada parcela. Consideramos un modelo de abundancia Bayesiano con y sin covariantes de hábitat para explicar la abundancia de ambas especies. Para ambas especies el número de aves contadas en cada parcela fue influenciado por la cantidad de hábitat reproductivo apropiado dentro de la parcela (*C. alexandrinus* $\alpha_{habitat} = 0.52$, SD = 0.10, 95% CI = 0.33 – 0.71; *C. wilsonia* $\alpha_{habitat} = 0.48$, SD = 0.12, 95% CI = 0.24 – 0.71). Utilizando el modelo de covarianza para cada especie, estimamos un total de 416 individuos de *C. alexandrinus* (95% CI = 394 – 438) y de 279 adultos de *C. wilsonia* (95% CI = 262 – 296) en nuestra área de estudio. Nuestros resultados ilustran el uso de un método relativamente nuevo para estimar la abundancia. Este indica que la región estudiada en Laguna Madre es de importancia para la reproducción de ambas especies. Dada la documentación y la sospecha fundamentada de la reducción en número de ambas especies, recomendamos la protección de su hábitat reproductivo, del desarrollo urbano y de la degradación resultante del uso sin regulación de la costa en Texas.

Key words: *Charadrius alexandrinus*, *Charadrius wilsonia*, Laguna Madre, occupancy abundance estimation, Snowy Plover, Texas, Wilson's Plover

Abundance estimates are an important component of the study of animal populations, and are a necessary first step in any successful management program or investigation of a species' population dynamics. Many methods for population estimation are available, and choice of method depends on the species of interest, amount and type of habitat to be surveyed, and the time and funds available. Estimates are typically obtained either by census (direct,

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complete counts) or by some type of sampling that involves counting only a portion of the population, with inferences then made about the population of interest. When the area to be covered is large, a complete census may be impractical because of the time and labor involved. In addition, census results lack measures of sampling variability and are based on the assumption that every animal present at a site is seen and counted, or that detectability is equal to 1, a situation rarely encountered in the field. Consequently, it is impossible to determine if changes in census counts from one year to the next are a result of changes in population size or changes in detectability due to factors such as observer differences, weather patterns, predators, and habitat changes (Thompson et al. 1998).

Several methods are available to account for detection probability being <1 and provide a means to estimate detection probability (Thompson et al. 1998, Buckland et al. 2001). These are primarily distance-based methods, with assumptions that may be difficult to meet when working with certain species. Of primary concern is the assumption that animals are detected at their initial locations (Buckland et al. 2001). Some species may exhibit either attraction or avoidance behavior toward the observer, resulting in a violation of this assumption and thus biased estimates of abundance.

Recently, a method was developed to estimate abundance from count data obtained from repeated visits to sample plots (Royle and Nichols 2003, Royle 2004). This method accounts for both detection probability and the probability that a sample unit is occupied by the species of interest. These probabilities are then incorporated into a model that provides estimates of mean abundance for each sample unit and, in turn, allows total abundance to be estimated by area expansion (Royle 2004). Key assumptions of this method are: (1) the population of interest is demographically closed during the sampling period, (2) the number of animals available for detection varies among sampling units, and this variation results in variation in detection probability, and (3) detection events are independent (Royle and Nichols 2003). This method is not distance-based and, therefore, relaxes the assumption that all animals are detected at their original locations.

Snowy Plovers (*Charadrius alexandrinus*) and Wilson's Plovers (*C. wilsonia*) are shorebirds of conservation concern, and populations of both species are either known or believed to be declining throughout much of their ranges (Brown et al. 2001). These plovers depend on coastal areas along the Gulf Coast of the United States for breeding, wintering, and migration stopover areas (Page et al. 1995). The amount and quality of coastal habitats available to these and other shorebirds continues to decline as human presence and development in these coastal areas increases. There is little doubt that this pressure is having a negative impact on shorebird populations, particularly those that rely on coastal areas for breeding (Page et al. 1995, Corbat and Bergstrom 2000).

