BREEDING ECOLOGY AND MANAGEMENT OF LEAST TERNS, SNOWY PLOVERS, AND AMERICAN AVOCETS

By

MARCUS THEODOR KOENEN
Bachelor of Arts
University of Michigan
Ann Arbor, Michigan
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PREFACE

Chapters in this thesis are written in manuscript formats suitable for submission to selected scientific journals. Each manuscript is complete without supporting materials. Chapter I follows the format of the Journal of Wildlife Management; Chapter II the format of the Journal of Field Ornithology; Chapter III the Wilson Bulletin; and Chapter IV the Condor.

Russell Utych presented findings from the first 2 years of this project in 2 Annual Reports (1991 and 1992) and a M. S. thesis (1993). These reports cover results of: 1) an assessment of compatibility of the annual harvest of selenite crystals near Clay Creek in Salt Plains National Wildlife Refuge with breeding activities of least terns and snowy plovers, 2) an assessment of least tern and snowy plover use of the selenite crystal dig site, and 3) a study determining the efficacy of electrified fencing to decrease predation of least tern and snowy plover nests. One additional Annual Report (1993) and 1 Final Report (1995) were completed as part of this project. The Annual Reports presented preliminary results of this study, and the Final Report presented the same data as Chapter I. All reports were submitted to Salt Plains National Wildlife Refuge and are available to interested individuals from the Oklahoma Cooperative Fish and Wildlife Research Unit, Oklahoma State University, Stillwater, Oklahoma 74078 (telephone 405-744-6342)

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Chapter I

COMPATABILITY OF SELENITE CRYSTAL DIGGING AND NESTING INTERIOR LEAST TERNS AT SALT PLAINS NATIONAL WILDLIFE REFUGE

Abstract: A 4-year study was initiated in 1991 and completed in 1994 to evaluate the impact of selenite crystal digging on endangered interior least terns (*Sterna antillarum*) at Salt Plains National Wildlife Refuge, Alfalfa County, Oklahoma. Least tern nests were located and monitored every 3-4 days to determine spatial use and nest success. Nests were mapped and harmonic mean isoclines were used to define nesting colonies. Significant ($P < 0.05$) colony shifts occurred between each year of the study. Least tern colony shifts may have been in response to changes of crystal digging activity; however, interpretation was confounded by flooding effects, stream dynamics, demographic changes, habitat changes, or unknown factors. Nest success, flush distances, and time spent on the nest were used to evaluate human impact; however, no significant differences ($P > 0.05$) were noted between least terns nesting near digging activities and those nesting at a control location where human activity was restricted between 1991 and 1994. Least tern area use was not different when visitors were present or absent. Management recommendations include continued monitoring of nesting terns by refuge personnel and if least tern

colonies establish within about 500 m of active dig units, cessation or moving of digging activities may be warranted.

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Key words: colonial waterbirds, human disturbance, least terns, Sterna antillarum, Oklahoma, Salt Plains National Wildlife Refuge.

National Wildlife Refuges are guided by a doctrine of compatibility that permits only those uses on a refuge compatible with the primary purpose for which the refuge was established (Curtin 1993). At present, numerous refuges are reviewing the compatibility of alternate refuge uses with their primary use. There has been concern that recreational human uses may not be compatible with recovery objectives for the endangered interior population of least terns (Boyd 1990, U.S. Fish and Wildl. Serv. 1990, Young 1993). The interior population of least terns has been listed as endangered since 27 June 1985 (U.S. Fish and Wildl. Serv. 1985). Salt Plains National Wildlife Refuge (NWR) hosts Oklahoma's largest concentration of nesting least terns (U.S. Fish and Wildl. Serv. 1990). Recreationists can cause a variety of disturbances to nesting birds including reduction in reproductive success (Hunt 1972, Safina and Burger 1983, Keller 1989, Smith and Renken 1993), reduced fledging success (Fetterolf 1983), nest abandonment (Burger 1981a, Piatt et al. 1990), colony desertion (Massey 1974, Burger 1984), increased flush distances (Fraser et al. 1985), and reduction in suitable areas used for foraging, nesting, or roosting (Burger 1981a, Klein 1993).

A 4-year study was initiated in summer 1991 at Salt Plains NWR to determine compatibility between crystal digging activities and nesting least terns. To determine the impact of crystal digging, we analyzed: (1) colony shifts between years; (2) nest success as determined by the Mayfield Method (Mayfield 1975, Johnson 1979); (3) flush distances of nesting least terns; (4) time spent on the nest; and (5) area use patterns by least terns. If crystal digging activities at Salt Plains NWR adversely affected least tern breeding biology, we hypothesized that (1) colonies would shift away from digging activities on an annual basis; (2) nesting success would be lower in the dig area than in control colonies not associated with digging activities; (3) least terns in the dig area would flush from their nests at different distances than those in the control colonies (i.e., dig unit greater than control if terns were disturbed by diggers, or dig unit shorter than control if terns habituated to diggers' presence); (4) least terns in the dig area would spend less time incubating eggs than in the control colonies; and (5) least terns would use the dig area less frequently when crystal diggers are present than when absent.

We thank C. Anderson, B. McAbee, S. L. Gale Koenen, S. H. Schweitzer, K. A. Shannon, and S. Smith for countless hours of field work. Great appreciation also is extended to the refuge personnel, particularly manager R. Krey, for their immense and gracious support. Funding for this study was provided by Region 2 of the U.S. Fish and Wildlife Service, Salt Plains NWR, and the Oklahoma Cooperative Fish and Wildlife Research Unit (U.S. Nat. Biol. Serv.,

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STUDY AREA

Salt Plains NWR is located in Alfalfa County in northcentral Oklahoma (Fig. 1) and contains a 4,050-ha salt flat that serves as a breeding ground for least terns (Grover and Knopf 1982). The flat is nearly level and poorly drained. The altitude ranges from approximately 340-350 m. The salt flats consist of reddish brown salorthid soil series with a thin (approximately 0.01-3.00 cm) layer of white crystalline salt crust that forms on the surface (Williams and Grover 1975). The salt is the result of brine upflows from underlying Permian rock (Johnson 1972). Most surfaces are bare, but vegetation includes sea purslane (Sesuvium verrucosum), inland salt grass (Distichlis stricta) and saltmarsh bulrush (Scirpus paludosis). Exotic salt cedar (Tamarix spp.) is invading on the boundary of the salt flats, particularly along waterways. Standing water on the salt flats is ephemeral and of variable depth and amount; it may contain chloride concentrations of 825-5,156 mEq/l (Purdue and Haines 1977). Salt Plains NWR receives an average annual rainfall of 68 cm. Almost 60% of that occurs in spring and summer. Average wind speed is 21 kph, but southwesterly winds of 48-72 kph are common in spring (Williams and Grover 1975).

