

HABITAT CHANGES AND SUCCESS OF ARTIFICIAL NESTS ON AN ALKALINE FLAT

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ABSTRACT.—We studied habitat changes and success of artificial ground nests on an expansive alkaline flat at Salt Plains National Wildlife Refuge (NWR), Oklahoma, in 1993 and 1994. Aerial photographs of the refuge taken during 1941–1942, 1966, and 1989 were digitized to evaluate changes of the alkaline flat, herbaceous rangeland, and shrub rangeland that was dominated by saltcedar (*Tamarix* spp.). Vegetation cover increased by about 600 ha between 1941 and 1989, and alkaline flat decreased by >240 ha. Field experiments were conducted to determine predator and flooding impacts on artificial nests that simulated Least Tern (*Sterna antillarum*) and Snowy Plover (*Charadrius alexandrinus*) nests. Experimental nest plots were placed on the alkaline flat adjacent to, 500 m from, and 1000 m from herbaceous rangeland, shrub rangeland, and stream habitat that was not associated with vegetation. Plot comparisons were made by calculating the probability of nest success with a modified Mayfield Method. Nests near vegetation had significantly higher losses to mammalian predators ($P < 0.05$) but significantly lower losses to flooding ($P < 0.05$) than nests at 500 or 1000 m from vegetation. Encroaching vegetation will likely continue to reduce habitat for ground-nesting birds and simultaneously increase predation rates on nests. Received 20 June 1995, accepted 10 Jan. 1996.

The interior population of the Least Tern (*Sterna antillarum*) has been listed as endangered since 27 June 1985 (U.S. Fish and Wildl. Serv. 1985). The inland population of the Snowy Plover (*Charadrius alexandrinus*) is currently listed as a Category 2 species (U.S. Fish and Wildl. Serv. 1991), and the coastal population of the Snowy Plover was federally listed as threatened on 5 March 1993 (U.S. Fish and Wildl. Serv. 1993). The population decline of the interior Least Tern has been attributed largely to loss of breeding habitat due to river channelization and construction of impoundments (U.S. Fish and Wildl. Serv. 1990). Snowy Plovers use similar habitat and likely are affected by the same habitat changes that caused the population decline of the interior Least Tern.

An alkaline flat at Salt Plains NWR contains the largest concentration of breeding Least Terns in Oklahoma (U.S. Fish and Wildl. Serv. 1990). Predation and flooding have been identified as the major causes of Least Tern and Snowy Plover egg losses on the flat (Grover and Knopf 1982, Hill 1985, Utych 1993). Coyotes (*Canis latrans*) are the main egg predator, and rain causes sheet flooding on the flat which can wash eggs out of nests.

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Predation and flooding are likely consequences of habitat changes that have occurred at Salt Plains NWR since its creation in the 1930s. Reservoir construction and the spread of saltcedar (*Tamarix* spp.) have altered riparian habitats in the southwestern United States, including parts of Oklahoma (Brock 1994, Stinnet et al. 1987). Several studies have reported higher predation rates on artificial bird nests close to forest-prairie or forest-farmland edge habitats than on nests farther from the edge (Andr n and Angelstr m 1988, Burger 1988, Paton 1993, Wilcove et al. 1986), but no studies have examined predation rates on Least Terns and Snowy Plover eggs relative to proximity to vegetated habitat. We assessed habitat changes at Salt Plains NWR and evaluated their impact on predation and flooding of Least Tern and Snowy Plover nests. As our alternate hypotheses, we predicted that predation rates would be higher on nests situated close to vegetation that provides cover for predators than nests farther from vegetation and that nests closer to streams would be more susceptible to flooding losses than nests farther away from streams.

STUDY AREA AND METHODS

Salt Plains NWR is located in Alfalfa County in northcentral Oklahoma and currently contains an alkaline flat of 5095 ha where Least Terns and Snowy Plovers nest (Grover and Knopf 1982, Hill 1985, Utych 1993, Schweitzer 1994). The alkaline flat is closed to the general public except for a small public use area on the southwestern corner of the flat that is open between 1 April and 15 October for collecting selenite crystals (Koenen 1995).

