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METHODS USED TO IMPROVE LEAST TERN AND SNOWY PLOVER NESTING SUCCESS ON ALKALINE FLATS

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Abstract.—We evaluated two management methods to increase nesting success of endangered interior Least Terns (*Sterna antillarum*) and Snowy Plovers (*Charadrius alexandrinus*) at Salt Plains National Wildlife Refuge, Oklahoma. Nest ridges were constructed from existing substrate and designed to provide elevated habitat safe from sheet flooding. Solar-powered electric fences were built to reduce predation by mammals. Least Tern and Snowy Plover nests on and off ridges were located inside and outside fenced areas and revisited every 3–4 d to quantify nest success using the Mayfield Method and determine causes of nest failure. Nest ridges did not reduce nest losses to flooding and further design improvements are necessary. Electric fences did not significantly reduce annual egg predation except for Least Terns during one year of the study. Pooled data for 1991–1994, however, indicated significantly higher Least Tern and slightly higher Snowy Plover nest success inside than outside of electric fences.

MÉTODOS USADOS PARA MEJORAR EL ÉXITO EN ANIDAJE DE *STERNA ANTILLARUM* Y DE *CHARADRIUS ALEXANDRINUS* EN PLANICIES ALCALINAS

Sinopsis.—Evaluamos dos métodos de manejo para aumentar el exìto en anidar de las especies en peligro *Sterna antillarum* y de *Charadrius alexandrinus* en el Refugio de Vida Silvestre Nacional de Salt Plains en Oklahoma. Se construyeron lomos de nidos de sustrato existente diseñados para proveer un habitáculo elevado seguro de inundaciones extensas. Se construyeron cercas eléctricas funcionales con energia solar para reducir la depredación por mamíferos. Se localizaron nidos de ambas especies dentro y fuera de las áreas cercadas y tanto sobre los lomos como fuera de ellos y se revisitaron cada 3–4 días para cuantificar el éxito en anidamiento según el método de Mayfield y para determinar las causas de fracaso en anidamiento. Los lomos de nidos no redujeron la pérdido de nidos debido a las inundaciones y se necesita mejorar el diseño. Las cercas eléctricas no redujeron significativamente la depredación anual de huevos excepto de *Sterna antillarum* durante un año del estudio. Sin embargo, los datos combinados entre 1991–1994 indicaron un exito de anidamiento significativamente alto para *Sterna antillarum* y ligeramente alto para *Charadrius alexandrinus* dentro de las cercas electricas.

The interior population of the Least Tern (*Sterna antillarum*) has been listed as endangered since 1985 (U.S. Fish and Wildlife Service 1985).

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The inland population of the Snowy Plover (*Charadrius alexandrinus*) is currently listed under Category 2 (U.S. Fish and Wildlife Service 1991) of the Endangered Species Act; the coastal population of the Snowy Plover was federally listed as threatened in 1993 (U.S. Fish and Wildlife Service 1993). The decline of the interior population of Least Terns has been attributed largely to loss of breeding habitat due to river channelization and construction of impoundments (U.S. Fish and Wildlife Service 1990). Snowy Plovers use similar habitat and likely are affected by the same habitat changes that caused the Least Tern population to decline. Due to loss of breeding habitat, management of remaining nesting areas is important to the conservation and recovery of both species. Flooding and predation have been identified as the major causes of interior Least Tern (Boyd 1993, Sidle et al. 1992, Smith and Renken 1993, Wood 1994) and Snowy Plover (Koenen 1995, Warriner et al. 1986, Wilson 1980) egg losses throughout their breeding ranges.

Alkaline flats at Salt Plains National Wildlife Refuge (NWR), Oklahoma contain one the largest breeding populations of Interior Least Terns in the United States (U.S. Fish and Wildlife Service 1990). Annual population estimates recorded on the salt flats since 1982 have ranged from 82–270 adult birds (Hill 1993). Rain during May–August can cause sheet flooding on the alkaline flats and wash eggs out of nests or completely submerge nests; flooding may account for up to 67% of all nest failures (Grover and Knopf 1982). Coyotes (*Canis latrans*), Ring-billed Gulls (*Larus delawarensis*), and Cattle Egrets (*Bubulcus ibis*) are the only known egg predators on these flats (Grover and Knopf 1982, Hill 1985, Koenen 1995, Utych 1993). Grover and Knopf (1982) attributed up to 57.7% of all nest losses at Salt Plains NWR to coyotes.