Unique selenite crystals with an hourglass sand inclusion form just below the surface of the salt flats. The crystals ($CaSO_4 \cdot 2H_2O$) only precipitate in areas where upflowing brine has adequate concentrations of Ca and SO_4 (Johnson 1972). A crystal rich area was identified on the southwestern corner of the salt flats in the mid-1940's and was delineated as a public crystal dig area in the early 1950's. In the early 1970's, the dig area was divided into 6 units; only 1 unit is open to the public during each year between 1 April and 15 October to allow selenite crystals to reform. Approximately 25,000 to 30,000 people visit annually from around the world to view the salt flats and collect the prized crystals (Fig. 2).

Visitors drive to and park their vehicles in designated areas adjacent to each year's open dig unit. The dig areas extended from the parking area to the Great Salt Lake in 1991 and 1992. However, approximately 90% of human activity occurred within 350 m of the parking area (Utych 1993). In 1993 and 1994, the designated dig areas were confined to 9-15 ha areas (Fig 3). Visitors walk into the designated crystal dig unit and dig holes, typically 10-50 cm deep x 10-200 cm wide, with trowels and shovels. People remain relatively still while digging and tend to remain at 1 location during their visits. Visitors leave holes unfilled, which facilitates crystal reformation and results in mounds of dirt that may take 1-4 years to level out by wind erosion and normal fluvial processes.

Least terns nest in loosely defined colonies around the dig area, along Clay Creek north of the dig area, on the northeastern side of the salt flats near the West Branch of the Salt Fork of the Arkansas River, and in scattered patches throughout the salt flat habitat (Hill 1985, Schweitzer 1994). Clay Creek flows into the salt lake and is ephemeral and multibranched by nature. It tends to dry up by late

July and early August. During the least tern breeding season in 1991-1993, the creek bisected parts of the dig area, but it was dry throughout most of the 1994 breeding season.

METHODS

Least tern nests were located by systematic searches of the salt flats between May and August 1991-1994. Nests were marked with 30-cm dowels placed at least 10 m from the nest cup and monitored every 3-4 days. We monitored nesting least terns within about 2.5 km of the dig area and at a control area on the northeastern corner of the salt flats, which was closed to the public. After the nesting season, we mapped all nests, regardless of outcome, using a measuring wheel and grid overlay established prior to the tern's arrival at the salt flats.

Least tern nests are widely spaced on the salt flats (Schweitzer 1994) making them difficult to locate and colonies difficult to define. However, a colony definition was necessary to quantify shifts in nesting areas and reduce the influence of outlying nests. Harmonic mean isoclines have been used to define animal home ranges and concentrated use areas in radio telemetry studies (Harris et al. 1990) and can be applied to similar spatial data composed of colonial nest sites. Colonies represent concentrated areas used by least terns and were defined by 60% harmonic mean isoclines (Dixon and Chapman 1980) because they best represented perceived activity centers of least terns. Isoclines were determined using Calhome software (Kie et al. 1994). For further analysis, we defined core colonies as the closest colony to each year's active dig unit with ≥13 nests (Fig. 3). We reasoned that the closest colony to the dig unit in a particular year would be most affected by human disturbances. We also emphasized large colonies (≥ 13 nests) because those areas were likely to be more critical due to greater densities of nesting birds. Distances were measured from a fixed point (center of the southernmost dig unit active in 1993) to all nests in a core colony in each of the 4 years of study. Mean distances from the fixed point to all nests around the dig area and to all core colony nests were compared between years to evaluate colony shifts.

In addition, spatial use of the nesting area near the dig area was evaluated by establishing buffer areas with a 500- and 1,000-m radius around the center of each year's active dig unit. Least tern nests within the 500- and 1,000-m radii were enumerated and compared to assess nesting activity between years.

Ground cover attributes were measured by randomly placing 30 1-m transects in 1993 and 60 1-m transects in 1994 in a least tern colony and in control areas not used by nesting terns. Control areas were placed in a random cardinal direction from the colony and 100 m beyond the perceived colony boundary. Percent cover was measured for: (1) flat substrate; (2) debris 1-50 cm long; (3) debris 50-100 cm long; (4) debris >100 cm long; (5) ripples in sand (1-5 cm high); (6) hoof prints (1-5 cm high ridges) left by escaped cattle; and (7) vegetation (primarily grasses and salt cedar). Percent cover comparisons were made between areas used by least terns for nesting and areas not used for nesting. In addition, percent cover comparisons were made between areas used by terns in 1993 but not used in 1994 to determine habitat changes that may have influenced colony shifts.

Nest success from 1991 through 1994 was calculated for least terns nesting within 2.5 km of the 1994 dig unit, in the control area on the north side of the salt flats, and in core colonies. Nest success was determined for the incubation period as discussed by Mayfield (1961, 1975). A nest was considered successful if ≥1 egg hatched. Hatched eggs were determined by the presence of chicks in or near the nest, the presence of chick fecal material, and/or small eggshell fragments resulting from the hatching process. Nests were considered predated if crushed eggs, large shell fragments, and/or predator footprints were located at the nest. Nests were considered flooded if found under water, or without eggs after a rain event before the expected hatch date. Abandoned nests were defined by the absence of adult least terns associated with a nest for ≥3 consecutive visits. Nests without clear signs of outcome were categorized as unknown outcome.

In 1993, flush distances of incubating terns were estimated ocularly as researchers approached nests. In 1994, we paced the distance from the flush point to the nest to increase precision (the last 10 m were estimated ocularly to avoid direct disturbance to the nest). Nests were placed into 2 age groups (incubation for 1-10 days or 11-21 days) to determine if nest age affected flush distances. Comparisons were made among: (1) least tern nests in the dig and control areas, (2) 6 least tern nests located within 500 m of the 1994 dig unit in 1994, and (3) least tern nests representing the closest 25% of all nests to the active dig units in 1993 and 1994.

Focal nest observations (Altman 1974) were conducted at 36 nests for 30-60 min periods between 0800 and 2000 hrs using a 20-mm spotting scope from a distance that did not cause an incubating bird to flush. The percentage of time that a least tern spent on a nest was determined for: (1) tern nests in the dig and control areas, (2) 6 tern nests located within 500 m of the 1994 dig unit in 1994, and (3) tern nests representing the closest 25% of all nests to the active dig units in 1993 and 1994.

Systematic point counts were conducted in 1993 and 1994 in each dig unit to determine area use patterns by least terns when crystal diggers were present and absent. All counts were conducted for 5 min in each dig unit between 0800 and 2000 hrs (Bibby et al. 1992). Counts were made from the approximate center of each dig unit, and all birds seen within 100 m of the center were counted. Bushnell binoculars (8 x 23 or 10 x 50) were used to identify species. Least terns may have been brooding, feeding, flying, incubating, loafing, mobbing, or preening. Point counts started in the southeastern dig unit and moved counterclockwise through all dig units.