The alkaline flat is nearly level and poorly drained. The water table is at the surface in some areas and up to 1-m deep in others (Williams and Grover 1975). Salt Plains NWR receives an average annual rainfall of 68 cm, of which about 60% occurs in spring and summer. Rain can cause 1–3 cm sheets of moving water on the alkaline flat, which can remain for several hours to several days. Sheet flooding can wash eggs out of nests and submerge entire colonies.

The alkaline flat at Salt Plains NWR is nearly bare; sparse vegetation includes sea purslane (*Sesuvium verrucosum*) and inland salt grass (*Distichlis stricta*). Vegetation forms well-defined borders at the edge of the alkaline flats. The east and south sides of the alkaline flat are dominated by exotic saltcedar; the north and west sides of the alkaline flat are primarily bordered by grazed mixed-grass prairie.

Creeks flow across the alkaline flat into the Great Salt Lake of Oklahoma and are ephemeral and multibranched. The Great Salt Lake was created by a dam across the Salt Fork of the Arkansas River in 1941. The resulting reservoir flooded about 30% of the original 11, 137-ha alkaline flat (Purdue 1976).

Least Terns nest in loosely defined colonies along the west branch of the Salt Fork of the Arkansas River, Clay Creek, Cottonwood Creek, and Spring Creek and in scattered patches throughout the alkaline flat (Hill 1985, Schweitzer 1994). The average distance between Least Tern nests is 70 m (Schweitzer 1994). Snowy Plover nests are widely scattered and can be found in Least Tern colonies and areas not used by terns. Nests of both species are shallow scrapes (ca 0.5–4 cm deep $\times$ 5–10 cm wide) and typically contain 1–3 eggs (Harrison 1979).

We identified and manually digitized habitat at Salt Plains NWR from 1:16,000 and 1:

20,000 aerial photographs obtained from the Natural Resource Conservation Service, U.S. Dept. of Agriculture, using an Altek graphic digitizer board and GRASS#4.0 (USACERL 1991) Geographical Information System software. Aerial photographs were taken on (1) 24 November 1941 and 22 January 1942, (2) 10 June 1966, and (3) 2 December 1989. The refuge boundary was superimposed over the 1966 photograph, digitized as a separate file, and laid over each digitized habitat map. Digitized habitat (vector) maps were labeled according to major cover types and converted to 30-m resolution raster maps for habitat analyses (Johnson 1993). Cover (ha) was calculated for herbaceous rangeland, shrub rangeland, alkaline flat, and the Great Salt Lake, including an island within Salt Plains NWR's boundary south of Highway 11.

To evaluate the impact of habitat changes and predators on survival of nests of ground nesting birds, we conducted controlled experiments with artificial nests and Japanese Quail (*Coturnix coturnix*) eggs that simulated Least Tern and Snowy Plover nests. Artificial nests were used because we could control nest placement in desired treatment areas. The goal was to identify potential predators, areas sensitive to predation, and areas sensitive to flooding.

In 1993, 60- × 90-m plots were placed adjacent to, 500 m from, and 1000 m from shrub rangeland and the west branch of the Salt Fork of the Arkansas River in the northeastern corner of the alkaline flat (N = 3 plots). In 1994, the experiment was expanded with 15 new plots. A new plot was established about 1000 m north of each of the 1993 plots (N = 3 plots) to replicate assessment of proximity to shrub rangeland. Paired plots were placed about 1000 m from one another and adjacent to, 500 m from, and 1000 m from grazed herbaceous rangeland on the west side of the alkaline flat (N = 6 plots). Similarly, paired plots were placed adjacent to, 500 m from, and 1000 m from Cottonwood Creek, not associated with vegetation cover (N = 6 plots).

Each plot contained 12 artificial nest scrapes placed 30 m apart, and each nest contained 2–3 quail eggs. Eggs were placed in the nests for three 21-day trials (17 May–6 June; 16 June–6 July; and 16 July–6 August) in 1993 and 1994 to imitate the incubation period of Least Terns and Snowy Plovers (Hill 1985). The remaining eggs were removed after each 21-day trial, and scrapes were left empty for 10 days before the beginning of the next trial. Nests were monitored every 3–4 days to determine predation rates and other factors causing nest losses.