North American populations of Snowy Plovers are listed as Highly Imperiled by the United States Shorebird Conservation Plan (Brown et al. 2001). The Pacific Coast population of the Snowy Plover was listed as Threatened in 1993 by the U.S. Fish and Wildlife Service (U.S. Department of the Interior 1993); Gulf Coast populations are not listed. No studies of Snowy Plover population trends or dynamics have been conducted in this area (Page et al. 1995, Gorman and Haig 2002). In 2004, a survey of Snowy Plover breeding sites along the coast of Texas was conducted by the National Audubon Society, and yielded a baseline population estimate of 526 individuals for the lower Laguna Madre area of Texas (Zdravkovic 2004).

Wilson's Plovers occur only in the Americas and are uncommon breeders along the southern Atlantic, southern Pacific, and Gulf coasts (Corbat and Bergstrom 2000). These plovers are listed as a Species of High Concern by the United States Shorebird Conservation Plan (Brown et al. 2001). The current population estimate for the species in North America is 6000 individuals (Brown et al. 2001), but the accuracy of this estimate needs to be assessed (Brown et al. 2000, 2001). A survey of the Texas coast in 2004 by the National Audubon Society resulted in an estimate of 562 breeding adults (Zdravkovic 2004) in the lower Laguna Madre region of Texas, and this is the only population estimate currently available for the area.

Interest in developing effective conservation and management planning for these species and their habitats is increasing, but population

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estimates are needed before long-term monitoring or planning can begin (Brown et al 2001, Gorman and Haig 2002). The objectives of our study were to use an occupancy-based sampling approach to estimate the number of breeding adult Snowy and Wilson's plovers in the lower Laguna Madre region of Texas, an important breeding site for both species, and to suggest how this information might prove useful to future conservation planning efforts.

METHODS

Study area. Our study area was the lower Laguna Madre region of southern Texas in portions of Cameron, Willacy, and Hidalgo counties. For the purposes of this study, we defined the "lower Laguna Madre" region to be the areas of land surrounding the Laguna Madre from the southern border of Padre Island National Seashore south to the Rio Grande. Most of the area covered included U.S. Fish and Wildlife Service tracts within the Lower Rio Grande Valley National Wildlife Refuge Complex, with additional areas on public and private lands. Study areas included portions of Laguna Atascosa National Wildlife Refuge, La Sal del Rey, East Lake, Brazos Island, Boca Chica/South Bay area and the mouth of the Rio Grande, Bahia Grande, and South Padre Island (Fig. 1).

La Sal del Rey and East Lake are two hypersaline lakes located about 70 km inland and used as breeding sites by Snowy Plovers. Birds breeding at these lakes used lake shorelines, areas surrounding salt evaporation ponds, and limestone gravel, or *caliche,* causeways for nesting. The shorelines are relatively bare, but contain sparse patches of vegetation, primarily shoregrass (*Monanthochloe littoralis*), glasswort (*Salicornia* sp.), and sea blite (*Suaeda* sp.). The area immediately surrounding and slightly elevated from the lake shoreline is composed of a strip of grasses, shrubs, and succulents ranging from 5 to 30 m wide, leading into thorn-scrub woodland dominated by mesquite (*Prosopis* sp.).

The remaining study areas were coastal sites and included the shorelines and associated flats of coastal lakes (Bahia Grande lakes) and bays (Laguna Madre, South Bay) as well as the barrier island flats of Brazos Island and South Padre Island. On the barrier islands, Snowy and Wilson's plovers used the flats extending from the dunes to the bayshore for nesting (the bay side of the island). The barrier flats used for nesting extend to the bayshore and typically contain tidal flats, high sand flats, algal flats, washover flats/channels, and active back-island dunes (Britton and Morton 1989). The flats surrounding South Bay resembled the habitat on the barrier islands, and the same dominant plant species were present in and around plover breeding areas.