In spring 1990, refuge personnel built nest ridges from existing substrate to protect and enhance Snowy Plover and essential Least Tern breeding habitat as directed by the Interior Least Tern recovery plan objectives (U.S. Fish and Wildlife Service 1990). Nest mounds constructed from a 19-liter bucket of gravel topped with 19-liter bucket of sand have been used in Kansas to enhance nest sites for Least Terns (Boyd 1993). However, the efficacy of nest ridges and nest mounds have not been evaluated critically in the literature.

The refuge placed electric fences around the nest ridges in 1991 to decrease egg predation. Electric predator fences have been used to protect waterfowl, Least Terns, and Sandwich Terns (*Sterna sandvicensis*) by excluding small carnivores such as skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), or badger (*Taxidea taxus*) (Lokemoen et al. 1982, Minsky 1980, Sargeant et al. 1974). A variety of coyote-exclusion fence designs have been used to protect livestock pastures (Linhart et al. 1982, Nass and Theade 1988), Piping Plover (*Charadrius melodus*) nesting areas in North Dakota (Mayer and Ryan 1991), and Least Terns in Kansas (Boyd and Rupert 1991). However, the value of electric fences designed to protect Least Terns and Snowy Plovers nesting on alkaline flats from coyote predation has not been assessed.

We evaluated the efficacy of nest ridges and electric fences employed at Salt Plains NWR to increase nest success of Least Terns and Snowy Plovers. We hypothesized that: (1) nest ridges reduce nest loss due to flooding and (2) electric fences reduce egg predation by mammals.

STUDY AREA AND METHODS

Salt Plains NWR, located in Alfalfa County in north-central Oklahoma (36°45′N, 98°15′E), contains 5095 ha of alkaline flats that serve as an important breeding area for Least Terns and Snowy Plovers (Grover and Knopf 1982, Hill 1985, Schweitzer 1994, Utych 1993). The flats are nearly level and poorly drained. Salt Plains NWR receives an average annual rainfall of 68 cm; almost 60% of that may occur in spring and summer during the breeding periods of Least Tern (May–August) and Snowy Plover (April–September). Ephemeral and multibranched creeks flow across the flats into the Great Salt Lake, a reservoir built in 1941. The alkaline flats are closed to the general public, except for a rotating 9–15 ha public use area that is open annually between 1 April and 15 October for selenite crystal digging.

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 (Hill 1985, Utych 1993). The average distance between Least Tern nests is 70 m (Schweitzer 1994), but nest distances range from 5 m to >500 m. Snowy Plovers nest among Least Tern colonies and in scattered patches throughout the alkaline flats.

In spring 1990, prior to the breeding season, refuge personnel plowed 14 nest ridges (ca. 10-m long × 1-m wide × 0.5-m high). Ridges were placed approximately 20–30 m apart adjacent to areas previously used by Least Terns to avoid disturbing historically occupied habitat (L. Hill, pers. comm.). Wind and rain eroded the ridges to a height of 30–40 cm in 1991, 10–20 cm in 1992, 3–6 cm in 1993, and 0–3 cm in 1994. In fall 1990, a square 16-ha electric fence exclosure was built around these experimental ridges. In 1993, spring floods damaged the exclosure prior to the Least Tern breeding season; the exclosure was partially rebuilt and enclosed only 4.5-ha. A second 24-ha (300 × 800 m) electric fence exclosure was established in May 1993 approximately 1,000 m south of the 4.5-ha exclosure. Eight sand and gravel nest mounds, as described above and used by Boyd and Rupert (1991), were placed in the exclosure after fence completion and before the tern nesting season. The sand washed away within 1 mo leaving only 4-cm high gravel pads. Sixty-five new ridges were added to the electrically fenced areas in fall 1993. In addition, 14 experimental mounds consisting of local clay, sand, and debris (20–150 cm sticks) to reduce erosion were constructed in the fenced areas. Mounds were approximately 2-m wide at the base and 0.5-m high.

