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RECENT DECLINES IN APPARENT SURVIVAL AND SURVEY COUNTS OF SNOWY PLOVERS BREEDING IN THE SOUTHERN HIGH PLAINS OF TEXAS

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ABSTRACT.—We quantified changes in long-term Snowy Plover (*Charadrius nivosus*) survey counts and return rates, estimated current sex and age-specific apparent survival and encounter rates, and calculated recruitment thresholds needed to maintain a stable population in the Southern High Plains of Texas. Mean survey counts of adult Snowy Plovers decreased by 78% at one saline lake (from 80 adults/survey to 18 adults/survey) from 1999–2000 to 2008–2010 but remained consistent at an alternate lake (from 45 adults/survey to 41 adults/survey). Adult and juvenile return rates have similarly declined within this time frame by 25 and 62%, respectively. Long-term declines in return rates may be the result of increased mortality from declining habitat conditions either within or outside the breeding season. Current estimates of adult (65%) and juvenile (12%) apparent survival are lower than most other estimates for Snowy Plovers throughout their range. Current estimates of adult and juvenile apparent survival and return rates indicate 5.8–10.0 hatchlings per adult per year are needed to maintain the current population without immigration, a 3–5 fold increase in the past 10 years. *Received 31 January 2012. Accepted 12 July 2012.*

Key words: apparent survival, *Charadrius nivosus*, Cormack-Jolly-Seber, demographics, saline lakes, Southern High Plains, Texas.

Snowy Plovers (*Charadrius nivosus*) are currently listed as threatened by the U.S. Fish and Wildlife Service along the Pacific Coast (USDI 1993) and listed as endangered, threatened, or of special concern in Washington, Oregon, California, Mississippi, Florida, Puerto Rico, and Kansas (Page et al. 2009). Western Snowy Plovers (*C. n. nivosus*) have declined because of human recreational use of beaches, beach development, disturbance during the nesting season, increased predation rates, and habitat degradation (e.g., exotic invasive plant species) resulting in decreased nest success (Page et al. 1991, USDI 1993). Snowy Plover populations along the Pacific Coast have received considerable attention (Page et al. 2009), but few data exist (Conway et al. 2005a; Saalfeld et al. 2011, 2012a, 2012b) to evaluate the current status and threats to Snowy Plovers nesting within the Southern High Plains of Texas. Snowy Plovers in Texas nest primarily on edges of saline lakes (Conway et al. 2005a), discharge wetlands containing springs fed by the Ogallala Aquifer which, historically, provided a reliable source of freshwater during the breeding season (Brune 2002). The presence of surface water during the breeding season is essential not only for foraging on aquatic insects, but may help facilitate cooling of nests and adults during extreme temperatures (Saalfeld et al. 2012a, 2012b). However, increased water use since the 1950s has caused spring flows and aquifer levels to decline (Brune 2002), frequently making saline lakes unsuitable for migrant (Andrei et al. 2008) and nesting shorebirds. Therefore, these changes in nesting habitat can have profound effects on regional demographic parameters and population stability.

Age-specific survival rates are key parameters for understanding current population trends. Species with low reproductive rates (i.e., few offspring produced per female) and relatively high adult survivorship are highly sensitive to declines in adult survival (Hitchcock and Gratto-Trevor 1997, Plissner and Haig 2000, Sandercock 2003). Adult and juvenile apparent survival estimates can

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also be used to calculate recruitment thresholds for population maintenance, which can be used to understand current population growth and stability, and evaluate source-sink dynamics (Ricklefs 1973, Page et al. 1983, Mullin et al. 2010).

The objectives of our study were to: (1) compare survey counts of adult Snowy Plovers between 1999–2000 and 2008–2009, (2) compare estimates of adult and juvenile return rates between 1999–2000 and 2008–2010, (3) quantify sex and age (i.e., adult and juvenile) specific apparent survival and encounter rates from 2008–2010, and (4) calculate recruitment thresholds needed to maintain a stable population during 1999–2000 and 2008–2010.

METHODS

The Southern High Plains is ~80,000 km^2 in the western Texas panhandle, south to Midland, Texas, and into New Mexico (Osterkamp and Wood 1987). Approximately 40 saline lakes occur within this region (Reeves and Temple 1986) of which only ~6 have functional freshwater springs (DAH, pers. obs.). We studied three important saline lakes (i.e., having consistent surface water throughout the nesting season and containing the majority of regional nesting Snowy Plovers) ranging in size from ~270–600 ha (Lake A ~285 ha, Lake B ~600 ha, and Lake C ~270 ha) as study sites in 1999–2000 and 2008–2010 (Conway et al. 2005a), referenced as Lake A, B, and C. Each study site lake contained 2–6 fresh to slightly saline springs distributed along lake margins (Brune 2002). The primary land-use practice immediately surrounding study-site lakes was pasture/grassland with some held within the U.S. Department of Agriculture Conservation Reserve/Permanent Cover Program. Other land-use practices occurring within surrounding areas included row-crop agriculture production (i.e., mostly cotton), mineral excavation (e.g., caliche), and development (i.e., mostly small home/ranch developments).