Data from measured distances between nests to the fixed point in the southernmost dig unit, and flush distances had normal distributions. Therefore, all distance measurements were compared between areas using 1-way and 2-way ANOVA and t-tests. Multiple mean comparisons were made using Fisher's LSD test (Steel and Torrie 1980). In addition, a chi-square contingency table was used to compare the number of least tern nests within and beyond the 500- and 1,000-m radii buffers.

Habitat parameters, timed nest observations, and area use patterns were not normally distributed. Habitat and nest observation comparisons were made using Kruskal-Wallis nonparametric technique (Wilkinson et al. 1992). Area use patterns were analyzed with Mann-Whitney U tests (Wilkinson et al. 1992) to determine differences in the number of least terns present when crystal diggers were present and absent. All parametric and nonparametric tests were run on SYSTAT software (Wilkinson et al. 1992). Nest success for terns nesting in the dig and control areas and core colonies were compared with 95% confidence intervals (Johnson 1979) around Mayfield estimates (Mayfield 1961, 1975).

RESULTS

We monitored 252 least tern nests between 1991 and 1994 within 2.5 km of the 1994 dig unit (Table 1). This represented at least 17 to 35 active nests during each year based on the minimum number of nests active during a 4-day period (Table 2). The 4-day period was selected because least terns may renest within 4-15 days after nest loss during the incubation period (Massey and Fancher 1989). We also monitored 129 least tern nests between 1991 and 1994 in the control area for comparative purposes.

Least tern nests averaged between 1,294 m to 1,429 m from the fixed point at the center of the 1993 dig unit for 1991-1994 (Table 3). On average, nests were closest to the fixed point in 1993. Significant differences between years were only noted between 1991 and 1993 ($\underline{P} = 0.037$).

Between 1991 and 1994, least terns inhabited 20 colonies near the dig areas as defined by the 60% Harmonic Mean; each year, our methods delimited between 3 and 7 colonies. Average distance from the fixed point in the 1993 dig unit to nests in each colony ranged from 554 m to 1,953 m. Core colonies (Fig. 3) were significantly closer to the fixed point in 1992 than in 1991 ($\underline{P} < 0.001$) and in 1993 than in 1992 ($\underline{P} < 0.001$) (Table 4). Core colonies shifted further from the fixed point in 1994 compared to 1993 ($\underline{P} < 0.001$).

From 1991 to 1994, core colonies maintained mean distances between 656 m and 1,071 m from the center of the active dig unit (Table 5). The closest (656 m) core colony to an active dig unit occurred in 1993; it was significantly ($\underline{P} < 0.001$) closer to the center of the active dig area than the 1991 and 1992 core colonies. In 1994, the core colony moved further away ($\underline{P} < 0.001$) from the year's active dig unit than in 1993.

There were significantly more nests within 1,000 m of the active dig units in 1991 than in 1992 ($\underline{X}^2 = 3.368$, $\underline{P} = 0.066$) and 1993 ($\underline{X}^2 = 6.260$, $\underline{P} = 0.0123$). The 1,000-m radius buffer area also contained more nests in 1994 than in 1992 ($\underline{X}^2 = 8.709$, $\underline{P} = 0.003$) and 1993 ($\underline{X}^2 = 15.367$, $\underline{P} < 0.001$) (Fig. 4). There were no significant differences between 1991 and 1994 ($\underline{X}^2 = 0.548$, $\underline{P} = 0.459$) and 1992 and 1993 ($\underline{X}^2 = 0.278$, $\underline{P} = 0.598$). There also were no differences between years in the number of tern nests within 500 m of the center of each year's active dig unit. Between 25-76% of the nests occurred at distances greater than 1,000 m from 1991 to 1994.

There were no habitat differences between nesting and nonnesting areas in 1993 ($P > 0.05$) (Table 6). In 1994, a significant difference in the percentage of flat substrate ($\underline{X}^2$ = 4.128, P = 0.042) occurred between nesting and non-nesting areas. No other habitat differences were noted. Two areas assessed for habitat characteristics in 1993 contained ≥13 nests but contained ≤1 nest in 1994. Two habitat parameters (flat substrate [$\underline{X}^2$ = 35.171, $\underline{P}$ < 0.001] and ridges [$\underline{X}^2$ = 35.323, $\underline{P}$ = 0.001]) in the first area changed significantly between the 2 years (Table 7). Percent cover of 3 parameters (flat substrate [$\underline{X}^2$ = 11.291, $\underline{P}$ < 0.001], debris 0-50 cm [$\underline{X}^2$ = 4.045, $\underline{P}$ = 0.044]), and ripples [$\underline{X}^2$ = 12.700, $\underline{P}$ < 0.001] changed significantly between 1993 and 1994 in the second area.

Overall, nest success in the dig area and control area ranged from 0.15 to 0.52 for 1991-1994 (Table 8). Nest success in the dig area was not significantly different from the control area in each year of the study. Nest success of core colonies also did not differ significantly from the control area (Tables 8 and 9). Predation in the dig and control areas ranged between 9 and 45% of nest losses; flooding caused between 0 to 46% of nest losses. Chi-square comparisons showed no significant differences in predation, flooding, or other causes of nest losses between core colonies and control areas for 1991-1994 ($\underline{P}$ > 0.05).

Overall, flush distances of incubating birds ranged from 50 to 547 m (Table 10). There were no significant differences ($\underline{F}$ = 0.965, $\underline{P}$ = 0.330) between the 2 years, despite the change in the distance estimation method made between years. Age of nest did not affect flush distances ($\underline{F}$ = 2.497, $\underline{P}$ = 0.120). Mean flush distances of nesting terns in the dig area were 138 m in 1993 and 173 m in 1994 (Table 11); mean flush distances in the control area were 110 m in

1993 and 148 m in 1994. Terns nesting in the dig and control areas, within 500 m of the active 1994 dig unit, and the 25% closest of all dig area nests to the 1993 and 1994 active dig unit center did not flush at significantly different distances ($\underline{P} > 0.05$).

Observations of incubating birds indicated that terns in the dig and control areas were on the nest an average 94 and 88% of the observed time, respectively (Table 12). There were no significant differences in the amount of time spent on the nest among the dig area, 6 nests within 500 m of the dig unit in 1994, and the control area (Kruskal-Wallis = 1.641, $\underline{P}$= 0.440). Terns nests comprising 25% of those nearest to the 1994 dig unit also did not differ in amount of time spent on the nest compared to terns comprising 50% of the closest nests to the active dig unit and the control area (Kruskal-Wallis = 3.051, $\underline{P}$ = 0.218).

Mean number of least terns per 5-min point count in a dig unit ranged from 0 to 3.53 birds (Table 13). In 1993, significantly more terns were counted in the 1991 dig unit during visitor presence (Mann-Whitney U = 25, $\underline{P}$ = 0.046). There were no significant differences in tern's use of the remaining dig units and for all dig units in 1994 ($\underline{P} > 0.05$).