Survey design and methods. We initially intended to use line transect distance sampling to estimate abundance of both species, but a pilot study in 2003 revealed substantial attraction behavior as a result of group defense of nesting territories (Tomkins 1944, Corbat and Bergstrom 2000), and we were forced to switch to an occupancy abundance estimation approach. Using high-resolution aerial photographs (1995/96 Digital Ortho Quarter Quads, DOQQs) of the study area, we placed a sampling frame consisting of 1 km^2 squares over all known and suspected suitable plover breeding habitat in the study area. We used 1 km^2 plots because they could be surveyed quickly (about 15 min), but were large enough to provide sufficient opportunity for detections. Suitable plover breeding habitat included sparsely vegetated flats behind the foredunes or back dunes on barrier islands, the shorelines of inland alkali lakes, and the shorelines and associated flats of coastal bays and lagoons. We delineated 181 plots and, from those, randomly selected 30 plots to survey. This number was based on simulation results with Mountain Plovers (*C. montanus*) indicating that estimates of abundance were reasonable and bias was minimal with about 30 sample plots and five visits per plot (J. A. Royle, pers. comm.). We then chose to increase number of visits per plot to six to ensure a reasonable abundance estimate with low bias.

We visited each plot six times between 21 April and 27 June 2004. Timing of the surveys included the peak nesting periods for both species and also served to meet the demographic closure assumption of this method. Survey dates were timed to begin late enough to ensure that spring migrants would no longer be moving through the area, and end early enough to ensure that breeding birds would not be leaving the area. Although some movement in or out of the population may have occurred, slight relaxation of the demographic closure assumption is acceptable if movements occur at random (MacKenzie

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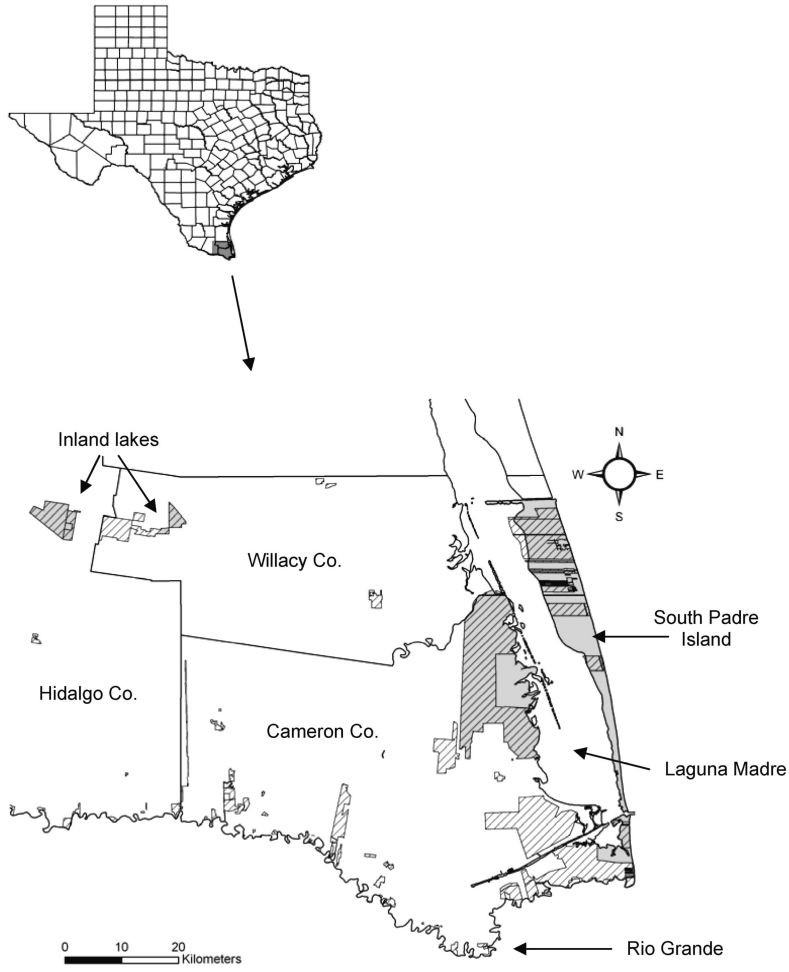

