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Nest Success of Snowy Plovers (*Charadrius nivosus*) in the Southern High Plains of Texas

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Abstract.—Snowy Plovers (*Charadrius nivosus*) nesting on edges of saline lakes within the Southern High Plains (SHP) of Texas are threatened by habitat degradation due to reduced artesian spring flow, making many saline lakes unsuitable for nesting and migrating shorebirds. Factors influencing nest success were evaluated, current nest success estimates in the SHP of Texas were compared to estimates obtained ten years prior, and causes and timing of nest failures determined. Overall, 215 nests were monitored from three saline lakes in 2008 -2009, with nest success estimates from Program MARK ranging from 7-33% ($\bar{x}$ = 22%). The leading causes of nest failures were attributed to predation (40%) and weather (36%). Nest success was negatively influenced by number of plants within 707-cm^2 plot, positively influenced by percent surface water availability, and at one saline lake, negatively influenced by day during the nesting season (i.e., nest success declined later in the nesting season). When compared to estimates ten years prior (1998-1999), mean nest success has declined by 31%. If nesting Snowy Plovers continue to experience increased predation rates, decreased hydrological integrity, and habitat alterations, populations will continue to decline throughout this region. *Received 2 April 2011, accepted 10 August 2011.*

Key words.—breeding, *Charadrius nivosus*, nesting, nest success, nest survival, Program MARK, saline lake, surface water.

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Snowy Plovers (*Charadrius nivosus*) have experienced declines throughout their range in the United States and are currently listed as threatened by the U.S. Fish and Wildlife Service along the Pacific Coast (U.S. Fish and Wildlife Service 1993) and endangered, threatened, or a species of special concern by several states, including Washington, Oregon, California, Mississippi, Florida, Puerto Rico, and Kansas (see Page *et al.* 2009). A primary cause for the decline of western Snowy Plovers is poor nest success (U.S. Fish and Wildlife Service 1993), with nest success showing considerable regional and annual variation (i.e., 5-67%, see Page *et al.* 2009). Nest failures are often attributed to predation by both mammalian and avian predators, weather (e.g., hail, wind, storm tides, and rain storms), trampling (by cattle, humans, and vehicles), and human disturbance (Page *et al.* 2009). Snowy Plovers have evolved with many of these pressures and should cope with losses attributed to these risks (Wilson-Jacobs and Meslow 1984). However, if population declines are a result of poor nest success, then current causes of nest failures may be more intense or widespread today than historically (Wilson-Jacobs and Meslow 1984). Therefore, estimating nest success and understanding current causes of Snowy Plover nest failures remain important in order to assess current population stability and provide conservation guidelines.

Numerous factors may influence avian nest success, including parental condition, clutch initiation date, nest site selection, and surface water availability. Female condition can directly influence nest success, as individuals in better condition produce larger eggs and clutches (Davis 1975; Thomas 1983; Croxall *et al.* 1992; Nol *et al.* 1997; Amat *et al.* 2001b), compensate for (or withstand) high physiological costs of incubation, occupy nest sites of better quality (i.e., lower predation risks, lower risks of destruction from weather events, and/or closer to optimal foraging areas), and/or defend nests from predation risks (Blomqvist *et al.* 1997). Although factors influencing laying date (e.g., food abundance, competition, weather, etc.) can vary seasonally, annually, and spatially, earlier egg laying dates in most avian species typically result in greater nest success (Perrins 1996). A relationship may exist between Snowy Plover nest success and laying date, but results have been inconsistent (Page *et al.* 1983; Powell 2001; Norte and Ramos 2004; Conway *et al.* 2005a; Hood and Dinsmore 2007). Nest site selection is a key mechanism that birds use to reduce risks to both nest contents and themselves during incubation. For example, amount and type of objects surrounding nests (Page *et al.* 1985; Norte and Ramos 2004; Hood and Dinsmore 2007; Colwell *et al.* 2011), amount of cover surrounding nests (Amat and Masero 2004b; Norte and Ramos 2004; Hood and Dinsmore 2007), substrate type (Hill 1985; Page *et al.* 1985; Colwell *et al.* 2005), distance to upland areas (Koenen *et al.* 1996a), and degree of clustering with conspecific and nonconspecific nests (Hill 1985; Burger 1987; Powell 2001; Norte and Ramos 2004) could all influence Snowy Plover nest success.