Drought conditions were present in 1998, 2008, and 2009 with cumulative rainfall in the city of Tahoka (Lynn County, Texas), the closest city to all three study lakes (<40 km), from January–July estimated at 11.8, 10.5, and 19.9 cm below the long-term average, respectively (U.S. Department of Commerce 2010). Conversely, wet conditions were present in 1999, 2000, 2007, and 2010 with cumulative rainfall in the city of Tahoka from January–July estimated at 7.1, 9.0, 13.4, and 53.8 cm above the long-term average, respectively (U.S. Department of Commerce 2010). Average temperatures among years tended to be similar, ranging from −3.3–42.2 °C from April–July (U.S. Department of Commerce 2010).

Field Procedures.—We captured adult Snowy Plovers at feeding locations using mist nets and on nests using nest traps (Conway and Smith 2000) in early April–early August in 1999–2000 and 2008–2009. We banded all adults with a uniquely numbered U.S. Geological Survey aluminum band on the tibiotarsus of their left leg and a unique combination of color bands on both right and left tarsometatarsi. We collected a 50-µl blood sample from each adult using brachial veinopuncture, stored in lysis buffer, and refrigerated or kept cool in coolers with ice packs while in the field (Longmire et al. 1997). We captured Snowy Plover chicks within 24 hrs of hatching in 1999–2000 and 2008–2009 either by hand in nests or with adult(s) after hatching. We used the same handling and banding techniques as used for adults for chicks, except we collected a droplet of blood by puncturing the vein at the tibia-knee joint (Animal Care and Use Committee Approval # TECMW10-08-07).

Classification of Males and Females.—We extracted blood stored in lysis buffer using phenol-chloroform extraction following Longmire et al. (1997). We performed polymerase chain reaction (PCR) to ascertain gender following Conway et al. (2004) using CHD primers (Griffiths et al. 1996) P2—5′-TCT GCA TCG CTA AAT CCT TT-3′ and labeled primer P8-6FAM—5′-CTC CCA AGG ATG AGR AAY TG-3′ (Applied Biosystems, Foster City, CA, USA).

Surveys.—We counted Snowy Plovers in the Southern High Plains of Texas during May–July 1998–2000 and 2007–2010. We conducted approximately weekly surveys in 1998–2000 at Lakes A and B. We conducted two surveys in 2007 at Lakes A and C and one at Lake B as part of the International Snowy Plover Survey (Thomas et al. 2012). We performed weekly surveys in 2008 and 2009 at Lakes A, B, and C. We conducted three surveys in 2010 at Lakes A, B, and C spaced throughout the breeding season. One observer traveled (by foot) similar survey routes (~ 2–3 km in length) covering only a portion of a given lake during each survey prior to 1200 hrs CST. Observers used sound and sight with binoculars and spotting scopes to locate Snowy

Plovers and record all individuals and band combinations for identification.

Analysis of Survey Counts.—We used a negative binomial distribution (PROC GENMOD; SAS Institute 2002) to model number of adult Snowy Plovers detected during surveys. Survey effort (i.e., number of surveys conducted) and research activities (e.g., banding) varied among years, and we restricted data to eliminate potential biases prior to analyses. We restricted analyses to years in which research activities and survey effort were similar (i.e., 1999, 2000, 2008, and 2009), because Snowy Plovers may have been more wary during periods in which we were banding. We removed all counts obtained early (prior to 1 May) and late (after 31 Jul) within the breeding season to avoid inclusion of migrants within counts. We created a *post-hoc* balanced survey design, where we restricted the number of surveys per month to be equal among years. The number of surveys included for each month was equal to the minimum number of surveys conducted for a given month in any year. We selected surveys for inclusion based on survey dates, where surveys closest to a given date were included, if more surveys were conducted within a month than the minimum. We used a negative binomial distribution, following restrictions, to examine differences in number of Snowy Plovers observed during surveys among years (i.e., 1999, 2000, 2008, and 2009) and between temporal periods (i.e., 1999–2000 and 2008–2009) for Lakes A and B.