Fig. 1. Areas where Snowy and Wilson's plovers were studied in the lower Laguna Madre region of Texas, 2003–2004. Study areas are shown in gray; USDI Fish and Wildlife Service properties are designated by hatch marks.

et al. 2004). We also believed that the effects of such demographic changes would be negligible, based on the monogamous behavior of both species (SLH, pers. obs., Zdravkovic 2004) and observations of pairs retaining territories after nest loss (SLH, pers. obs.). We covered each plot in a standardized pattern at a speed of <10 km/hr on an all-terrain vehicle (ATV), and attempted to keep the survey time to 15–20 min/plot to hold sampling effort equal across all plot visits. Surveys were conducted under standardized weather conditions (no precipitation and winds <25 km/h) and by a single observer, thus eliminating extraneous sources of variation in detection probability. During each visit, we recorded the number of adults of each species observed within the plot boundaries. Because we moved through each plot in a standardized pattern in a single pass, and birds were never seen "following" observers through a plot, we feel that we were not at risk of double-counting individuals.

Not all plots within the sampling frame contained an equal amount of suitable nesting habitat, and most plots included areas where the focal species would not be found, such as water or

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dense vegetation. We assumed that the number of birds counted in each plot would be influenced by amount of suitable nesting habitat in that plot. Therefore, during the first visit to each plot, we also estimated the percentage of suitable nesting habitat in the plot (i.e., areas within a plot not covered by water or dense vegetation). For example, a plot containing only high sand flats was considered 100% suitable, whereas a plot was considered to contain 75% suitable nesting habitat if about one-quarter of the plot contained densely vegetated dunes. These values were then included as a plot-specific covariate when modeling abundance.

Modeling. We modeled abundance of each species in R software (R Development Core Team 2005) using a Bayesian occupancy abundance model (Royle 2004). We considered two simple models for each species, one with the habitat covariate (percent suitable habitat within each plot) and one without. It is not possible to compute AIC (Akaike 1973) values in a Bayesian modeling framework (J.A. Royle, pers. comm.), so we used the coefficient on the habitat covariate (α) to evaluate each pair of competing models. A coefficient of zero would indicate no habitat effect, suggesting the model without the habitat covariate as the best approximating model. A nonzero habitat coefficient, however, would indicate a habitat effect and consequently use of the model containing the habitat covariate for inference. We used the best model for each species to estimate detection probability, p, and mean number of individuals per plot, λ. We then multiplied each species-specific estimate of λ by total number of plots ($N = 181$) to obtain an estimate of abundance for each species within the study area (Royle and Nichols 2003, Royle 2004). Variance for each abundance estimate was estimated using Equation 1:

$$\mathrm{Var}(N) = n^2 \mathrm{Var}(\lambda) \quad (1)$$

We then used these variance estimates to construct 95% confidence intervals (CI) for the abundance estimate for each species.

RESULTS

For Snowy Plovers, we chose the model with the habitat covariate for inference because there was evidence of a strong habitat effect ($\alpha_{\mathrm{habitat}} = 0.52$, SD = 0.10, 95% CI = 0.33, 0.71). Under this model, detection probability was 0.58 (SD = 0.04, 95% CI = 0.50, 0.65), the mean number of Snowy Plovers per plot was 2.30 (SD = 0.32), and the estimated number of Snowy Plovers in the study area was 416 adults (95% CI = 394, 438).