Mayfield's method (1975) was used to compare the probability of nest success in each plot. We used a slight modification of the Mayfield method to compare effects of flooding and predation. The Mayfield method determined daily mortality rates and the probability of nest success based on nest failure over the number of days that nests were observed (exposure). Because nest failure may have been the result of flooding, predation, abandonment, or other factors, we modified the Mayfield method to calculate separate rates of daily mortality due to predators (predator mortality) and flooding (flooding mortality). Only clutches lost to predators were considered to have failed when calculating predator mortality. Similarly, only clutches lost to flooding were considered to have failed when calculating flooding mortality. The number of days that $\geq$ one egg remained in nest scrapes was used to determine exposure. Predator and flooding mortality rates were compared among treatments with 95% confidence intervals; significant differences ($P < 0.05$) were demonstrated by non-overlapping confidence intervals (Johnson 1979). Nest success comparisons were made by pooling data for similar treatments (i.e., similar distance from a vegetation type) and trial periods when there were no significant differences.

A nest was considered successful if $\geq$ one egg remained in the nest scrape at the end of the 21-day trial. Nests were considered predated if crushed eggs, large shell fragments, and/or predator footprints were located at a nest. Nests were considered flooded if eggs were

TABLE 1

AERIAL COVERAGE OF DOMINANT HABITAT (HA) AT SALT PLAINS NATIONAL WILDLIFE REFUGE

	1941/1942	1966	1989
Herbaceous rangeland	311	197	336
Shrub rangeland (north)	1546	1853	2142
Shrub rangeland (south)	1044	937	1014
Salt flat	5342	5688	5095
Great Salt Lake	3811	3290	3349
Total area	12,175	12,175	12,175

washed out of nests and relocated in the area. Nests without clear signs of outcome were categorized as unknown and were not included in the final analysis.

RESULTS

Habitat changes.—The refuge boundary south of Highway 11 encompassed 12,175 ha (Table 1). Herbaceous rangeland decreased by 114 ha between 1941 and 1966 and increased by 139 ha between 1966 and 1989. The most dramatic changes occurred on the northeastern side of the refuge where shrub rangeland increased from 1546 to 1853 ha from 1941 to 1966 and increased to 2142 ha between 1966 to 1989. The shrub vegetation spread 12.3 ha/yr between 1941 and 1966 and 12.6 ha/yr between 1966 and 1989. Total herbaceous and shrub rangeland cover increased from 2901 ha in 1941 to 3492 ha in 1989, which represented a 3.4 ha/yr spread from 1941 to 1966 and a 22.0 ha/yr spread from 1966 to 1989. The alkaline flat decreased from 5342 ha in 1941 to 5095 ha in 1989, and the Great Salt Lake decreased 462 ha over the same period. This represented a net loss of 709 ha of alkaline flat and lake cover.

Predator and flooding impact.—In 1993, there were no significant differences ($P > 0.05$) in overall nesting success of artificial nests at various distances from shrub rangeland (Table 2). In 1994, overall nest success adjacent to shrub rangeland (0.42) and adjacent to Cottonwood Creek (0.47) was significantly higher ($P > 0.05$) than nest success in plots 500 m from Cottonwood Creek (0.16) (Table 3). Nest success was not significantly different among plots placed adjacent to, 500 m, and 1000 m from shrub rangeland or herbaceous rangeland. In contrast, nest success was higher adjacent to Cottonwood Creek than 500 m from the Creek.