We did not correct counts based on detection rates. We assumed detection probabilities were relatively high and consistent among years because of the open nature of saline lakes (e.g., little to no vegetation, few view obstructions, and flat topography) and conspicuous behaviors of nesting Snowy Plovers (e.g., distraction displays). Direct evidence supporting this assumption comes from surveying Lakes A and C on consecutive days in 2007, where counts differed by 1–4 individuals, respectively. Survey effort, survey protocols, and number of observers remained consistent among years included in analysis (i.e., 1999, 2000, 2008, and 2009). Surface water was variable within and among years (from precipitation events), but vegetation remained consistent. Effects of variable water level conditions are likely negated when comparing among years, the result of conducting several surveys within a season (some with high and low surface water). Counts presented were not indicative of population size at a given lake but were used as an index of population size from which we discerned changes over time.

Analysis of Return Rates.—We examined adult and juvenile (i.e., interval from hatching to first year of adulthood) return rates for each temporal period (i.e., 1999–2000 and 2008–2010) using a standard proportion (i.e., number of adults observed at least 1 year following capture divided by total number of adults captured). We considered the reobservation period to be any time during the breeding season at least 1 year following capture; most reobservations were obtained from direct surveys. We used a Chi-square analysis with Yates' correction for continuity (PROC FREQ; SAS Institute 2002) to test for independence in adult and juvenile return rates between males and females, and temporal periods.

Analysis of Apparent Survival.—We estimated yearly apparent survival for 2008–2010 in Program MARK using Cormack-Jolly-Seber (CJS) models (Cormack 1964, Jolly 1965, Seber 1965). We developed apparent survival models separately for adults and juveniles. Models for adult survival included combinations of apparent survival (φ) and/or encounter rates (p) that were allowed to: (1) vary between years (i.e., φ_t), (2) vary between males and females (i.e., φ_{sex} or p_{sex}), (3) remain constant (i.e., φ_c or p_c), and/or (4) vary based on the interaction between males and females, and year (i.e., φ_{sex*t}) (Sandercock et al. 2005). We modeled juvenile apparent survival based on age class, where survival during their first year (i.e., interval from hatching to first year of adulthood; φ^1) was modeled separately from survival during their second year (φ^2). We used Akaike's Information Criterion corrected for small sample size (AIC_c) to rank candidate models. An individual model was considered plausible when $\Delta AIC_c < 2$ (Burnham and Anderson 2002). We calculated estimates of apparent survival and encounter rates using the model averaging procedure in Program MARK. We used the median $\hat{c}$ procedure in Program MARK to test for over-dispersion (Cooch and White 2002). We compared recruitment thresholds required to maintain a stable population without immigration between temporal periods (i.e., 1999–2000 and 2008–2010) using the equation: recruitment threshold = 2*(adult mortality)/(1 − juvenile mortality) (Ricklefs 1973, Page et al. 1983, Mullin et al. 2010).

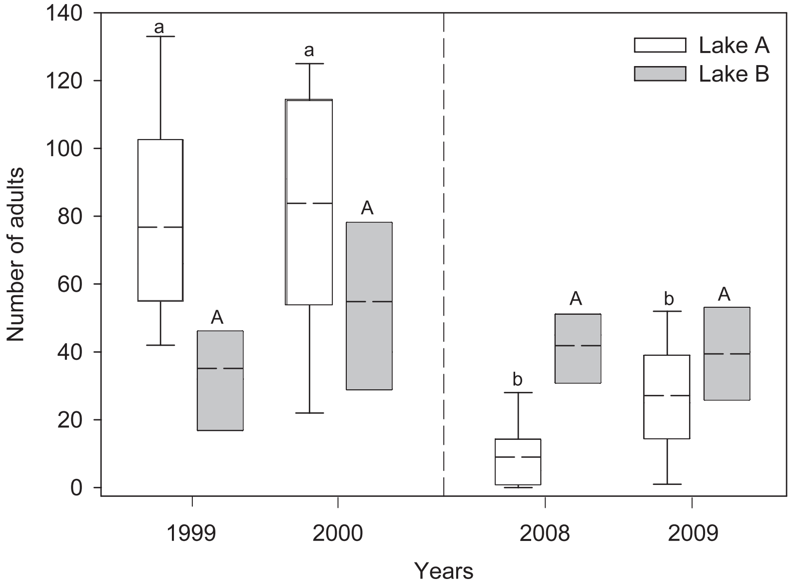

FIG. 1. Box-plot of mean survey counts of adult Snowy Plovers observed on saline lakes within the Southern High Plains of Texas, USA, 1999–2000 and 2008–2009. Years with the same letter within a lake are not different (least squares cross validation).