Surface water availability is an important landscape feature affecting nesting Snowy Plovers in inland areas. Surface water on saline lakes in the SHP of Texas during the breeding season is not only a necessary landscape feature for nesting Snowy Plovers (Conway *et al.* 2005b), but also supports invertebrate prey (Andrei *et al.* 2009) and provides a means to alleviate heat stress (e.g., belly soaking and standing in water; Maclean 1975; Purdue 1976; Amat and Masero 2004a; Amat and Masero 2007; Amat and Masero 2009; Saalfeld 2010). However, surface water availability fluctuates weekly due to unpredictable rain events, evapotranspiration, and reduced freshwater spring flow (S. Saalfeld per. obs.), all of which exhibit more exaggerated fluctuations today than historically. Because saline lakes within this semi-arid region are discharge wetlands containing springs fed by the Ogallala aquifer, historically, many provided reliable freshwater during the breeding season (Brune 2002). However, declining spring flow due to decreasing water table levels of the aquifer has occurred since the 1950s (Brune 2002), resulting in shortened hydroperiods and greater salinity, making many of them unsuitable for migrating (Andrei *et al.* 2008) and nesting shorebirds. Similar to other regions (e.g., Oregon and Nevada; Herman *et al.* 1988), groundwater removal for irrigation during the breeding season can exacerbate these effects during crucial times when nesting Snowy Plovers rely on freshwater from saline lake springs (Conway *et al.* 2005a).

Saline lakes within the SHP of Texas are of continental importance to nesting Snowy Plovers, as a large proportion of the interior population nest within as well as migrate through the region (Conway 2001; Conway *et al.* 2005a). Due to the declining habitat conditions (i.e., reduced artesian spring flow on saline lakes) of saline lakes within the SHP of Texas, it is important to determine the current status of Snowy Plovers within this region, as well as examine potential causes of population declines. Therefore, the objectives of this study were to 1) estimate nest success, 2) determine timing and causes of nest failures, and 3) evaluate potential factors affecting nest success within the SHP of Texas.

Methods

Study Area

The SHP is an approximately 80,000 km^2 region in the western Texas panhandle, south to Midland, Texas, and into New Mexico (Osterkamp and Wood 1987). Within this region, approximately 40 saline lakes (i.e., primary regional nesting location for Snowy Plovers; Conway *et al.* 2005a) occur (Reeves and Temple 1986). Saline lakes are discharge wetlands containing freshwater springs fed by the Ogallala aquifer (Brune 2002), but having an overall saline water chemistry (often >200g/L of dissolved solids; Osterkamp and Wood 1987). Three previously identified important (i.e., having consistent surface water throughout the nesting season and containing the majority of regional nesting Snowy Plovers) saline lakes ranging in size from ~270-600 ha were used as study sites in 2008 and 2009 (Conway *et al.* 2005a). Each study site lake contained two-six 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 (i.e., mostly cotton, *Gossypium* spp., production), mineral excavation (e.g., caliche), and development (i.e., mostly small home/ranches). To maintain landowner anonymity, study site lakes will be referred to as lakes A, B, and C.

Weather conditions were similar between 2008 and 2009, with Apri-July temperatures in Tahoka (Lynn County, Texas) ranging from 1.1-39.4°C in 2008 and -2.8-40°C in 2009, with 57 days in 2008 and 50 days in 2009 ≥ 32°C (National Climatic Data Center). Additionally, cumulative rainfall in Tahoka between April and July in 2008 and 2009 was similar, estimated at 19.7 cm and 19.1 cm, respectively, with the greatest amount of precipitation occurring in May in 2008 (11.3 cm) and in July in 2009 (8.8 cm; National Climatic Data Center). Drought conditions were present in both years of this study, with cumulative rainfall in Tahoka from January-July 2008 and 2009 estimated at 10.5 cm and 19.9 cm below the long-term average, respectively (National Climatic Data Center).