DISCUSSION

Colony Shifts

Least terns often nest in the same general areas year after year. Erwin (1977) reported only 9% and Burger (1984) reported between 16 and 30% colony site abandonment for coastal areas in New

England. Colony abandonment has been attributed to predators, human activities, and/or physical changes of the habitat. Our study was designed, in part, to monitor shifts of nesting areas used by least terns relative to the annual rotation of active crystal digging units. We expected that if digging activities occurred in areas preferred by least terns, or disturbed terns during the nesting season, then terns would shift their nesting colonies as digging activities shifted.

Although least terns nested in the same general area from 1991 to 1994, core colonies, as defined by the Harmonic Mean method, shifted in the same direction as shifts in crystal digging between all 4 years of the study. Between 1991 and 1993, core colonies and digging activities shifted closer to the fixed point in the 1993 dig unit. In 1994, the core colony and the dig unit shifted further away from the fixed point. The average distance from the center of each year's active dig unit to the nests in each year's core colony was approximately 1,000 m. The core colony was significantly closer to the active dig area in 1993 compared to other years. These core colony shifts suggested an interplay with the annual shifts in digging activities; however, colony shifts may have been due to a variety of confounding factors including: (1) flooding effects; (2) stream dynamics; (3) demographic changes; (4) habitat changes; and (5) unknown reasons.

Flooding Effects.--Least terns on the salt flats nest in areas that are relatively unstable and subject to sheet flooding. Seasonal and yearly precipitation cause flooding of nesting areas and influence nest site selection. Prior to the 1993 breeding season in

May, the salt flats received approximately 37 cm of rain. The Great Salt Lake (Fig. 1) rose to the second highest level in its 54-year history, and Clay Creek expanded onto nesting areas used in previous years. Only scattered patches of nesting areas, both outside and within the dig area, were available for least terns at the beginning of the 1993 breeding season (Fig. 3). Terns nested further south from the creek and further upstream than during previous years of the study. Heavy rains during June-July 1993 season also washed away numerous nests, likely causing least terns to renest in new areas. Grover and Knopf (1982) and Utych (1993) also suspected that flooding and stream dynamics influenced colony shifts at Salt Plains NWR.

Stream Dynamics.--Schweitzer (1994) established that least terns on the salt flats selected nesting areas closer to streams than random points. Changes in the creek location due to normal flooding events from 1991 to 1994, therefore, may have caused shifts in nest locations. Overall, however, least terns appeared to nest close to the creek during all 4 years of the study. When digging activities occurred in the 2 northern dig units in 1991 and 1994, a greater percentage of known terns nests occurred within 1,000 m of the dig units than in 1992 and 1993 when dig units were in the 2 southernmost locations. The northern dig units are closest to Clay Creek where terns are likely to nest.

Demographic Factors.--Nests illustrated in Fig. 2 represent nest attempts and do not indicate the actual number of least tern pairs using the salt flats. Tern numbers were difficult to estimate from nest numbers because of renesting after nest losses (Massey and

Atwood 1981, Hill 1985). However, we had an increase in the number of nests monitored between 1991 and 1993, and a small decrease between 1993 and 1994 (Tables 1 and 2). Those changes may be due in part to: (1) use of different field researchers during the first 2 and second 2 years of the study; (2) increased experience in field methods and search abilities by each researcher as the study progressed; (3) variable nest loss and renesting rates; or (4) fluctuations in number of terns using the salt flats. Schweitzer (1994) and Wood (pers. commun.) also found fluctuating numbers of least terns on the salt flats and along the Arkansas River, respectively, in 1992 and 1993.

Habitat Changes.--Grover and Knopf (1982) found that 59% of least tern nests occur within 5 cm of debris and 27% settled in debris-free areas. The purpose of nesting near debris is uncertain, but the debris may offer visual cues for relocating nests, or offer protection from the elements. We evaluated a variety of habitat parameters to further evaluate gross features of areas selected by nesting terns. Debris, sand characteristics such as ripples and ridges, or small amounts of vegetation are among the few habitat characteristics that can be counted and measured on the salt flats at Salt Plains NWR. Despite our attempts to measure habitat characteristics, we did not identify key attributes that characterize used vs. unused habitats. In 1993, least terns nested in areas with the same habitat parameters as non-nesting areas; however, this was not the case in 1994 when terns selected areas with less flat substrate than control areas. Overall, habitat differences between nesting and non-nesting areas were not consistent between years.

On the salt flats, least terns likely use subtle cues for selecting certain nesting areas and avoiding others.

Dramatic habitat changes can cause least tern colony abandonment (Burger 1984, U.S. Fish and Wildl. Serv. 1990). Habitat measurements conducted in 2 nesting areas used in 1993, but not in 1994, did not indicate that abandonment was due to habitat changes. Cattle hoof prints gave one area a "ridgy" appearance in 1993, but they filled in with sand in 1994 creating flat substrate. (Cattle are not permitted on the salt flats; hoof prints were caused by 2 rare events of 10-100 cattle escaping onto the salt flats from adjacent private land.) However, the percent cover of all habitat parameters in this area during 1994 was similar to other least tern nesting areas used in 1994. Percent cover of flat substrate in the second nesting area also increased between 1993 and 1994, which was attributable to a decrease in sand ripples and debris (0-50 cm). However, sites selected for colonies in 1994 had the same debris characteristics as this former nesting area. Habitat changes occurring between 1993 and 1994 did not appear to be the cause of site abandonment in the 2 sampled areas.

Unknown Factors.--Throughout our 4-year study, least tern colonies also shifted in the control area, >5 km away from crystal digging activities (Utych unpubl. data, M. Koenen pers. observ.). Schweitzer (1994) also counted significantly different numbers of least terns in the control area between 1992 and 1993. Causes for the shifts were unknown, but flooding was likely involved. Nesting colony shifts in the control area are our strongest indication that site tenacity may not be an adequate indicator of human disturbances. Because confounding factors influenced colony shifts, we used additional methods to evaluate effects of human disturbances on nesting least terns.

Nest Success

It has been well established that human disturbances can reduce reproductive success of nesting birds (Hunt 1972, Robert and Ralph 1975, Safina and Burger 1983, Piatt et al. 1990). We viewed nest success as an indirect measure of human disturbances. Nest success was not significantly different between least terns nesting in the dig and control areas. Interestingly, nest success of the core colonies appeared slightly higher than in control areas; however, differences were not significant. Nest losses were largely due to predation and flooding for each year of the study. Occasionally, nests were abandoned, and eggs were found that did not hatch, or were cracked. One nest was lost by direct human disturbance in 1991 when crystal diggers ventured out of the designated crystal dig area. This was an unfortunate incident; however, there was no trend suggesting that crystal digging activities reduced nest success or increased predation, abandonment, and egg cracking of least terns nesting near the crystal dig areas.