RESULTS

Survey Counts.—We conducted 184 surveys during 1998–2000 and 2007–2010. Nine surveys (3 in May, 4 in Jun, and 2 in Jul) per year (i.e., 1999, 2000, 2008, 2009), following survey restrictions, were included in analyses for Lake A and seven surveys (three in May, three in Jun, and one in Jul) per year for Lake B. Survey counts in 1999 and 2000 at Lake A had more adults detected than in 2008 and 2009 ($\chi^2 = 33.10$, df = 3, $P < 0.001$; Fig. 1). However, at Lake B, no differences in mean survey counts were detected among years ($\chi^2 = 3.93$, df = 3, $P = 0.27$; Fig. 1). Similarly, mean (± SE) survey counts in 2008–2009 ($\bar{x} = 18 \pm 4$ adults; range = 0–52 adults) declined ($\chi^2 = 23.03$, df = 3, $P < 0.001$) by 78% at Lake A compared to 1999–2000 ($\bar{x} = 80 \pm 8$ adults; range = 22–133 adults). No differences were detected between time periods for Lake B (2008–2009: mean ± SE = 41 ± 3 adults; range = 26–59 adults; 1999–2000: mean ± SE = 45 ± 7 adults; range = 14–106 adults; $\chi^2 = 0.35$, df = 3, $P = 0.56$).

Return Rates.—We estimated a return rate of 77% (94 of 122) in 2000 for adult Snowy Plovers banded at Lakes A and B in 1999. Return rates in 2009–2010 declined by 25% compared to 2000 (Yates corrected Chi-square: $\chi^2 = 7.34$, df = 1, $P = 0.007$) with 58% (42 of 73) of adults banded at Lakes A, B, and C in 2008 and 2009 returning at least 1 year following capture. A greater percentage of males (70–82%) returned than females (52–73%) in both time periods, but there was no sex bias in return rates (all $P > 0.05$).

We estimated a return rate of 22% (17 of 77) in 2000 for juvenile Snowy Plovers banded at Lakes A and B in 1999. Return rates in 2009–2010 declined by 62% (Yates corrected Chi-square: $\chi^2 = 6.13$, df = 1, $P = 0.013$) with 8% (10 of 118) of juveniles banded at Lakes A, B, and C in 2008 and 2009 returning at least 1 year following capture. Return rates were similar among first-year males (10–24%) and females (7–19%) in both time periods (all $P > 0.05$).

Apparent Survival.—The first four ranked models of the eight candidate CJS models for adult Snowy Plover apparent survival were considered plausible (i.e., $\Delta AIC_c < 2$; Table 1). The top-ranked model contained constant apparent survival and encounter rates varying between males and females; however, models containing apparent survival varying between years and males and females were equally plausible (Table 1). Apparent annual survival (± SE) for adults from the top-ranked model was estimated to be 0.65 ± 0.07 with female encounter rates (0.70 ±

TABLE 1. Cormack-Jolly-Seber models from Program MARK to estimate apparent survival (φ) and encounter rates (*p*) of adult Snowy Plovers on saline lakes within the Southern High Plains of Texas, USA, 2008–2010.

Model structure[a]		Model statistics		
φ	*p*	No. parameters	ΔAIC_c[b]	w_i[c]
c	sex	3	0.00	0.33
t	sex	4	0.89	0.21
sex	sex	4	1.46	0.16
sex	c	3	1.88	0.13
c	c	2	3.11	0.07
t	c	3	3.82	0.05
sex*t[d]	c	5	5.01	0.03
sex*t	sex	6	5.03	0.03

[a] Model factors included: *c* = φ or *p* remained constant between years, *t* = φ showed annual variation, and *sex* = φ or *p* varied between males and females.
[b] Difference between model's Akaike's Information Criterion corrected for small sample size and the lowest AIC_c value.
[c] AIC_c relative weight attributed to model.
[d] Model of additive effects of sex and time, and the interaction between them.

0.13) lower than males (1.00 ± 0.00). Competing models also indicated apparent survival was lower in 2008–2009 than in 2009–2010 and greater for males than females (Table 2). The goodness of fit statistic from the general model indicated the model fit the data well (median $\hat{c}$ = 1.10), although models were not corrected for overdispersion.

The first four ranked of the eight candidate CJS models for juvenile Snowy Plover apparent survival were plausible (i.e., $\Delta AIC_c < 2$; Table 3). The top-ranked model contained constant apparent survival and encounter rates; however, models containing apparent survival varying between years and males and females, and encounter rates varying between males and females were equally plausible (Table 3). Apparent survival (± SE) for juveniles from the top-ranked model was estimated to be 0.12 ± 0.06 with encounter rates estimated at 0.62 ± 0.30. Apparent survival during the second year of adulthood (i.e., φ^2) was estimated to be 0.80 ± 0.47; however, this estimate was based on few individuals for 1 year and was not a robust estimate. Competing models also indicated apparent survival was lower in 2008–2009 than in 2009–2010 and greater for females than males; however, encounter rates were greater for males than females (Table 4). The goodness of fit statistic from the general model indicated the model fit the data well (median $\hat{c}$ = 1.57), although models were not corrected for overdispersion.