For Wilson's Plovers, there also was evidence of a habitat effect ($\alpha_{\mathrm{habitat}} = 0.48$, SD = 0.12, 95% CI = 0.24, 0.71) so we again chose the habitat covariate model for inference. Under this model, detection probability was 0.59 (SD = 0.04, 95% CI = 0.50, 0.66), the mean number of Wilson's Plovers per plot was 1.54 (SD = 0.26), and we estimated that 279 adults were present in the study area (95% CI = 262, 296).

DISCUSSION

Our results demonstrate the utility of occupancy abundance surveys to estimate the abundance of two shorebird species. This method can be a practical alternative to a more costly and labor-intensive census and has two important benefits: (1) the assumption that focal species do not exhibit attraction or avoidance behavior during sampling is relaxed, making this method applicable to a wide range of species, and (2) covariates, such as observer differences or plot-specific habitat characteristics, can be included in the model to explain variation in detection probabilities and provide more precise estimates.

The estimates obtained for our study area were based on the precision of estimated detection probabilities. Simulation results have shown that when $P \geq 0.3$, λ is estimated adequately and with little bias if the number of visits per sample plot is ≥ 5 (Royle and Nichols 2003). We met both of these standards in our study, with six visits to each sample plot and detection probabilities of 0.58 for Snowy Plovers and 0.59 for Wilson's Plovers.

Concurrent to our study, an attempt was made to census breeding Snowy and Wilson's plovers along the entire Texas coast (Zdravkovic 2004). Zdravkovic (2004) provided site-specific counts so we were able to make some comparisons. For Snowy Plovers, we estimated that 416 Snowy Plovers were present in our study area, whereas Zdravkovic (2004) counted 456 plovers. For Wilson's Plovers, however, we estimated that 279 were present, but Zdravkovic (2004) counted 416. One possible reason for these differences was the length of our sampling period. We

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intended to conduct the surveys over a 6–7 week period beginning in mid-April and ending in late May or early June. However, due to logistic constraints and above-average rainfall that made site accessibility difficult at times, surveys took about 2 weeks longer to complete than anticipated. As a result, some birds may have left our plots by the end of the sampling period. This would result in violation of the population closure assumption, negatively biasing the abundance estimate or lowering detection probabilities because lower counts would be obtained in many plots at the end of the sampling period. This would suggest that birds were going undetected when, in reality, there were fewer individuals present. Although our detection probabilities were relatively high (Mackenzie and Royle 2005), they probably would have been higher if the sampling period had not been extended by 2 weeks.

Sampling periods will vary among species and locations, but should be during peak nesting periods and as short in duration as possible while allowing an adequate number of plot visits. For our study areas in south Texas, the period from about 1 April to 15 May would be ideal for sampling Snowy Plovers, and 20 April–1 June for Wilson's Plovers. For concurrent sampling of both species, 15 April–31 May would be optimal. These time periods would allow a single observer to make 5–6 visits to each plot in about 6 weeks. With multiple observers, sampling periods could be shorter, reducing the likelihood of birds moving into or out of the population.

Although we surveyed a high percentage of the areas used by Snowy and Wilson's plovers, we later learned of breeding areas outside of our study area that were used by plovers in 2004. These areas provided more breeding sites for Wilson's Plovers than for Snowy Plovers (SLH, pers. obs.), one possible reason why our estimate for Wilson's Plovers was lower than the census results. In addition, some areas that appeared to be suitable habitat in aerial photographs were later found to not be suitable (i.e., flooded or overgrown with vegetation). The aerial photographs we used to select suitable habitat were about 10 yr old and, unfortunately, did not always accurately reflect the current distribution of water or vegetation. Such errors can occur when study areas are selected using aerial photographs, but can be minimized by using the most current photographs available and conducting pilot studies in the areas to be surveyed.