Flush Distances

Human activities near nests may cause birds to flush from nesting or roosting areas (Hardy 1957, Burger 1981a, Klein 1993). Eggs not protected by an incubating adult from the high ambient temperatures on the salt flat in summer may be killed in about an hour (Grant 1982). To resolve how close nesting least terns can be approached, we measured distances from the flush point to the nest. The range of distances that an incubating least tern on the salt flats flushed from a nest and elicited mobbing behavior was 50-547 m when approached by a person. Overall, 82% of incubating terns flushed between 50 and 200 m. Only 5% of least terns were flushed at >300 m and only 1% flushed >350 m (Table 10). Flush distances of brooding least terns were not evaluated, but occasional observations suggested that distances may be greater than for incubating terns. During 1991 and 1993, normal crystal digging activities did not elicit mobbing responses by least terns. In 1994, however, 6 tern nests occurred within 500 m of the active dig unit boundary. Terns from these nests were known to mob visitors within the active dig unit and designated parking lot.

Nesting bald eagles (Haliaeetus leucocephalus) became sensitized to pedestrians by flushing at greater distances after successive visits (Fraser et al. 1985). Frequently disturbed herring gulls (Larus argentatus), however, may not respond as quickly as less frequently disturbed gulls (Burger and Gochfeld 1983). We compared flush distances for terns near the dig area, within 500 m of the active dig unit in 1994, and in the control area as a way to measure adaptation of terns to people. We expected that if least terns became sensitized to people at the dig area, they would flush at greater distances than terns in the control; in contrast, if least terns became habituated to people, they would flush at shorter distances than terns in the control. Flush distances of least terns, however, were not different between the areas, which suggested that the terns did not become sensitized or habituated to visitors.

Nest Observations

When disturbed during incubation, least terns may respond by reducing nest attendance (Burger 1981b). Excessive exposure of eggs to the elements may create temperature stress and result in egg mortality (Hunt 1972, Grant 1982). We used the amount of time that adult least terns spent on the nest to determine if terns near the dig area were being distracted by visitors to the dig area and spending less time on the nest. There was no difference between nests near the dig units when visitors were present and the control area indicating that terns spent an equal amount of time incubating eggs. Even the least terns at the 6 nests within 500 m of the active dig unit in 1994, incubated for the same amount as terns at the control nests. This suggested that incubating least terns were not distracted by human visitors to the dig area.

Area Use

Burger (1981a) found reduced presence of non-breeding waterbirds during times when humans were present. We used systematic point counts in each dig unit to determine area use by least terns. All least terns standing, incubating, brooding, or flying over the dig area were counted. A tern's presence in the count may have indicated a nest near the point count due to territorial defense behavior. A few terns also may have been drawn in by social facilitation, or flying to and from feeding areas. The point counts indicated that the same number of least terns used the dig units, regardless of human presence or absence. There were no differences in least tern use of the dig area during 1993 and 1994 except in 1 dig unit in 1993. Overall, crystal digging activities did not reduce or increase least tern use of the crystal dig area.

Summary

Human disturbances can affect nesting birds in a variety of ways such as causing nest abandonment, reduced reproductive success, reduced nest or chick attendance, increased energy expenditures toward territorial defense, altered parent-offspring bonds, and changing area use patterns. However, our study supports previous studies that least terns can successfully nest close to human activities without adverse effects (Carreker 1985, Gore and Kinnison 1991). Colony shifts may be a subtle response to digging activity, but nest shifts are difficult to interpret due to confounding effects of flooding, stream dynamics, habitat and demographic changes, and other unknown factors. Because of colony shifts in the control area, we believe that human disturbances at the crystal dig area are not a primary cause of colony shifts, although they may influence tern occupation slightly. Despite our attempts to measure habitat characteristics, we could not identify overall habitat characteristics that influence least terns to nest in certain areas and avoid others.

Nest success, flush distances, nest observations, and point counts did not differ between our sample areas and did not indicate that least terns were habituated to or distracted by visitors to the dig area. Crystal digging is a relatively stationary form of human behavior like worm-digging, which does not elicit strong reactions by colonial nesting birds (Burger 1981b). Least terns have nested on the salt flat since at least the beginning of the century (Nice and Nice 1924), and digging activities have occurred at least since the 1940's. Least terns on the salt flats may have adapted to crystal diggers over this long-term association.

MANAGEMENT IMPLICATIONS

Our evidence suggested that crystal digging activities did not alter nest success or behavior of least terns at Salt Plains NWR. Our biggest concern, however, is that least terns will nest in areas that are within or very near to the crystal dig area. The 1993 colony shifts indicated that least terns nested in areas used for digging in previous years when humans were in the southernmost dig unit. Least terns also will nest relatively close to current digging activities. In 1994, for example, least terns nesting near the dig unit occasionally defended their nests against people digging for crystals. Least terns flushed when approached within 50-547 m of their nest. Diggers occasionally approached to within 500 m of 5 nests and within 1 m of another nest and flushed incubating least terns. Exposed eggs may be killed by the heat. The refuge should continue monitoring colonies around the active dig areas and if least tern colonies establish within 500 m of active dig units, cessation or moving of digging activities may be warranted. Significantly, 90-100% of all tern nests mapped from 1991- 1994 were >500 m from the active dig unit, suggesting that least terns typically maintain a buffer between them and digging activities. We recommend that refuge personnel walk the perimeter of each year's active dig area weekly during the least tern breeding season (15 May-15 August) to identify nests within 500 m of digging activities that may be in need of particular protection (as determined by flushing frequencies and mobbing behavior).

Another problem occurred when crystal diggers wandered onto the flats beyond the designated dig area. Least tern eggs and nests are highly cryptic and may be stepped on and crushed if not seen. We recommend that the refuge post signs around the dig area to inform visitors of the terns' presence and delimit dig units. Additional methods may be necessary to discourage visitors from walking into nesting areas (e.g., ropes, fences around posted dig area or temporary fences around the colonies), particularly when least terns are nesting within 500 m of the active dig unit.

LITERATURE CITED

Altman, J. 1974. Observational study of behavior: sampling methods. Behaviour 49:227-265.

Bibby, C. J., N. D. Burgess, and D. A. Hill. 1992. Bird census techniques. Academic Press, N.Y. 257pp.

Boyd, R. L. 1990. Habitat management and population ecology studies of the least tern in Kansas and Oklahoma, 1990. Kansas Dep. Wildl. and Parks Nongame Wildl. Proj. Rep. 47pp.

Burger, J. 1981a. Effects of human disturbance on colonial species, particularly gulls. Colonial Waterbirds 4:28-36.

_____, 1981b. The effect of human activity on birds at a coastal bay. Biol. Conserv. 21:231-241.

_____, 1984. Colony stability in least terns. Condor 86:61-67.

_____, and M. Gochfeld. 1983. Behavioural responses to human intruders of herring gulls (Larus argentatus) and great black-backed gulls (L. marinus) with varying exposure to human disturbance. Behav. Processes 8:327-344.

Carreker, R. G. 1985. Habitat suitability index models: least tern. U. S. Fish and Wildl. Serv. Biol. Rep. 82(10.103). 29pp.