We generated 20 random points on a grid laid over a diagram of the fenced area with experimental ridges and compared actual nest locations to the location of random points. A chi-square test was used to determine if nests were placed on ridges more than would be expected by chance.

Fences were powered by a deep cycle 12-volt marine battery supported by a Gallaghar B-150 solar energizer resulting in a 1000–6000 volt charge. Wire strands were placed approximately 14, 28, 42, 62, and 86 cm from the ground to prevent coyotes from entering exclosures. Wires were fastened with plastic insulators to steel posts that were spaced at 6-m intervals. Fence costs were estimated at $0.85/m (Utych 1993).

Least Tern and Snowy Plover nests were located by systematic searches of the alkaline flats between May and August 1991–1994. Nests were marked with 30-cm dowels placed at least 10 m north of each nest cup. We revisited Least Tern and Snowy Plover nests every 3–4 d in all fenced exclosures and at control areas that were located within about 2 km of the fences.

Determining seasonal fecundity for Least Terns and Snowy Plovers on the alkaline flats was not possible due to the expansive habitat and our inability to systematically relocate chicks after they left the nest. Analyses of nest success were therefore limited to estimating hatching success of both species as discussed by Mayfield (1975). We calculated nest success for Least Terns and Snowy Plovers from 1991 through 1994 on and off nest ridges inside the electric fences. Nests on ridges included nests on mounds to increase sample size for the final analyses. After finding no significant differences between nests on and off ridges, we pooled all nests in fenced exclosures for nest success comparison to the nests in the control area.

We modified Mayfield's method to separately assess effects of flooding and predation on nest success. The Mayfield method determined nest success based on nest failure over the number of days that nests were observed (exposure). Nest failure is a general term and may result from flooding, predation, abandonment, or other factors. The Mayfield Method was modified to determine nest success using only failed nests lost to predation to determine the daily mortality rate due to predators. Only nests lost to flooding were considered failed nests when calculating daily mortality rate due to flooding. The number of days that nests had ≥1 eggs was used to determine exposure. We assumed a 21-d incubation period for Least Terns and a 25-d period for Snowy Plovers (Hill 1985). Mortality rates due to predators or flooding were used separately to determine nest success and calculate associated standard errors (Johnson 1979). Multiple comparisons among years were made with 95% confidence intervals; combined data from 1991–1994 were compared with two-tailed t-tests.

A nest was considered successful if ≥1 egg hatched. Hatching was indicated by (1) the presence of chicks in or near the nest, (2) chick fecal material, or (3) eggshell fragments that were approximately the size of a pencil tip and resulted from hatching. Nests were considered lost to predators if crushed eggs, larger shell fragments than described above, or predator footprints were located at the nest site. Nests were considered flooded if found under water or eggs were washed out of nests and relocated in the area. Least Tern and Snowy Plover nests were considered abandoned if eggs became partially buried by windblown sand or no adult birds were associated with a nest for ≥3 consecutive observer visits. Nests without clear signs of outcome were categorized as unknown.

RESULTS

The number of Least Tern nests within 500 m of the center of the original ridge area increased from 2 in 1990 to a peak of 16 in 1993. Snowy Plover nests increased from 1 in 1991 to a peak of 20 in 1993. Least Tern and Snowy Plover nest numbers decreased from 1993 to 1994. No more than 10 Least Tern or 8 Snowy Plover nests occurred in the original fenced area, and no more than 8 Least Tern or 8 Snowy Plover nests were located on a ridge during any year of the study.