Conservation implications. Our abundance estimates and detection probabilities can provide a foundation for implementing conservation planning and long-term population monitoring of Snowy and Wilson's plovers in this region. Our results also indicate that the lower Laguna Madre region of Texas is an important breeding area for both species, and may provide one of the last large, relatively continuous tracts of breeding habitat available for these plovers (Page et al. 1995). Based on our results, the number of breeding adult Snowy Plovers in the lower Laguna Madre could comprise as much as 14% of the breeding population of the southeastern U.S. (about 3000 individuals; Gorman and Haig 2002). The population of Wilson's Plovers breeding in this area could comprise approximately 5% of the North American population, given the current estimate of 6000 individuals (Brown et al. 2001). Many of the habitats used by these two species during the nesting season (e.g., sand and salt flats and algal flats) are also used as wintering habitat by these and other shorebirds (Elliott-Smith et al. 2004), further illustrating their importance. Given the documented and suspected population declines for Snowy and Wilson's plovers, we recommend protection of their breeding habitats along the coast of Texas, both from development and degradation as a result of unregulated use.

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LITERATURE CITED

AKAIKE, H. 1973. Information theory and an extension of the maximum likelihood principle. In: International symposium on information theory (B. N. Petran and F. Csake, eds.), pp. 267–281. Akademiai Kiado, Budapest, Hungary.

BRITTON, J. C., AND B. MORTON. 1989. Shore ecology of the Gulf of Mexico. University of Texas Press, Austin, TX.

15579263, 2007, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/j.1557-9263.2007.00124.x by Iowa State University Library, Wiley Online Library on [13/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

BROWN, S., C. HICKEY, B. GILL, L. GORMAN, C. GRATTO-TREVOR, S. HAIG, B. HARRINGTON, C. HUNTER, G. MORRISON, G. PAGE, P. SANZENBACHER, S. SKAGEN, AND N. WARNOCK [online]. 2000. National shorebird conservation assessment: shorebird conservation status, conservation units, population estimates, population targets, and species prioritization. Manomet Center for Conservation Sciences. http://www.Manomet.org/USSCP/files.htm (18 August 2005).

———, B. HARRINGTON, AND R. GILL (eds.). 2001. The U.S. shorebird conservation plan, 2nd ed. Manomet Center for Conservation Sciences, Manomet, MA.

BUCKLAND, S. T., D. R. ANDERSON, K. P. BURNHAM, J. L. LAAKE, AND D. BORCHERS. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, London, UK.

CORBAT, C. A., AND P. W. BERGSTROM. 2000. Wilson's Plover (*Charadrius wilsonia*). In: The Birds of North America, No. 516 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

ELLIOTT-SMITH, E., S. M. HAIG, C. L. FERLAND, AND L. R. GORMAN. 2004. Winter distribution and abundance of Snowy Plovers in SE North America and the West Indies. Wader Study Group Bulletin 104: 2–7.

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.

MACKENZIE, D. I., J. A. ROYLE, J. A. BROWN, AND J. D. NICHOLS. 2004. Occupancy estimation and modeling for rare and elusive populations. In: Sampling rare or elusive species (W. L. Thompson, ed.), pp. 149–172. Island Press, Washington, D.C.

———, AND ———. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42: 1105–1114.

PAGE, G. W., J. S. WARRINER, J. C. WARRINER, AND P. W. C. PATON. 1995. Snowy Plover (*Charadrius alexandrinus*). In: The Birds of North America, No. 154 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C.

R Development Core Team 2005. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

ROYLE, J. A. 2004. *N*-Mixture models for estimating population size from spatially replicated counts. Biometrics 60: 108–115.

———, AND J. D. NICHOLS. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84: 777–790.

THOMPSON, W. L., G. C. WHITE, AND C. GOWAN. 1998. Monitoring vertebrate populations. Academic Press, San Diego, CA.

TOMPKINS, I. R. 1944. Wilson's Plover in its summer home. Auk 61: 259–269.

U. S. Department of the Interior. 1993. Endangered and threatened wildlife and plants: determination of threatened status for the Pacific coast population of the western Snowy Plover. Federal Register 58: 12864–12874.

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

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