Curtin, C. G. 1993. The evolution of the U.S. National Wildlife Refuge. Conserv. Biol. 7:29-38.

Dixon, K. R., and J. A. Chapman. 1980. Harmonic mean measure of animal activity areas. Ecology 61:1040-1044.

Erwin, R. M. 1977. Population and colony site dynamics in selected Massachusetts Waterbirds. Proc. Colonial Waterbird Group 1:19-25.

Fetterolf, P. M. 1983. Effects of investigator activity on ring-billed gull behavior and reproductive performance. Wilson Bull. 95:23-41.

Fraser, J. D., L. D. Frenzel, and J. E. Mathiesen. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. J. Wildl. Manage. 49:585-592.

Gore, J. A., and M. J. Kinnison. 1991. Hatching success in roof and ground colonies of least terns. Condor 93:759-762.

Grant, G. S. 1982. Avian incubation: egg temperature, nest humidity, and bahavioral thermoregulation in a hot environment. Ornithol. Monogr. 30. 75pp.

Grover, P. B., and F. L. Knopf. 1982. Habitat requirements and breeding success of charadriiform birds nesting at Salt Plains National Wildlife Refuge. J. Field Ornithol. 53:139-148.

Hardy, J. W. 1957. The least tern in the Mississippi valley. Publ. Mus. Michigan State Univ., Lansing. 60pp.

Harris, S., W. J. Cressell, P. G. Forde, W. J. Trewhella, T. Woollard, and S. Wray. 1990. Home-range analysis using radio-tracking data-- a review of problems and techniques particularly as applied to the study of mammals. Mammal Rev. 20:97-123.

Hill, L. A. 1985. Breeding ecology of interior least terns, snowy plovers, and American avocets at Salt Plains National Wildlife Refuge, Oklahoma. M.S. Thesis, Oklahoma State Univ., Stillwater. 106pp.

Hunt, G. L. 1972. Influence of food distribution and human disturbance on the reproductive success of herring gulls. Ecology 53:1051-1061.

Johnson, D. H. 1979. Estimating nest success: the Mayfield Method and an alternative. Auk 96:651-661.

Johnson, K. S. 1972. Guidebook for geological trips in Oklahoma. Book 2. Univ. Oklahoma Press, Norman. 42pp.

Keller, V. 1989. Variations in the response of great crested grebes Podiceps crisatus to human disturbance--a sign of adaptation. Biol. Conserv. 49:31-45.

Kie, J. G., J. A. Baldwin, and C. J. Evans. 1994. Calhome: home range analysis program electronic user's manual. U. S. For. Serv. Pac. Southwest Res. Stn., Fresno, Calif. 19pp.

Klein, M. L. 1993. Waterbird behavioral responses to human disturbances. Wildl. Soc. Bull. 21:31-39.

Massey, B. W. 1974. Breeding biology of the California least tern. Proc. Linn. Soc. N. Y. 72:1-24.

Massey, B. W., and J. L. Atwood. 1981. Second-wave nesting of the California least tern: age composition and reproductive success. Auk 98:596-605.

Massey, B. W., and J. M. Fancher. 1989. Renesting by California least terns. J. Field Ornithol. 60:350-357.

Mayfield, H. F. 1961. Nesting success calculated from exposure. Wilson Bull. 73:255-261.

Mayfield, H. F. 1975. Suggestions for calculating nest success. Wilson Bull. 87:456-466.

Nice, M. M., and L. B. Nice. 1924. The birds of Oklahoma. Univ. of Oklahoma. Bull. 20. 119pp.

Piatt, J. F., B. D. Roberts, W. W. Lidster, J. L. Wells, and S. A. Hatch. 1990. Effects of human disturbance on breeding least and crested auklets at St. Lawrence Island, Alaska. Auk 107:342-350.

Purdue, J. R., and H. Haines. 1977. Salt water tolerance and water turnover in the snowy plover. Auk 94:248-255.

Robert, H. C., and C. J. Ralph. 1975. Effects of human disturbance on the breeding success of gulls. Condor 77:495-499.

Safina, C., and J. Burger. 1983. Effects of human disturbance on reproductive success in the black skimmer. Condor 85:164-171.

Schweitzer, S. H. 1994. Abundance and conservation of endangered interior least terns nesting on salt flat habitat. Ph.D. Thesis, Oklahoma State Univ., Stillwater. 129pp.

Smith, J. W., and R. B. Renken. 1993. Reproductive success of least terns in the Mississippi River valley. Colonial Waterbirds 16:39-44.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach. Second ed. McGraw-Hill, Inc., New York, N.Y. 633pp.

U. S. Fish and Wildlife Service. 1985. Interior population of the least tern determined to be endangered. Federal Register 50:21784-21792.

U. S. Fish and Wildlife Service. 1990. Interior population of the least tern (Sterna antillarum): recovery plan. Twin Cities, Minn. 90pp.

Utych, R. B. 1993. Compatibility of selenite crystal digging with breeding ecology of least terns and snowy plovers at salt plains National Wildlife Refuge. M.S. Thesis, Oklahoma State Univ., Stillwater. 45pp.

Wilkinson, L., M. A. Hill, and E. Yang. 1992. SYSTAT 5.2: Statistics. Systat, Inc. Evanston, Ill. 724pp.

Williams, G. E., and E. S. Grover. 1975. Soil survey of Alfalfa County, Oklahoma. U.S. Soil Conserv. Serv., Stillwater, Okla. 74pp.

Young, M. A. 1993 The role of the national wildlife refuge system in endangered species management. Endangered Species Update 10 (7):1-10.

Table 1. Total number of least tern nests located and monitored between 1991 and 1994 near the dig and control areas, Salt Plains National Wildlife Refuge, Oklahoma.

	1991	1992	1993	1994
Dig area	34	59	99	60
Control	11	9	50	59

Table 2. Minimum number of least tern nests active during 4-day periods near the crystal dig area 1991-1994, Salt Plains National Wildlife Refuge, Oklahoma.

	4-day periods (Jun.-Jul.)								
	6/12 - 6/16	6/17 - 6/21	6/22 - 6/26	6/27 - 7/1	7/2 - 7/6	7/7 - 7/11	7/12 - 7/16	7/17 - 7/21	7/22 - 7/26
1991	9	9	6	14	17	14	13	8	2
1992	11	12	11	15	21	24	20	23	14
1993	34	34	41	33	33	25	19	18	17
1994	35	34	32	30	23	15	12	12	12

Table 3. Mean distances (m) from the fixed point in the center of the 1993 dig unit to all least tern nests near the dig area, 1991-1994, Salt Plains National Wildlife Refuge, Oklahoma.

Year	No. Nests	Distance (m)	SE
1991	34	1,429	56
1992	57	1,330	43
1993	99	1,294	33
1994	60	1,342	42

Table 4. Mean distances (m) from the fixed point in the center of the 1993 dig unit to nests in core colonies 1991-1994, Salt Plains National Wildlife Refuge, Oklahoma.