Nest Surveys

Surveys were conducted ≥ 1 time per week at each lake during the breeding season (i.e., early April-mid August; Conway *et al.* 2005a) in 2008-2009 to locate new nests or monitor known nests until nest fate was determined. Nests were located by observing adult Snowy Plovers incubating nests, flushing from or returning to nests, and searching appropriate habitat (Conway *et al.* 2005a), where search effort and personnel remained consistent between years. If a nest was discovered with one egg, it was assumed that the nest was initiated the day of discovery; however if nests were discovered with two eggs, it was assumed that the nest was initiated the day prior to discovery. In some instances only two egg clutches were laid. If no third egg was laid within 2-3 days of discovery or if nests were located after all three eggs (modal clutch size) were laid, the eggs were floated to determine incubation stage (Hays and LeCroy 1971). Once located, the length (mm) and breadth (mm) of all eggs were measured with calipers (Coulson 1963). Egg volume (V_e; a measure of parental quality) was calculated similar to Amat *et al.* (2001a) using the equation $V_e = K_v LW^2$, where K_v corrects for variation in egg shape and is calculated by $K_v = 0.5236\text{-}[0.5236*2(L/W)/100]$, with L = egg length (cm) and W = egg width (cm).

A successful nest was defined as a nest in which ≥ 1 egg hatched (Mayfield 1975). Evidence of hatching included visually locating chicks in/near nest (<5 m from nest and/or with banded adult), breeding pair displaying distraction displays, and/or presence of egg shell fragments indicative of hatching (i.e., <1 mm shell fragments found in scrape and/or top or bottom of egg shell located <10 m from nest with membrane detached; Mabee 1997). Nests were considered failed when 1) eggs were absent prior to estimated hatching date, 2) there were signs of predation (i.e., egg shell fragments in/near nest scrape not indicative of hatching [see above] and/or predator tracks near nest) or trampling (i.e., crushed eggs in nest cavity and footprints near or on nest scrape), 3) evidence suggested nests were destroyed by weather (i.e., nest scrape flooded, eggs/nest scrape silted in, eggs cracked due to hail, and/or eggs blown out of nest scrape), 4) evidence suggested abandonment (i.e., eggs were present one week after estimated hatching date or when one egg was moved such that the smaller end pointed up and remained for >24 hrs), or 5) evidence suggested eggs were unviable (i.e., eggs present in nest >7 days after estimated hatch date). If nest fate did not match these definitions, it was classified as unknown (Manolis *et al.* 2000). Removing unknown fates can result in extreme bias of nest success estimates; therefore, nests with unknown fates were treated as failures in nest success estimates (Manolis *et al.* 2000).

During weekly surveys, ocular estimates of percent dry ground, mud (areas wet from spring flow rather than rainwater), shallow water (1-5 cm deep; shallow enough for wading Snowy Plover), medium water (5-15 cm deep; too deep for wading Snowy Plover, but shallow enough for wading American Avocet [*Recurvirostra americana*]), and deep water (>15 cm deep; too deep for wading American Avocet) were recorded for a saline lake from vantage points overlooking the entire lake bottom. These estimates allowed us to determine availability of surface water for nesting plovers throughout the breeding season. Specifically, during weekly surveys, locations of above categories were drawn on 2004 NAIP digital orthophoto quarter-quadrangle (DOQQ) aerial photographs (Texas Natural Resources Information System 2004) to estimate percent composition. To obtain total surface water availability, percent mud, shallow water, medium water, and deep water were summed for each survey. Mean percent surface water availability for the entire saline lake was then estimated for each nest during the time the nest was active (i.e., from time first egg was laid until hatching or failure).

Nest Habitat Measurements

Upon nest discovery, a 30-cm diameter hoop (707 cm^2) was centered on each nest and two photographs were taken of each nest with a Canon Digital Rebel XT SLR equipped with a Canon EF 50 mm compact macro standard auto focusing lens, mounted on a tripod, and kept at the same height (i.e., 126 cm from ground to top of camera), focal length, and aperture. From pictures, all rocks (i.e., > 8 cm), pebbles (i.e., < 8 cm; includes gypsum), plant stems, woody debris, and other objects (i.e., cow feces, feathers and bones, clumps of dirt, and manmade objects) were counted within the 707-cm^2 plot. Because parents often bring additional objects (e.g., pebbles) into the nest scrape (Page *et al.* 2009), any objects located within the nest scrape were not counted.

In order to reduce disturbance and predation to nests, habitat characteristics were recorded after nest fate was determined. At each nest, we recorded primary nest substrate (i.e., sand or pebble), measured the distance (cm) to the nearest object (e.g., rock, pebble, woody debris, plant, etc.) up to 50 cm away, and measured the height (cm) of the nearest object in all directions up to 50 cm away. In some instances, no object was located within 50 cm of the nest. In these instances, 0 cm was used as the average height of surrounding objects and 50 cm (i.e., slightly longer than longest distance measured to nearest object [40.5 cm]) as the distance to nearest object. In instances where habitat characteristics were altered (e.g., flooded) during incubation, measurements were not recorded. If habitat characteristics were presumed unaltered after nest fate was determined, pictures taken during incubation were used to verify consistency in habitat characteristics.