Coyotes were the only mammalian nest predator positively identified on the salt flats by sight or tracks; however, some tracks may have been from feral dogs (*Canis familiaris*). Canids left distinctive eggshell remains at nests where eggs were eaten; egg remains were similar to those shown

TABLE 2

PROBABILITY OF NEST SUCCESS (MAYFIELD METHOD) AND 95% CONFIDENCE INTERVAL OF ALL NEST PLOTS PLACED AT THREE INTERVALS (0 M, 500 M, AND 1000 M) FROM SHRUB RANGELAND AT SALT PLAINS NATIONAL WILDLIFE REFUGE, OKLAHOMA, IN 1993 (N = 36)

	Shrub rangeland		
	Adjacent to	500 m	1000 m
Overall nest success	0.49 ^a	0.37 ^a	0.28 ^a
Confidence interval (95%)	0.35–0.68	0.25–0.55	0.21–0.50
Nest success based on canid mortality	0.24	0.31	0.15
Confidence interval (95%)	0.08–0.69	0.12–0.79	0.02–1.21
Nest success based on flood mortality	0.52	0.43	0.49
Confidence interval (95%)	0.24–1.09	0.18–0.98	0.23–0.99

^a Probabilities followed by the same letter are not significantly different among columns; 95% confidence interval comparisons (Johnson 1979).

and discussed by Sooter (1946). Ring-billed Gulls (*Larus delawarensis*) increased substantially on the alkaline flat in late July and August 1993 and 1994. They predated up to 83% of artificial nests in treatment plots, but this was not included in our analysis of predation because they did not predate the relatively few Least Tern and Snowy Plover nests that remained that late in the nesting season (Hill 1985, Schweitzer 1994, Koenen 1995). Therefore, our estimates of predator mortality on artificial nests represented predation by only canids, primarily coyotes.

In 1993, there were no significant ($P < 0.05$) differences in nest success among plots associated with shrub rangeland based on mortality due to canids (Table 2). However, comparison of canid predated plots in 1994 indicated significant lower nest success for plots adjacent to shrub and herbaceous rangelands and within 500 m of herbaceous rangeland than 500 m and 1000 m from shrub rangeland, 1000 m from herbaceous rangeland, and all Cottonwood Creek plots (Table 3).

Losses of artificial nests associated with shrub rangeland due to flooding were not significantly different among plots in 1993 (Table 2). Comparison of flooded nests in 1994 indicated significantly ($P > 0.05$) higher nest success adjacent to shrub rangeland (0.89) than on plots located 500 m and 1000 m from shrub rangeland, 1000 m from herbaceous rangeland, and all Cottonwood Creek plots (Table 3). Plots adjacent to herbaceous rangeland also had higher nest success than plots located 500 m and 1000 m from Cottonwood Creek.

DISCUSSION

The absence of high scouring floods due to flood control by reservoir construction has resulted in dense saltcedar stands in sandy floodplains

TABLE 3

PROBABILITY OF NEST SUCCESS (MAYFIELD METHOD) AND 95% CONFIDENCE INTERVAL OF ALL NEST PLOTS (AND REPLICATES) PLACED AT THREE INTERVALS (0 M, 500 M, AND 1000 M) FROM SHRUB RANGELAND, HERBACEOUS RANGELAND, AND COTTONWOOD CREEK AT SALT PLAINS NATIONAL WILDLIFE REFUGE, OKLAHOMA, IN 1994 (N = 36)

	Shrub rangeland			Herbaceous rangeland			Cottonwood Creek		
	0 m	500 m	1000 m	0 m	500 m	1000 m	0 m	500 m	1000 m
Overall nest success	0.42 ^a	0.32 ^{ab}	0.40 ^{ab}	0.29 ^{ab}	0.27 ^{ab}	0.23 ^{ab}	0.47 ^a	0.16 ^b	0.26 ^{ab}
Confidence interval (95%)	0.30–0.59	0.21–0.48	0.27–0.51	0.18–0.47	0.16–0.42	0.13–0.39	0.34–0.65	0.08–0.28	0.16–0.42
Nest success based on candi mortality	0.39 ^a	0.83 ^b	0.86 ^b	0.38 ^a	0.31 ^a	0.86 ^b	0.78 ^b	1.00 ^c	0.93 ^{bc}
Confidence interval (95%)	0.29–0.55	0.72–0.97	0.76–0.90	0.27–0.55	0.21–0.47	0.75–0.98	0.65–0.92	—	0.84–1.03
Nest success based on flood mortality	0.89 ^a	0.59 ^b	0.59 ^b	0.69 ^{ab}	0.64 ^{ab}	0.41 ^{bc}	0.49 ^{bc}	0.26 ^c	0.36 ^{bc}
Confidence interval (95%)	0.80–0.99	0.45–0.76	0.45–0.76	0.55–0.86	0.50–0.82	0.29–0.57	0.36–0.66	0.16–0.39	0.25–0.55