Year Active	No. Nests	Distance (m)	SE
1991	17	1,594	38
1992	28	1,261	29
1993	13	656	43
1994	15	1,152	40

Table 5. Mean distances (m) from the center of each year's active dig unit to nests in core colonies, 1991-1994, Salt Plains National Wildlife Refuge, Oklahoma.

Year Active	No. Nests	Distance (m)	SE
1991	17	1,071	32
1992	28	1,039	25
1993	13	656	36
1994	15	904	34

Table 6. Percent cover of ground cover attributes in areas used by nesting terns and in areas not used by nesting terns (control) during 1993 and 1994, Salt Plains National Wildlife Refuge, Oklahoma.

	1993		1994	
	Nesting area	Control	Nesting area	Control
Flat Substrate (%)	98.4[a]	98.4[a]	93.7[a]	98.4[b]
Debris (0-50 cm)	0.1[a]	0.0[a]	0.1[a]	0.0[a]
Debris (50-100 cm)	0.1[a]	0.2[a]	0.0[a]	0.0[a]
Debris (> 100 cm)	0.6[a]	0.0[a]	0.0[a]	0.0[a]
Sand ripples (<3 cm high)	0.4[a]	0.3[a]	3.3[a]	0.2[a]
Hoof Ridges (1-5 cm high)	0.5[a]	0.1[a]	0.0[a]	0.0[a]
Vegetation (%)	0.0[a]	0.0[a]	0.1[a]	0.0[a]

[a] Means with same letter are not different ($P > 0.05$) within same year.

Table 7. Percent cover of ground cover attributes in 2 areas used by nesting terns in 1993 and not used in 1994, Salt Plains National Wildlife Refuge, Oklahoma.

	Area 1		Area 2	
	Used in 1993	Not used in 1994	Used in 1993	Not used in 1994
Flat Substrate (%)	98.1[a]	100.0[b]	97.1[a]	97.7[b]
Debris (0-50 cm)	0.0[a]	0.0[a]	0.3[b]	0.0[a]
Debris (50-100 cm)	0.0[a]	0.0[a]	0.3[a]	0.0[a]
Debris (> 100 cm)	0.0[a]	0.0[a]	0.0[a]	0.3[a]
Sand ripples (<3 cm high)	0.0[a]	0.0[a]	2.3[b]	0.0[a]
Hoof Ridges (1-5 cm high)	1.2[b]	0.0[a]	0.0[a]	0.0[a]
Vegetation (%)	0.0[a]	0.0[a]	0.1[a]	2.0[a]

[a] Means with same letter are not different ($P > 0.05$) within same year.

Table 8. Least tern nest success (Mayfield Method) and losses for all dig area and control area nests, Salt Plains National Wildlife Refuge, Oklahoma.

	1991		1992		1993		1994	
	Dig area	Control	Dig area	Control	Dig area	Control	Dig area	Control
N	34	11	59	9	99	50	60	59
Nest Success	0.40	0.17	0.25	0.20	0.21	0.15	0.52	0.34
95% CI	0.25-0.63	0.03-0.78	0.15-0.39	0.06-0.66	0.14-0.31	0.08-0.29	0.37-0.73	0.21-0.54
Predation (%)	18	45	17	33	9	14	9	22
Flood (%)	18	0	31	33	46	46	8	2
Other (%) (cr/ab/d-h)[a]	12	0	12	11	6	6	8	9
Unknown outcome (%)	9	27	8	22	15	18	18	15

a cr = nests with cracked eggs/ ab = abandoned nests / d-h = chicks died during hatching process.

Table 9. Least tern nest success (Mayfield Method) and losses for nests in core colonies, Salt Plains National Wildlife Refuge, Oklahoma.

	1991	1992	1993	1994
N	17	28	13	15
Nest Success	0.52	0.32	0.36	0.42
95% CI	0.30-0.88	0.17-0.58	0.17-0.77	0.19-0.90
Predation (%)	18	11	8	7
Flood (%)	6	25	38	7
Other (%) (cr/ab/d-h)[a]	12	14	8	20
Unknown outcome (%)	6	4	23	33

a cr = nests with cracked eggs/ ab = abandoned nests / d-h = chicks died during hatching process.

Table 10. Number of least tern nest flushed at distances between 50 - 547 m, 1993 (n = 26) and 1994 (n = 50), Salt Plains National Wildlife Refuge, Oklahoma.

	Number of tern nests flushed	
Distance (m)	1993	1994
50-99	8	9
100-149	12	11
150-199	2	20
200-249	1	7
250-299	1	1
300-349	2	1
547	0	1

Table 11. Flush distances of least terns at nests observed: 1) in the dig area; 2) within 500 m of the active 1994 dig unit; 3) among the 25% of the total known nests closest to the center of the active dig units in 1993 and 1994; and 4) in the control area, Salt Plains National Wildlife Refuge, Oklahoma (N = number of flushed observations).

		Dig area			
		All nests near dig area	Nests within 500 m of the active dig unit	Nests among the 25% of total nests closest to the active dig unit	Control
1993	N (Observations)	18	-	16	8
	Flush dist. (m)	138	-	143	110
	SE	73	-	76	40
1994	N (Observations)	28	11	14	22
	Flush dist. (m)	173	166	186	148
	SE	96	59	71	39

Table 12. Time (%) spent on the nest by incubating least terns: 1) in the dig area; 2) within 500 m of the active 1994 dig unit; 3) among the 25% of the total known nests closest to the center of the active dig units in 1993 and 1994; and 4) in the control area, Salt Plains National Wildlife Refuge, Oklahoma (N = number of timed observations).

	Dig area			
	All nests near dig area	Nests within 500 m of the active dig unit	Nests among the 25% of total nests closest to the active dig unit	Control
N (observations)	17	5	8	19
Time on nests (%)	94[a]	81[a]	84[a]	88[a]

[a] Means with same letter are not different ($\underline{P} > 0.05$).

Table 13. Mean number of least terns seen during 41 5-min point counts in the 6 dig units during 1993 and 1994 when visitors were present and absent, Salt Plains National Wildlife Refuge, Oklahoma. Comparisons are made between visitor and no visitor periods for each dig unit in 1993 and 1994.

	1993		1994	
	Visitors (N=7)	No visitors (N=15)	Visitors (N=5)	No visitors (N=14)
1993 Unit	0[a]	0.07[a]	0	0
1992 Unit	0[a]	0.07[a]	0[a]	0.07[a]
1991 Unit	1.86[a]	0.93[b]	0.07[a]	0[a]
1994 Unit	1.29[a]	2.40[a]	0.60[a]	0.28[a]
1990a Unit	2.14[a]	3.53[a]	1.20[a]	1.00[a]
1990b Unit	0.86[a]	0.80[a]	0.80[a]	0.57[a]

[a] Means in each unit with same letter are not different ($\underline{P} > 0.05$) within same year.