Recruitment Threshold.—The recruitment threshold for 1999–2000 was 2.1 hatchlings per adult using return rates for adults (0.77) and juveniles (0.22). The recruitment threshold for 2008–2010 was 5.8 hatchlings per adult using apparent survival rates for adults (0.65) and juveniles (0.12) obtained from the top-ranked

TABLE 2. Averaged parameter estimates from Cormack-Jolly-Seber models in Program MARK modeling apparent survival (φ) and encounter rates (*p*) of adult Snowy Plovers on saline lakes within the Southern High Plains of Texas, USA, 2008–2010.

			95% CI	
Parameter	Estimate	SE	Lower	Upper
φ (female, 2008–2009)	0.598	0.095	0.406	0.764
φ (female, 2009–2010)	0.642	0.104	0.425	0.813
φ (male, 2008–2009)	0.650	0.107	0.426	0.823
φ (male, 2009–2010)	0.696	0.099	0.477	0.851
p (female)	0.756	0.140	0.411	0.932
p (male)	0.963	0.076	0.288	0.999

TABLE 3. Cormack-Jolly-Seber models from Program MARK to estimate apparent survival for interval between hatching and first year (φ^1), interval between first year and second year (φ^2), and encounter rates (p) of juvenile Snowy Plovers on saline lakes within the Southern High Plains of Texas, USA, 2008–2010.

Model structure[a]			Model statistics		
φ^1	φ^2	p	No. parameters	ΔAIC_c[b]	w_i[c]
c	c	c	3	0.00	0.30
c	c	sex	4	0.78	0.20
t	c	c	4	1.33	0.15
sex	c	c	4	1.74	0.13
sex	c	sex	5	2.28	0.10
t	c	sex	5	2.66	0.08
sex*t[d]	c	c	6	5.18	0.02
sex*t	c	sex	7	5.77	0.02

[a] Model factors included: $c = \varphi^1$, φ^2, or p remained constant between years, $t = \varphi^1$ showed annual variation, and $sex = \varphi^1$ or p varied between males and females.
[b] Difference between model's Akaike's Information Criterion corrected for small sample size and the lowest AIC_c value.
[c] AIC_c relative weight attributed to model.
[d] Model of additive effects of sex and time, and the interaction between them.

CJS models. However, the recruitment threshold for 2008–2010 was 10.0 hatchlings per adult using return rates for adults (0.58) and juveniles (0.08).

DISCUSSION

Survey counts of Snowy Plovers in the Southern High Plains of Texas decreased by 78% from 1999–2000 to 2008–2010 at Lake A, but were similar at Lake B. We also found an 83% decline in number of nests found at Lake A between 1999–2000 (152 and 100 nests) and 2008–2009 (15 and 29 nests; Saalfeld et al. 2011; WCC, unpubl. data). These two lakes are important for nesting Snowy Plovers, because they support a large percentage of the regional population. Lakes A and B supported 56% of all adult Snowy Plovers detected on 15 saline lakes in the Southern High Plains of Texas during the International Snowy Plover Survey (WCC, unpubl. data). These lakes support the best remaining nesting habitat for Snowy Plovers within this region having relatively consistent surface water provided by functional freshwater springs throughout the nesting season, large areas suitable for nest placement (Saalfeld et al. 2012b), minimum anthropogenic disturbance, and intact surrounding habitat (Saalfeld 2010). Few other saline lakes in the region are supported by continued function of historical freshwater springs. Lakes may become unsuitable for nesting and migrating Snowy Plovers and other shorebirds because of decreased surface water availability (Andrei et al. 2008). Surface water is a necessary regional landscape feature for nesting Snowy Plovers (Conway et al. 2005b; Saalfeld et al. 2011, 2012a, 2012b). Declines in the Ogallala Aquifer and deterioration of spring integrity have degraded habitat conditions (i.e., amount and salinity of surface water available) of saline lakes since the wide-spread development of crop irrigation during the 1950s (Brune 2002). We have

TABLE 4. Averaged parameter estimates from Cormack-Jolly-Seber models in Program MARK modeling apparent survival for interval between hatching and first year (φ^1), interval between first year and second year (φ^2), and encounter rates (p) of juvenile Snowy Plovers on saline lakes within the Southern High Plains of Texas, USA, 2008–2010.

			95% CI	
Parameter	Estimate	SE	Lower	Upper
φ^1 (female, 2008–2009)	0.197	0.274	0.008	0.880
φ^1 (female, 2009–2010)	0.228	0.289	0.012	0.880
φ^1 (male, 2008–2009)	0.114	0.063	0.036	0.304
φ^1 (male, 2009–2010)	0.133	0.091	0.032	0.420
φ^2 (2009–2010)	0.769	0.464	0.019	0.998
p (female)	0.494	0.331	0.068	0.929
p (male)	0.734	0.376	0.059	0.992

observed substantial and rapid hydrological declines at Lake A in recent years (from 1999–2010), while declines at Lake B have been minimal (WCC, pers. obs). Differences in hydrological declines between these two lakes have likely influenced differences in population declines observed in this study.