Least Terns (χ^2 = 71.6, $P < 0.001$) and Snowy Plovers (χ^2 = 61.5, $P < 0.001$) selected nest sites on ridges more than expected in the fenced exclosure with ridges from 1991 to 1994. Of the eight sand and gravel nest mounds, one was selected for a nest site by Least Terns and one by Snowy Plovers in 1993 and again in 1994. Nest ridges built in fall 1993 were not selected more than expected by Least Terns (χ^2 = 0.1, P = 0.7) and Snowy Plovers (χ^2 = 0.3, P = 0.6) in 1994; only one Least Tern nest and two Snowy Plover nests were found on the new ridges. None of the 14 mounds built in 1993 were used by either species in 1994. In 1994, Least Terns (χ^2 = 18.5, $P < 0.001$) and Snowy Plovers (χ^2 = 7.3, P = 0.007) nested more on old ridges (built in 1990) than expected.

During this study, Least Tern nests on and off ridges in the fenced area were lost with ≥1.0 cm rains. Snowy Plover nests on ridges were lost during ≥2.8 cm of rain, but Snowy Plover nests off ridges were lost to flooding with ≥2.3 cm of rain. During this study, nest success for Least Terns on ridges ranged from 0.23 to 1.00 (Table 1). There were no differences ($P > 0.05$) in nest success between Least Terns nesting on or off ridges from 1991 to 1994. Snowy Plover nest success ranged from 0.13 to 1.00. Snowy Plover nests on ridges were not more successful than nests off of ridges ($P > 0.05$). Combined data for the 4-year study indicated that nest success was not different for terns or plovers on and off ridges.

Coyotes entered the fence exclosures on five occasions in 1991 and 1992, but no eggs were depredated. At least one coyote also entered the fence exclosures in both 1993 and 1994 and predated one and three Least Tern nests, respectively. Footprints suggested that avian predators took eggs from one Snowy Plover nest in 1992 and one in 1994 in the fenced exclosures. Eggs from one Least Tern nest in the fenced exclosure were depredated by avian predators in 1993. Eggs were depredated from one Least Tern nest and one Snowy Plover nest in the control area by avian predators in 1993 and 1994, respectively. In three of the nine cases, avian predators were Ring-billed Gulls.

Least Tern nests in the fenced exclosure had higher nest success ($P < 0.05$) in 1991 than nests outside of fenced exclosures (Table 2). There was no difference between Snowy Plover nest success inside and outside the exclosures in 1991. From 1992 to 1994, there were no significant

TABLE 1. Least Tern and Snowy Plover nest success (Mayfield Method), 95% confidence intervals, and losses for all nests on and off of nest ridges (includes nests on mounds), Salt Plains National Wildlife Refuge, Oklahoma.

	1990[a]	1991		1992		1993		1994		All years	
	On	On	Off	On	Off	On	Off	On	Off	On	Off
Least Terns											
n	2	4	0	7	7	13	15	8	6	32	28
Nest Success	0	1.00	—	0.61	0.60	0.23	0.47	1.00	0.62	0.53	0.53
Confidence Interval (95%)	—	—	—	0.30–1.00	0.29–1.00	0.08–0.64	0.23–0.91	—	0.23–1.00	0.36–0.79	0.34–0.83
Predation	2	0	0	0	0	0	3	2	1	2	4
Flood	0	0	0	2	2	8	5	0	1	10	8
Other nest losses[b]	0	0	0	1	0	0	0	1	1	2	1
Unknown nest outcome	0	0	0	0	0	2	1	1	1	3	2
Snowy Plover											
n	1	2	—	7	13	8	6	5	7	22	26
Nest Success	0	1.00	—	0.71	0.62	0.79	0.12	1.00	1.00	0.79	0.62
Confidence Interval (95%)	—	—	—	0.45–1.00	0.35–1.00	0.49–1.00	0.01–0.92	—	—	0.58–1.00	0.42–0.48
Predation	1	0	—	1	0	0	0	0	1	1	1
Flood	0	0	—	2	3	1	4	0	0	3	7
Other nest losses[b]	0	0	—	0	0	2	0	0	0	2	0
Unknown nest outcome	0	0	—	0	1	2	0	1	1	3	2

[a] From Boyd (1990).
[b] Includes nests with cracked eggs, abandoned nests, and chicks that died during hatching process.