Finally, 120 GPS positions per nest were obtained using a Trimble GeoXH GPS unit (Trimble Navigation Ltd, Sunnyvale, CA). All GPS positions were differentially corrected using GPS Pathfinder Office software (Trimble Navigation Ltd, Sunnyvale, CA) from six base stations and averaged to obtain one position for each nest. Using ArcGIS 9.2 (ESRI, Redlands, CA), distance (m) to nearest upland was measured using Euclidian distance to nearest upland edge (i.e., the interface between saline lake substrate/vegetation and upland vegetation). Upland boundaries were digitized using 2004 NAIP digital orthophoto quarter-quadrangle (DOQQ) aerial photographs (Texas Natural Resources Information System 2004). Also, distance (m) to nearest active (i.e., day first egg was laid to day hatched or failed) nest was measured using Hawth's Analysis Tools (Beyer 2004) in ArcGIS 9.2.

Data Analyses

Nest Success. Apparent nest success was calculated for each year and lake separately using a standard proportion (i.e., number of successful nests divided by total number of nests). To test for independence in apparent nest success between years for each lake a Chi-square analysis (PROC FREQ; SAS Institute 2002) was used. Additionally, Program MARK (Dinsmore *et al.* 2002) was used to estimate nest success for each year and lake separately, using a 30-day incubation period (mean incubation period of nests [i.e., from first egg laid until first egg hatched] with known egg laying date = 29.5 days). To estimate variances of nest success (from standard errors for daily survival rates given in Program MARK), the delta method (Seber 1982) was used. In some instances, nests were found the day of hatching or after nest failure (e.g., nest scrape found with crushed egg shells). Because the number of exposure days in both instances was zero, these nests were not included in Program MARK nest success estimates. However, these nests were included in estimates of apparent nest success.

Nest Survival Models. Program MARK nest survival models (Dinsmore *et al.* 2002) were used to examine the influence of temporal (e.g., year, day during the nesting season, and age of nest), spatial (e.g., lake and distance to nearest active nest), condition (e.g., egg volume), and habitat variables on nest success. Daily nest survival was modeled with a set of 85 *a priori* candidate models including a linear time trend (i.e., linear relationship between daily nest survival and days since the beginning of the nesting season; Cooch and White 2002; Dinsmore *et al.* 2002), nest age (i.e., number of days since first egg laid; Cooch and White 2002; Dinsmore *et al.* 2002), year, lake, mean egg volume per nest, distance to nearest active nest, mean surface water available during time nest was active (i.e., date first egg laid to hatching or failure), distance to upland, average height of surrounding objects, distance to nearest object, substrate type (i.e., sand or pebble), and total number of objects as well as number of pebbles/rocks, plants, woody debris, feathers/bones and other objects (i.e., manmade objects, cow feces, and clumps of dirt) within 707-cm^2 plot. Correlated variables ($P \leq 0.05$) were not permitted to enter the same model. In instances where there were missing covariate data for a given nest, the population mean (Cooch and White 2002) was used. Akaike's Information Criterion corrected for small sample size (AIC_c) was used to rank models (a model was considered plausible when $\Delta AIC_c < 2$; Burnham and Anderson 2002) and calculate AIC_c weights. Parameter likelihoods were determined using model averaging (i.e., sum of model weights for models that included a given parameter; Burnham and Anderson 2004). However, parameter estimates, standard errors, and 95% confidence intervals are presented from the top-ranked models.