We also observed a 25 and 62% decline in adult and juvenile return rates, respectively with nest success declines of 31% (Saalfeld et al. 2011). Declines should be interpreted cautiously as only 1 year of return rate data were obtained in early years (1999–2000). Current estimates of yearly apparent survival (juvenile: 8% using return rates and 12% using CJS models; adults: 58% using return rates and 65% using CJS models) are lower than most other estimates reported for juvenile (18% using Barker models in Stenzel et al. 2007) and adult Snowy Plovers (74% using return rates in Page et al. 1983; 73–79% using return rates in Warriner et al. 1986; 69% using Jolly-Seber models in Paton 1994; 69% using Barker models in Stenzel et al. 2007; 50–61% using CJS in Mullin et al. 2010; and 69–73% using Barker models in Stenzel et al. 2011).

Low apparent survival of both adults and juveniles may be related to greater mortality or dispersal (to alternate breeding locations [e.g., saline lakes] either within or outside the Southern High Plains of Texas), as these two factors cannot be separated. Both factors could be related to declining habitat quality (Haig and Oring 1988, Wiens and Cuthbert 1988, Stenzel et al. 1994), poor nest success (Gratto et al. 1985, Badzinski 2000), and/or increased predation rates (Badzinski 2000). Surface water availability on arrival may influence regional fidelity rates, if site fidelity decreases when surface water is low. We would expect survey counts to increase at lakes that had the greatest surface water integrity (e.g., Lake B) if individuals were moving among lakes in relation to surface water availability; but this trend was not observed. Snowy Plovers within this region have high breeding site fidelity, nesting at the same saline lake in subsequent years (Saalfeld 2010).

Observed declines in return rates are likely the result of increased mortality within or outside the breeding season. Decreased habitat quality (e.g., spring water integrity) may result in increased mortality of both adults and juveniles during the breeding season. Increased mortality may occur from associated stress and high energy requirements needed for growth if chicks cannot access necessary food resources after hatching. Both juveniles and adults must obtain sufficient energy prior to migration (Bairlein and Gwinner 1994) or greater mortality rates may occur during this physiologically and energetically costly time period (Alerstam et al. 2003).

Declines in apparent Snowy Plover survival within this region may also be a result of factors occurring outside the breeding season. Current survival rates and causes of mortality during the nonbreeding season (i.e., migration and wintering) remain unknown for this population. Potential increases in mortality during the nonbreeding season may occur from catastrophic events (e.g., hurricanes) or poor habitat conditions in wintering regions. We documented dramatic declines in survey counts between 2007–2008 (e.g., mean number of adults/survey in May at Lake A declined from 123 to 20 adults/survey) corresponding to four hurricanes that made landfall between the Texas coast and Yucatán Peninsula (presumed wintering area, as the majority of Snowy Plovers winter within this region; Mabee et al. 2001, Gorman and Haig 2002, Elliott-Smith et al. 2004) during August–September 2007. Direct and indirect mortality from these hurricanes could have partially caused the population declines observed during this timeframe. Wintering coastal populations are also threatened by habitat loss and degradation, coastal development, and disturbance from human recreation (Mabee et al. 2001, Elliott-Smith et al. 2004).

Estimates of recent adult and juvenile apparent survival and return rates indicate that 5.8–10.0 hatchlings per adult are needed to maintain the current population without immigration. This is in contrast to estimates 10 years prior (return rates of adults and juveniles were greater), when 2.1 hatchlings per adult were needed to maintain a stable population. Snowy Plovers are a determinant layer with a modal clutch size of three eggs. Each pair needs to successfully hatch more than three clutches each year to produce more than five hatchlings per adult. This is not physiologically possible, nor is there sufficient time during the nesting season for more than three clutches per pair to successfully hatch. Page and others (1983) estimated only $\geq$0.8 fledglings per adult were necessary in California for population maintenance; although Mullin and others (2010) estimated $\geq$2.7 fledglings per adult were necessary to maintain a stable population. Estimates obtained in our study (based on hatchlings) are not directly comparable to those of previous studies (based on fledglings). Our estimates suggest current populations of Snowy Plovers nesting on saline lakes in the Southern High Plains of Texas are currently unstable and, without immigration, may continue to decline.