TABLE 2. Least Tern and Snowy Plover nest success (Mayfield Method), 95% confidence intervals, and losses for all nests in and out of electric fences, Salt Plains National Wildlife Refuge, Oklahoma.

	1991		1992		1993		1994		All years	
	In	Out	In	Out	In	Out	In	Out	In	Out
Least Tern										
n	4	11	14	9	28	50	14	59	60	129
Nest Success	1.00	0.17	1.00	0.51	0.78	0.75	0.61	0.52	0.81	0.56
Confidence Interval (95%)	—	0.03–0.78	—	0.23–1.00	0.59–1.00	0.58–0.97	0.34–1.00	0.36–0.74	0.68–0.96	0.44–0.70
Predation	0	5	0	3	3[b]	5	3[c]	13	6	26
Flood	0	0	4	3	13	23	1	1	18	27
Other nest losses[a]	0	3	1	1	0	3	2	5	3	12
Unknown nest outcome	0	0	0	2	3	9	2	9	5	20
Snowy Plover										
n	2	9	20	23	18	67	12	24	52	123
Nest Success	1.00	0.82	0.91	0.55	0.87	0.77	0.89	1.00	0.90	0.76
Confidence Interval (95%)	—	0.55–1.00	0.75–1.00	0.34–0.86	0.66–1.00	0.61–0.97	0.70–1.00	—	0.79–1.00	0.64–0.88
Predation	0	1	1[d]	7	1	5	1[b]	0	3	13
Flood	0	1	5	7	5	30	0	1	10	39
Other nest losses[a]	0	1	0	0	0	7	0	2	0	10
Unknown nest outcome	0	0	1	3	6	15	2	5	9	23

[a] Includes nests with cracked eggs, abandoned nests, and chicks that died during hatching process.
[b] 1 nest predated by a Ring-billed gull.
[c] Predated by a coyote on 14 Jun. 1994.
[d] Predated by a Cattle Egret (Utych 1993)

differences in Least Tern and Snowy Plover nest success inside and outside of the exclosures. Combined data from 1991–1994 indicated higher nest success for Least Terns (t = 2.6, P = 0.01) in the fenced exclosures compared to outside the exclosures; Snowy Plovers had slightly higher nest success inside than outside of the fences (t = 1.8, P = 0.07).

DISCUSSION

Nest ridges.—Nest ridges (including mounds) were designed to offer elevated nesting sites safe from sheet flooding, which commonly occurs during and after rain on the alkaline flats. Least Terns began to use the experimental ridge area within 1 year after it was built. The rapid increase in number of birds nesting in the area suggested that the birds were attracted to the nest ridges. Some Least Terns and Snowy Plovers selected nest sites on ridges; however, neither species selected nest ridges built ≤6 mo before the breeding season. Boyd (1990) suggested that terns avoid nesting on pointed or new ridge tops such as those in the fenced exclosure in 1990 and 1993. Weathering rounds ridge tops, and Least Terns were more likely to nest on them >6 mo after construction. Ridges built in 1993 may not have weathered enough to attract nesting Least Terns and Snowy Plovers. However, because we could not replicate an area like this, we do not know definitely if nest ridges attracted nesting birds. Least Terns and Snowy Plovers may have moved into the fenced exclosure for a variety of factors including demographic changes, environmental or habitat changes (Burger 1984, Koenen 1995, Page et al. 1991, U.S. Fish and Wildlife Service 1990), or unknown factors.

Nest ridges did not offer protection from flooding to Least Terns. Least Tern nests on and off ridges were flooded with ≥1.0 cm rains. Other areas on the alkaline flats were at greater risk to flooding; some Least Tern nests were flooded after 0.5 cm of rain. Snowy Plover nests survived greater flooding events than Least Tern nests; plover nests did not flood until ≥2.3 cm of rain. Plover nests on ridges fared slightly better than nests off of ridges and did not flood until ≥2.8 cm or rain. Nesting behavior or nest site selection (Hill 1985) may account for the differential nest losses between terns and plovers.