RESULTS

Nest Success

In this study, 215 Snowy Plover nests were located, of which 44 were located at lake A (15 in 2008 and 29 in 2009), 125 at lake B

(47 in 2008 and 78 in 2009), and 46 at lake C (24 in 2008 and 22 in 2009). A 112-day nesting season was estimated from 16 April-5 August (i.e., day first nest discovered to day last nest hatched or failed). The most common cause of nest failure was predation by mammalian and avian predators (40.4%), followed by weather events that hailed, flooded, blew out, cracked, and/or silted in eggs (36.3%; Table 1). Other causes of nest failure included unknown causes; abandonment; trampling by cattle, vehicles, and humans; and unviable eggs (23.3%; Table 1). Nest fate was not determined for <4% (n = 8) of all nests in both years (see Table 1). Two nests failed at lake B due to capture myopathy of a parent; therefore, 213 nests were used for apparent nest success analyses. Apparent nest success ranged from 8-41% (Table 1), but never varied between years at lake A (χ^2 = 0.92; df = 1; P = 0.34), lake B (χ^2 = 1.65; df = 1; P = 0.20), or lake C (χ^2 = 0.98; df = 1; P = 0.32; Table 1). Of these 213 nests, one was found the day of hatching and seven were found after nest failure. Therefore, 205 nests (44 at lake A, 116 at lake B, and 45 at lake C) were used for Program MARK nest success estimates (Table 1) and nest survival analysis. Program MARK nest success estimates ranged from 7-33% among lakes, with overall nest success = 22.6% and mean nest success = 22.1% for all lakes and years (Table 1).

Nest Survival Models

Among 85 candidate models, the first four models were considered plausible (i.e., $\Delta AIC_c < 2$; Table 2). These models indicated that daily survival rates of Snowy Plover nests varied with number of plants within 707-cm^2 plot, percent surface water available during incubation, days since the beginning of the nesting season (i.e., linear time trend), and distance to nearest object (Table 3). Parameter likelihoods also indicated that percent surface water available during incubation (likelihood = 0.81), number of plants within 707-cm^2 plot (likelihood = 0.54), the interaction between linear time trend and lake (likelihood = 0.38), the interaction between number plants within 707-cm^2 plot and lake (likelihood = 0.21), and the interaction between distance to nearest object and lake (likelihood = 0.15) were the most important variables included in the top-ranked models. For all four top-ranked models (Table 3), a negative relationship existed between nest daily survival rate and number of plants within 707-cm^2 plot, but daily survival rate was positively related to percent surface water available during incubation. Within the top-ranked model, nest daily survival rates were positively influenced by days since the beginning of the nesting season (i.e., linear time trend) at lake A, but negatively influ-

Table 1. Number of nests, nest fates and nest success estimates for Snowy Plovers nesting on saline lakes within the Southern high plains of Texas, USA, 2008-2009.

	Lake A		Lake B		Lake C		
	2008	2009	2008	2009	2008	2009	Total
Total number of nests (n)	15	29	46	77	24	22	213
Successful (n)	4	12	17	20	2	4	59
Unsuccessful (n)	10	15	25	57	21	18	146
Predation (n, %)	5 (50.0)	6 (40.0)	9 (36.0)	19 (33.3)	10 (47.6)	10 (55.6)	59 (40.4)
Weather (n, %)	2 (20.0)	4 (26.7)	10 (40.0)	26 (45.6)	4 (19.0)	7 (38.9)	53 (36.3)
Trampled (n, %)	1 (10.0)	0 (0.0)	0 (0.0)	6 (10.5)	0 (0.0)	0 (0.0)	7 (4.8)
Abandonment (n, %)	0 (0.0)	3 (20.0)	1 (4.0)	6 (10.5)	0 (0.0)	0 (0.0)	10 (6.8)
Unviable (n, %)	0 (0.0)	1 (6.7)	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.6)	2 (1.4)
Unknown (n, %)	2 (20.0)	1 (6.7)	5 (20.0)	0 (0.0)	7 (33.3)	0 (0.0)	15 (10.3)
Unknown[a] (n)	1	2	4	0	1	0	8
Apparent nest success (%)	26.7	41.4	37.0	26.0	8.3	18.2	27.7
MARK[b] (%, 95% CI)	22.4 (3-42)	32.6 (15-50)	31.1 (18-44)	21.6 (13-31)	7.1 (0-15)	18.1 (3-33)	22.6 (17-28)[c]

[a]Unknown clutches may have been successful or failed, but were classified as failed for success estimates.
[b]Nest success estimates obtained from Program MARK.
[c]Overall nest success estimate from Program MARK with year and lake combined (mean of separate lake and year estimates = 22.1%).

Table 2. The ten most-supported models (i.e., $AIC_w > 0.01$) from a set of 85 candidate models (see Saalfeld 2010 for the full model set) describing daily survival rates of Snowy Plover nests on saline lakes within the Southern High Plains of Texas, USA, 2008-2009.