CONSERVATION IMPLICATIONS

Current conservation actions for Snowy Plovers typically focus on increasing nest success (e.g., predator exclosures, predator control, and reduction of human disturbance around nest sites; Page et al. 2009), which cannot reverse current rates of adult and juvenile mortality. Conservation efforts must focus on increasing adult and juvenile survival on both breeding and wintering areas. Techniques for improving adult and juvenile survival are lacking, exacerbating this problem for regional Snowy Plover populations. It remains important to conserve saline lake habitat, especially freshwater springs discharging into saline lakes. Retiring irrigation wells in the vicinity of saline lakes could be explored to maintain and/or increase groundwater levels and subsequent spring activity. The Ogallala Aquifer is recharged by playa wetlands (Osterkamp and Wood 1987, Bolen et al. 1989) and it remains important to conserve the entire complex of wetlands within the Southern High Plains of Texas (Andrei et al. 2008).

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LITERATURE CITED

Alerstam, T., A. Hedenström, and S. Åkesson. 2003. Long-distance migration: evolution and determinants. Oikos 103:247–260.

Andrei, A. E., L. M. Smith, D. A. Haukos, and J. G. Surles. 2008. Habitat use by migrant shorebirds in saline lakes of the Southern Great Plains. Journal of Wildlife Management 72:246–253.

Badzinski, D. S. 2000. Population dynamics of Semipalmated Plovers (*Charadrius semipalmatus*) breeding at Churchill, Manitoba. Thesis. Trent University, Peterborough, Ontario, Canada.

Bairlein, F. and E. Gwinner. 1994. Nutritional mechanisms and temporal control of migratory energy accumulation in birds. Annual Review of Nutrition 14:187–215.

Bolen, E. G., L. M. Smith, and H. L. Schramm Jr. 1989. Playa lakes: prairie wetlands of the Southern High Plains. Bioscience 39:615–623.

Brune, G. M. 2002. Springs of Texas. Volume 1. Texas A&M University Press, College Station, USA.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretical approach. Second Edition. Springer-Verlag, New York, USA.

Conway, W. C. and L. M. Smith. 2000. A nest trap for Snowy Plovers. North American Bird Bander 25:45–47.

Conway, W. C., L. M. Smith, and J. D. Ray. 2005a. Shorebird breeding biology in wetlands of the playa lakes, Texas, USA. Waterbirds 28:129–138.

Conway, W. C., L. M. Smith, and J. D. Ray. 2005b. Shorebird habitat use and nest-site selection in the Playa Lakes Region. Journal of Wildlife Management 69:174–184.

Conway, W. C., J. K. Wickliffe, F. G. Hoffmann, R. J. Baker, and L. M. Smith. 2004. An improved PCR-based method for gender identification in birds. Occasional Papers of the Museum of Texas Tech University 239:1–7.

Cooch, E. and G. White. 2002. Program MARK: a gentle introduction. Colorado State University, Fort Collins, USA. www.phidot.org/software/mark/docs/book

Cormack, R. M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51:429–438.

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 104:28–33.

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.

Gratto, C. L., R. I. G. Morrison, and F. Cooke. 1985. Philopatry, site tenacity, and mate fidelity in the Semipalmated Sandpiper. Auk 102:16–24.

Griffiths, R., S. Daan, and C. Dijkstra. 1996. Sex identification in birds using two CHD genes. Proceedings of the Royal Society of London, Series B 263:1251–1256.

Haig, S. M. and L. W. Oring. 1988. Distribution and dispersal in the Piping Plover. Auk 105:630–638.

Hitchcock, C. L. and C. Gratto-Trevor. 1997. Diagnosing a shorebird local population decline with a stage-structured population model. Ecology 78:522–534.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52:225–247.

LONGMIRE, J. L., M. MALTBIE, AND R. J. BAKER. 1997. Use of ''lysis buffer'' in DNA isolation and its implication for museum collections. Occasional Papers of the Museum of Texas Tech University 163:1–3.

MABEE, T. J., J. H. PLISSNER, S. M. HAIG, AND J. P. GOOSSEN. 2001. Winter distributions of North American plovers in the Laguna Madre regions of Tamaulipas, Mexico and Texas, USA. Wader Study Group Bulletin 94:39–43.

MULLIN, S. M., M. A. COLWELL, S. E. MCALLISTER, AND S. J. DINSMORE. 2010. Apparent survival and population growth of Snowy Plovers in coastal northern California. Journal of Wildlife Management 74:1792–1798.

OSTERKAMP, W. R. AND W. W. WOOD. 1987. Playa-lake basins on the Southern High Plains of Texas and New Mexico. Part I. Hydrologic, geomorphic, and geologic evidence for their development. Geological Society of America Bulletin 99:215–223.

PAGE, G. W., L. E. STENZEL, D. W. WINKLER, AND C. W. SWARTH. 1983. Spacing out at Mono Lake: breeding success, nest density, and predation in the Snowy Plover. Auk 100:13–24.

PAGE, G. W., L. E. STENZEL, W. D. SHUFORD, AND C. R. BRUCE. 1991. Distribution and abundance of the Snowy Plover on its western North American breeding grounds. Journal of Field Ornithology 62:245–255.