Lack of significant differences in nest success between nests on and off ridges may have been due, in part, to small sample sizes of terns and plovers nesting in the fenced exclosure (<20 nests per species) in most years of our study. In 1993, when sample sizes were greatest (n = 28 Least Tern nests), nest ridges had eroded to their lowest height. Least Terns and Snowy Plovers may not nest on ridges until after they are no longer high enough to protect nests from sheet flooding. Likewise, nest ridges and mounds made from the natural substrate are nearly impervious to rain; nest cups may have filled with water, which may have pushed eggs out. Gravel substrate without sand may be more effective material for nest ridges and mounds because nest cups did not fill with water. Relocating existing nests on mounds made of old tires and sand also has been used to protect nests from flooding in a coastal habitat (Loftin and Thompson

1979) but would be labor intensive at Salt Plains NWR due to the expansive habitat and widely spaced nests.

Electric fences.—Coyotes are major egg predators of Least Tern and Snowy Plovers (Boyd and Rupert 1991, Grover and Knopf 1982, Page et al. 1985, Utych 1993) and were the only mammalian egg predator identified on the alkaline flats from 1991 to 1994. About 5–60% of monitored tern and plover nests have been lost to coyotes annually from 1977–1994 at Salt Plains NWR (Grover and Knopf 1982, Hill 1985, Koenen 1995, Utych 1993). Annual nest success for Least Terns was increased by electric fences only during 1991. However, pooling the four years of data effectively reduced the standard error and demonstrated an overall efficacy of electric fences to improve nest success of Least Terns. Although fences proved to be effective at reducing predation on Least Terns and Snowy Plovers, there were a number of problems associated with fences on the alkaline flats.

(1) Electric fences can protect only a fraction of the terns nesting on the alkaline flats. Only 13.6% of all Least Tern and 9.4% of all Snowy Plover nests monitored during this and concurrent studies at Salt Plains NWR from 1991–1994 occurred in fenced areas.

(2) Least Tern colonies shift between years (Burger 1984, Koenen 1995), sometimes rendering permanently fenced areas unused. In 1994, for example, fewer Least Tern nests occurred in the fenced areas than in 1993. Placing temporary fences around each year's established tern colonies may provide better protection to a greater number of birds.

(3) Heavy winds, debris, or flooding may easily neutralize electric fences. At least one coyote entered an exclosure in 1994 and depredated eggs from three Least Tern nests because debris had blown into the fence temporarily damaging it. Fences need to be checked daily to ensure that they are functioning properly.

(4) Coyotes may jump through (Utych 1993) or over electric fences. Thompson (1978) noted that wild caught coyotes could jump over 152 cm high fences. Previous coyote exclusion experiments used 130-cm (Dorrance and Bourne 1980) and 168-cm tall fences (Linhart et al. 1982). Adding extra strands to the top of the 86 cm fence at Salt Plains NWR may reduce coyote intrusion.

(5) Fences do not protect chicks if they leave the fenced areas. There is currently little information about the activities and survival of Least Tern and Snowy Plover chicks on the alkaline flats. Boyd (1972) recorded <20-day-old Snowy Plover chicks moving approximately 3.2 km from their nest in Kansas. We relocated a 15-day-old banded Least Tern chick approximately 1 km from the nest in 1994. Large fences may provide greater protection to chicks but also will increase the potential for electrical malfunctions (Nass and Theade 1988).

(6) Avian predators such as Ring-billed Gulls are not hindered by electric fences and some species may even be attracted to fence posts for perching. Other potential avian predators at Salt Plains NWR include Cattle Egret, Great Blue Herons (*Ardea herodias*), Black-crowned Night-

Herons (*Nycticorax nycticorax*) (Kirsch 1992, Nisbet 1984), Northern Harriers (*Circus cyaneus*), Red-tailed Hawks (*Buteo jamaicensis*) (Wood 1994), American Kestrels (*Falco sparverius*) (Atwood and Massey 1988), icterids (Becker and Erdelen 1987, Page et al. 1985), corvids (Burger 1984, Page et al. 1985), and Great Horned Owls (*Bubo virginianus*) (Lingle 1993).

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