Model	No. parameters	ΔAIC_c[a]	ΔAIC_w[b]
S (linear time trend*lake + percent surface water + no. plants)[c]	8	0.00	0.24
S (no. plants*lake + percent surface water)	7	0.69	0.17
S (distance to object*lake + percent surface water + no. plants)	8	1.78	0.10
S (lake + percent surface water + no. plants)	5	1.96	0.09
S (linear time trend*lake + percent surface water)	7	2.47	0.07
S (percent surface water + no. plants)	3	3.03	0.05
S (no. plants*lake)	6	3.60	0.04
S (linear time trend*lake + percent surface water + avg. height objects)	8	3.89	0.03
S (percent surface water*lake + no. plants)	7	5.33	0.02
S (no. plants)	2	5.52	0.02

[a]Difference between model's Akaike's Information Criterion corrected for small sample size and the lowest ΔAIC_c value.
[b]AIC_c relative weight attributed to model.
[c]Model of additive effects of linear time trend, lake, percent surface water, and no. plants and the interaction between linear time trend and lake.

enced at lakes B and C, although the 95% confidence intervals about the beta coefficient overlapped zero for lakes A and B (Table 3). Within the second-ranked model, nest daily survival rates were negatively influenced by number of plants within 707-cm^2 plots at all lakes; however, the 95% confidence intervals included zero at lakes A and C (Table 3). Within the third-ranked model, nest daily survival rates were positively influenced by distance to nearest object at lakes B and C, but negatively influenced at lake A; however, the 95% confidence intervals included zero at all lakes (Table 3).

DISCUSSION

Program MARK nest success estimates for Snowy Plovers in the SHP of Texas ranged from 7-33% ($\bar{x}$ = 22.1%) depending upon lake, of which the majority of failures were attributed to predation by both mammalian and avian predators (i.e., 33-56% of total failures) and weather events (i.e., 19-46% of total failures). These estimates were generally within the range of nest success estimates from previous studies in the SHP of Texas (i.e., 30-34%: Conway *et al.* 2005a), Great Salt Lake, Utah (26-37%: Paton and Edwards 1990; 5-49%: Paton 1995), Salt Plains National Wildlife Refuge, Oklahoma (17-60%: Hill 1985), and Oregon (13%: Wilson-Jacobs and Meslow 1984), but lower than studies from California (50%: Powell 2001; 36-77%: Powell *et al.* 2002), Salt Plains National Wildlife Refuge, Oklahoma (37-58%: Winton *et al.* 2000), and Puerto Rico (61-73%: Lee 1989). Although upper estimates of current nest success were similar to those from 10 years prior (i.e., 1998-1999) from the same saline lakes within SHP of Texas (Conway *et al.* 2005a), mean nest success has declined by 31%.

Nest success declines could be a result of yearly variation in nest success, as nest success within this region is influenced by unpredictable weather events, variation in hydroperiod (e.g., surface water availability), and/or climatic conditions (Conway *et al.* 2005a). For example, during both years of this study, drought conditions existed, potentially reducing nest success (see Study Area section). However, drought conditions were also present in a year of the previous study (i.e., cumulative rainfall was 11.8 cm below average and 7.1 cm above average in 1998 and 1999, respectively) and did not affect yearly nest success estimates (data obtained from National Climatic Data Center). Similarly, little variation in nest success estimates occurred between years in this study, suggesting that dramatic yearly variation may not exist in this population.

The greater rate of nest failure in this study as compared to 10 years prior may be attributed to greater predation rates, which

Table 3. Maximum likelihood (logit-link) estimates from Program MARK for plausible models (i.e., $\Delta AIC_c < 2$) of daily survival rates of Snowy Plover nests on saline lakes within the Southern High Plains of Texas, USA, 2008-2009.