PAGE, G. W., L. E. STENZEL, G. W. PAGE, J. S. WARRINER, J. C. WARRINER, AND P. W. PATON. 2009. Snowy Plover (*Charadrius alexandrinus*). The birds of North America. Number 154.

PATON, P. W. C. 1994. Survival estimates for Snowy Plovers breeding at Great Salt Lake, Utah. Condor 96:1106–1109.

PLISSNER, J. H. AND S. M. HAIG. 2000. Viability of Piping Plover *Charadrius melodus* metapopulations. Biological Conservation 92:163–173.

REEVES JR., C. C. AND J. M. TEMPLE. 1986. Permian salt dissolution, alkaline lake basins, and nuclear-waste storage, Southern High Plains, Texas and New Mexico. Geology 14:939–942.

RICKLEFS, R. E. 1973. Fecundity, mortality, and avian demography. Pages 366–435 *in* Breeding biology of birds (D. S. Farner, Editor). National Academy of Sciences, Washington, D.C., USA.

SAALFELD, S. T. 2010. Snowy Plover population and breeding ecology in saline lakes of the Southern High Plains of Texas. Dissertation. Stephen F. Austin State University, Nacogdoches, Texas, USA.

SAALFELD, S. T., W. C. CONWAY, D. A. HAUKOS, AND W. P. JOHNSON. 2011. Nest success of Snowy Plovers (*Charadrius nivosus*) in the Southern High Plains of Texas. Waterbirds 34:389–399.

SAALFELD, S. T., W. C. CONWAY, D. A. HAUKOS, AND W. P. JOHNSON. 2012a. Alleviation of nest thermal extremes by incubating Snowy Plovers in the Southern High Plains of Texas. Wader Study Group Bulletin 119:77–83.

SAALFELD, S. T., W. C. CONWAY, D. A. HAUKOS, AND W. P. JOHNSON. 2012b. Snowy Plover nest site selection, spatial patterning, and temperatures in the Southern High Plains of Texas. Journal of Wildlife Management 76:1703–1711.

SANDERCOCK, B. K. 2003. Estimation of survival rates for wader populations: a review of mark-recapture methods. Wader Study Group Bulletin 100:163–174.

SANDERCOCK, B. K., T. SZÉKELY, AND A. KOSZTOLÁNYI. 2005. The effects of age and sex on the apparent survival of Kentish Plovers breeding in southern Turkey. Condor 107:583–596.

SAS INSTITUTE. 2002. SAS/STAT software. Version 9. SAS Institute Inc., Cary, North Carolina, USA.

SEBER, G. A. F. 1965. A note on the multiple-recapture census. Biometrika 52:249–259.

STENZEL, L. E., J. C. WARRINER, J. S. WARRINER, K. S. WILSON, F. C. BIDSTRUP, AND G. W. PAGE. 1994. Long-distance breeding dispersal of Snowy Plovers in western North America. Journal of Animal Ecology 63:887–902.

STENZEL, L. E., G. W. PAGE, J. C. WARRINER, J. S. WARRINER, D. E. GEORGE, C. R. EYSTER, B. A. RAMER, AND K. K. NEUMAN. 2007. Survival and natal dispersal of juvenile Snowy Plovers (*Charadrius alexandrinus*) in central coastal California. Auk 124:1023–1036.

STENZEL, L. E., G. W. PAGE, J. C. WARRINER, J. S. WARRINER, K. K. NEUMAN, D. E. GEORGE, C. R. EYSTER, AND F. C. BIDSTRUP. 2011. Male-skewed adult sex ratio, survival, mating opportunity and annual productivity in the Snowy Plover *Charadrius alexandrinus*. Ibis 153:312–322.

THOMAS, S. M., J. E. LYONS, B. A. ANDRES, E. ELLIOT T-SMITH, E. PALACIOS, J. F. CAVITT, J. A. ROYLE, S. D. FELLOWS, K. MATY, W. H. HOWE, E. MELLINK, S. MELVIN, AND T. ZIMMERMAN. 2012. Population size of Snowy Plovers breeding in North America. Waterbirds 35:1–14.

U.S. DEPARTMENT OF COMMERCE. 2010. National Climate Data Center. Asheville, North Carolina, USA. cdo.ncdc.noaa.gov

U.S. DEPARTMENT OF INTERIOR (USDI). 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.

WARRINER, J. S., J. C. WARRINER, G. W. PAGE, AND L. E. STENZEL. 1986. Mating system and reproductive success of a small population of polygamous Snowy Plovers. Wilson Bulletin 98:15–37.

WIENS, T. P. AND F. J. CUTHBERT. 1988. Nest-site tenacity and mate retention of the Piping Plover. Wilson Bulletin 100:545–553.