^{a,b,c} Probabilities followed by the same letter are not significantly different among columns; 95% confidence interval comparisons (Johnson 1979).

in the southwestern United States, including Oklahoma (Kerpez and Smith 1987, Stinnet et al. 1987). Sandbars along the Canadian River in western Oklahoma decreased from 68% to 15% of the total floodplain between 1954 and 1983; shrub dominated wetlands increased from 13% to 46%. Schulenberg and Ptacek (1984) noted that encroaching salt cedar on sandbanks in Kansas reduced nesting habitat available to Least Terns.

Vegetation in Least Tern colonies generally does not cover >20% of the ground surface (Thompson and Slack 1982, Gochfeld 1983). Encroaching vegetation and related habitat changes may cause terns to abandon a site (Gochfeld 1983, Burger 1984, U.S. Fish and Wildl. Serv. 1990, Boyd and Rupert 1991, Ziewitz 1992). Saltcedar tolerates the salt levels found on the alkaline flats at Salt Plains NWR (Ungar 1966) and dominated the shrub rangeland that encroached about 709 ha onto the alkaline flat and waterways between 1941 and 1989. The rate of spread on the northeastern alkaline flats was similar from 1941 to 1966 and from 1966 to 1989. Because of the high water table and often saturated soils on the salt flat, the saltcedar-dominated shrub rangeland will likely continue to spread away from the west branch of the Salt Fork of the Arkansas River and onto the alkaline flat. Herbaceous rangeland cover fluctuated slightly between periods analyzed; however, it does not appear to be encroaching onto the salt flat habitat.

Our artificial nest experiment indicated that overall nest success was relatively similar near vegetated or away from vegetated areas. However, causes of nest failure differed among experimental areas. In support of our alternate hypotheses, nests adjacent to shrub rangeland had greatest nest failure from predators in 1994 and areas near streams had highest nest losses due to flooding. However, areas adjacent to a stream with shrub rangeland had lower nest losses due to flooding than areas near a stream with no vegetation. The saltcedar-dominated rangeland may have encroached into these areas because flooding did not regularly occur there. In contrast, dense saltcedar stands also can stabilize substrate and alter fluvial processes (Stinnet et al. 1987). After established, vegetation may have channeled water away from the salt flats or acted as a barrier to sheet flooding. Saltcedar has not become fully established on the west bank of the west branch of the Salt Fork of the Arkansas River; continued saltcedar encroachment may further alter fluvial processes and have positive or negative consequences for ground nesting birds. Accelerated saltcedar growth along the Rio Grande, Pecos, and Gila rivers, for example, stabilized channel sediments, reduced stream velocity, accelerated sedimentation, and increased flood risks (Blackburn et al. 1982).

The increase in shrub rangeland over the last 50 years at Salt Plains NWR likely increased habitat favorable for canids and their predation of

tern and plover nests. Coyotes have been implicated as major nest predators of Least Tern and Snowy Plover nests at Salt Plains NWR; about 5 to 60% of monitored nests have been lost to predators annually between 1977 and 1994 (Grover and Knopf 1982, Hill 1985, Utych 1993, Koenen et al. 1996). Artificial nests may not be as vulnerable to predation as real nests (Angelstram 1986, Andrén and Angelstram 1988, Martin 1987, Willebrand and Marctström 1988, Paton 1993); however, there was no significant difference in the rate of canid predation of artificial nests and real nests in our study (Koenen 1995). Because of similarity between artificial nests and real nests, we contend that management must account for the different factors that cause nest losses on different areas of the alkaline flat. Nesting areas near vegetated areas should receive greater protection from predators, while areas farther from vegetation should be managed to minimize effects of flooding (Koenen et al. 1996). Long-term management plans also should consider vegetation control to maintain nesting areas, reduce impact of predators, and monitor changes in flooding potential.

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