			95% CI	
Parameter	Estimate	SE	Lower	Upper
Top-ranked model				
Lake A	1.997	0.519	0.979	3.015
Lake B	1.771	0.422	0.943	2.599
Lake C	2.524	0.512	1.521	3.527
Linear time trend (lake A)	0.005	0.008	-0.011	0.021
Linear time trend (lake B)	-0.004	0.006	-0.016	0.008
Linear time trend (lake C)	-0.021	0.008	-0.036	-0.006
Percent surface water	0.024	0.009	0.007	0.040
No. plants	-0.026	0.012	-0.048	-0.003
Second-ranked model				
Lake A	2.643	0.325	2.006	3.279
Lake B	2.174	0.433	1.326	3.022
Lake C	2.024	0.356	1.326	2.721
No. plants (lake A)	-0.078	0.086	-0.246	0.090
No. plants (lake B)	-0.140	0.056	-0.249	-0.031
No. plants (lake C)	-0.024	0.013	-0.049	0.001
Percent surface water	0.014	0.006	0.002	0.027
Third-ranked model				
Lake A	2.676	0.322	2.044	3.307
Lake B	1.966	0.411	1.160	2.773
Lake C	1.835	0.358	1.134	2.537
Dist. object (lake A)	-0.031	0.017	-0.065	0.003
Dist. object (lake B)	0.011	0.013	-0.013	0.036
Dist. object (lake C)	0.041	0.031	-0.020	0.103
Percent surface water	0.016	0.006	0.004	0.028
No. plants	-0.031	0.011	-0.053	-0.009
Fourth-ranked model				
Lake A	2.521	0.306	1.922	3.120
Lake B	1.977	0.409	1.175	2.779
Lake C	1.972	0.350	1.286	2.659
Percent surface water	0.017	0.006	0.005	0.029
No. plants	-0.033	0.011	-0.055	-0.011

increased from 27% (17-52% in 1998-1999) to 40% (39-43% in 2008-2009) between studies. Although no formal predator counts were conducted, nor did we observe predation events, the main predators observed (e.g., visual observations, tracks, etc.) in this study included coyote (*Canis latrans*), domestic dog (*C. lupus familiaris*), raven (*Corvus* spp.), and Black-crowned Night Heron (*Nycticorax nycticorax*). However, in the previous study, no avian predators (Conway *et al.* 2005a) or domestic dogs (W. Conway per. com.) were documented on saline lakes during the breeding season. Although Chihuahuan Ravens (*C. cryptoleucus*) have historically wintered throughout the SHP of Texas (Bednarz and Raitt 2002), few individuals were documented breeding within this region (Sauer 2008). However, both Common (*C. corax*) and Chihuahuan Ravens have experienced population increases and range expansions (Boarman and Heinrich 1999; Bednarz and Raitt 2002), and recently, individuals have been documented during the breeding season within the SHP of Texas more frequently (Sauer 2008). In other regions (California, Oklahoma, Oregon and Utah), avian predators, including ravens, American Crows (*C. brachyrhynchos*), and gulls (*Larus* spp.) are important Snowy Plover egg and chick predators (Page *et al.* 1983; Wilson-Jacobs and Meslow 1984; Paton 1995; Koenen *et al.*

1996b; Winton *et al.* 2000; Powell *et al.* 2002) and can have dramatic impacts on nest success. Therefore, if raven and other predator populations continue to increase, regional nest success may continue to decline.

Predation rates may also account for variability in nest success among lakes, where greater predation rates were observed at lake C, with 43% of nests predated, as compared to only 23-25% at lakes A and B. At lake C, more mammalian predators (i.e., coyotes and domestic dogs) were using lake bottoms, as tracks were observed more frequently than at other lakes (S. Saalfeld per. obs.). Ravens were also observed more frequently at lake C than other lakes, and were nesting in upland areas bordering this lake as well (S. Saalfeld per. obs.). Individual saline lake structure and/or location within the landscape may also influence predation rates at lake C as compared to other lakes, resulting in greater efficiency of predators to locate and approach nests undetected. At lake C, the majority of nesting habitat was located within a narrow strip between the average high water mark and upland areas. By nesting closer to upland areas, predation rates may increase (Koenen *et al.* 1996a), as predators are able to find and approach nests more easily than areas located further from upland areas or in areas with natural barriers (e.g., islands). Also, most nests located at lake C were placed on sand substrate, which tend to have higher predation rates than those placed on heterogeneous substrates (i.e., pebble) that are more camouflaged (Bowman and Harris 1980; Colwell *et al.* 2005).

Predation rates increased when nests were placed near plants. Previous studies examining relationships between nest success and vegetative cover in ground nesting shorebirds have shown mixed results (Prindiville Gaines and Ryan 1988; Colwell 1992; Koenen *et al.* 1996a; Mabee and Estelle 2000; Hood and Dinsmore 2007), due to regional differences in predator communities and behavioral responses to predators (Mabee and Estelle 2000). Most Snowy Plover nest sites are located adjacent to objects (e.g., rocks, woody debris, etc.; Saalfeld 2010) potentially due to the advantages of disruptive effects (Page *et al.* 1985; Flemming *et al.* 1992), temperature control, and safety from weather events. Snowy Plovers may select nest sites adjacent to plants for similar reasons as well as benefits due to shading (e.g., smaller temperature fluctuations; Amat and Masero 2004b). However, incubating adults may be more susceptible to predation while incubating nests near plants because of poorer detectability of approaching predators (Amat and Masero 2004b).

The second major cause of nest failures (36.3%) was from locally intense weather events (i.e., wind, flooding, and hail). Although unpredictable, similar weather-related failure rates were observed in the previous study (i.e., 44.5%; Conway *et al.* 2005a). However, the importance of weather events as a source of nest failure varies regionally and has been identified as important in Oklahoma (Grover and Knopf 1982; Winton *et al.* 2000) and Texas (45%: Conway *et al.* 2005a), but not important in California (4%: Warriner *et al.* 1986; <10%: Powell *et al.* 2002), Oregon (16%: Wilson-Jacobs and Meslow 1984), or Utah (14%: Paton 1995). These differences in nest failures due to weather events are likely the result of regional severity of precipitation events. For example, the probability of severe hail storm occurrence is much greater within the mid-continental U.S. than elsewhere (Schaefer *et al.* 2004). In regions where weather is an important cause of nest failures, timing of weather events can impact timing of nest failures. For example, in this study, devastating weather events (i.e., flooding and hail) occurred later in the season at lake C, causing daily survival rates to decline as the season progressed. Such localized weather events are unpredictable and provide inconsistent impacts on nest success from year to year. Despite these negative effects, precipitation, in general, during the nesting season is required to provide surface water, a necessary landscape feature for nesting Snowy Plovers (Conway *et al.* 2005b).

Surface water availability is likely the most important landscape feature affecting nesting Snowy Plovers in inland areas. In Oregon and Nevada, Herman *et al.* (1988) concluded that the most serious threats to nesting habitat were diversion of water for irrigation, high water conditions, and potentially lowered water levels from geothermal development. Similarly, presence of surface water on saline lakes during the nesting season in the SHP of Texas is dependent upon spring flow, unpredictable weather events, presence of exotic invasive plants (e.g., saltcedar [*Tamarix* spp.]), and irrigation for row-crop agriculture. Presence of saltcedar in and on the margins of regional saline lakes can reduce surface water presence; especially during the nesting season when ambient temperatures are high (Saalfeld 2010). Mature stands of saltcedar uptake large volumes of water (e.g., annual water consumption estimated 4-32 million L/ha; U.S. Bureau of Reclamation 1992), especially during summer (Sala *et al.* 1996). Also, saltcedar may provide nesting and roosting habitat for avian predators (e.g., ravens). Therefore, to conserve subsurface and surface water in saline lakes as well as reduce habitat for avian predators, saltcedar should be removed from areas surrounding lakes, and especially near freshwater springs.

Irrigation can also impact surface water availability. Crop irrigation in the upstream reaches of the Platte River has been suggested to contribute to declines in annual flow, ultimately negatively affecting (e.g., increased vegetation encroachment) Piping Plover (*Charadrius melodus*) and Least Tern (*Sternula antillarum*) nest sites in Nebraska (Faanes 1983). Similarly, irrigation has affected Snowy Plovers nesting on saline lakes in the SHP of Texas. Because these lakes have a direct input from springs connected to the Ogallala aquifer (Brune 2002), crop irrigation relying on the same aquifer during the nesting season has decreased the amount of freshwater input from functioning springs into saline lakes and resulted in permanent drying of most springs in saline lakes within this region (Conway *et al.* 2005a). Therefore, it remains important to conserve freshwater springs discharging into saline lakes as well as the Ogallala aquifer. Retiring irrigation wells in the vicinity of saline lakes should be explored as a means to maintain and/or increase groundwater levels and subsequent spring activity. Additionally, because the Ogallala aquifer is recharged by playa wetlands (Osterkamp and Wood 1987; Bolen *et al.* 1989), it also remains important to conserve the entire complex of wetlands within the SHP of Texas (Andrei *et al.* 2008; Andrei *et al.* 2009).

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