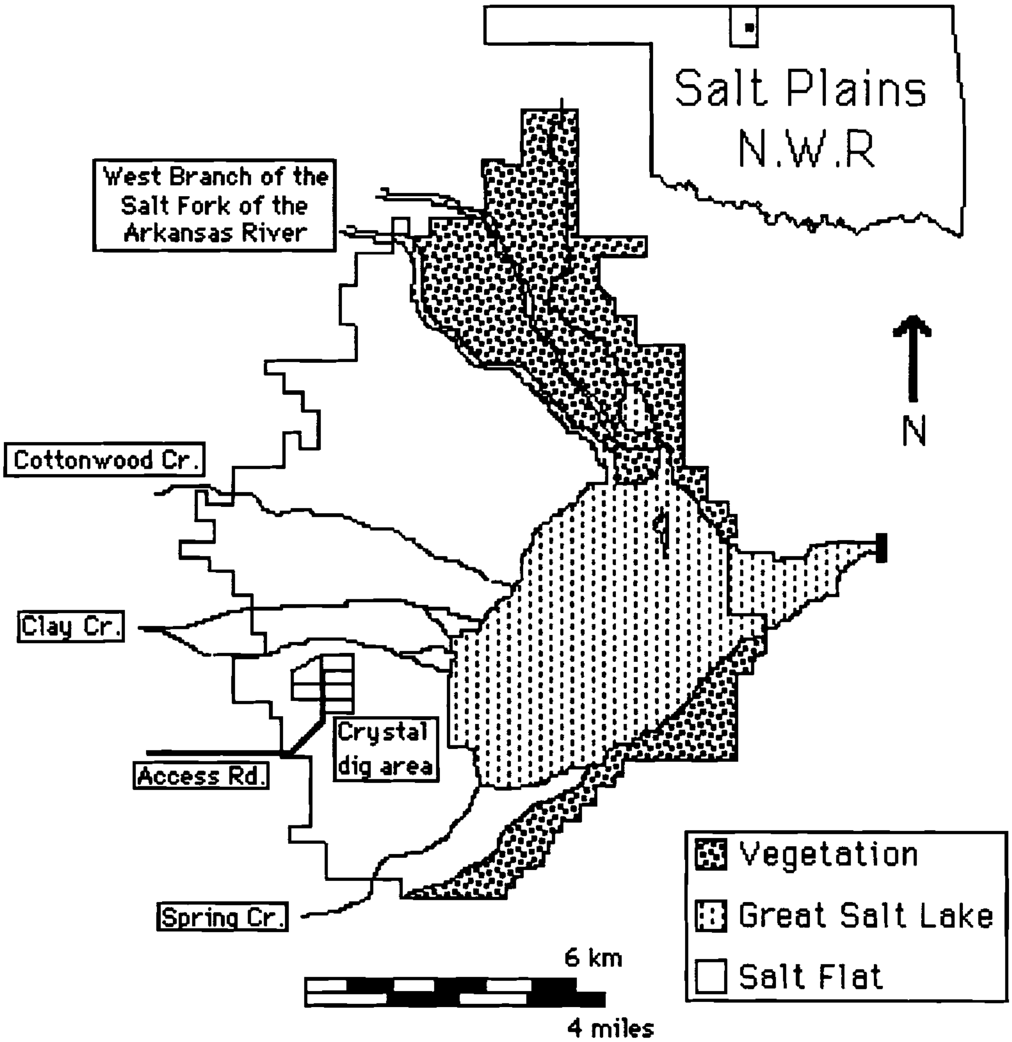

Fig. 1. Salt Plains National Wildlife Refuge in north-central Oklahoma; note the crystal dig area in the southwestern corner of the refuge.

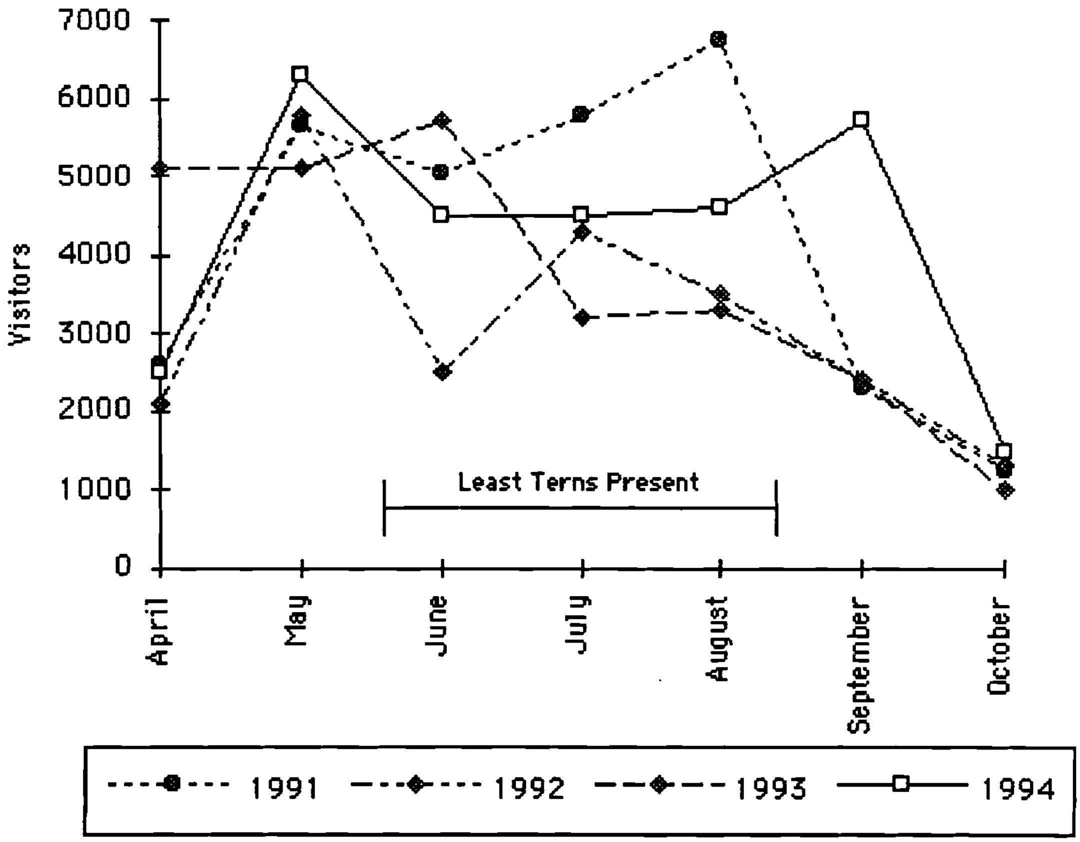

Fig. 2. Monthly visitors at the crystal dig area 1991 to 1994. The peak least tern breeding season is in June and July.

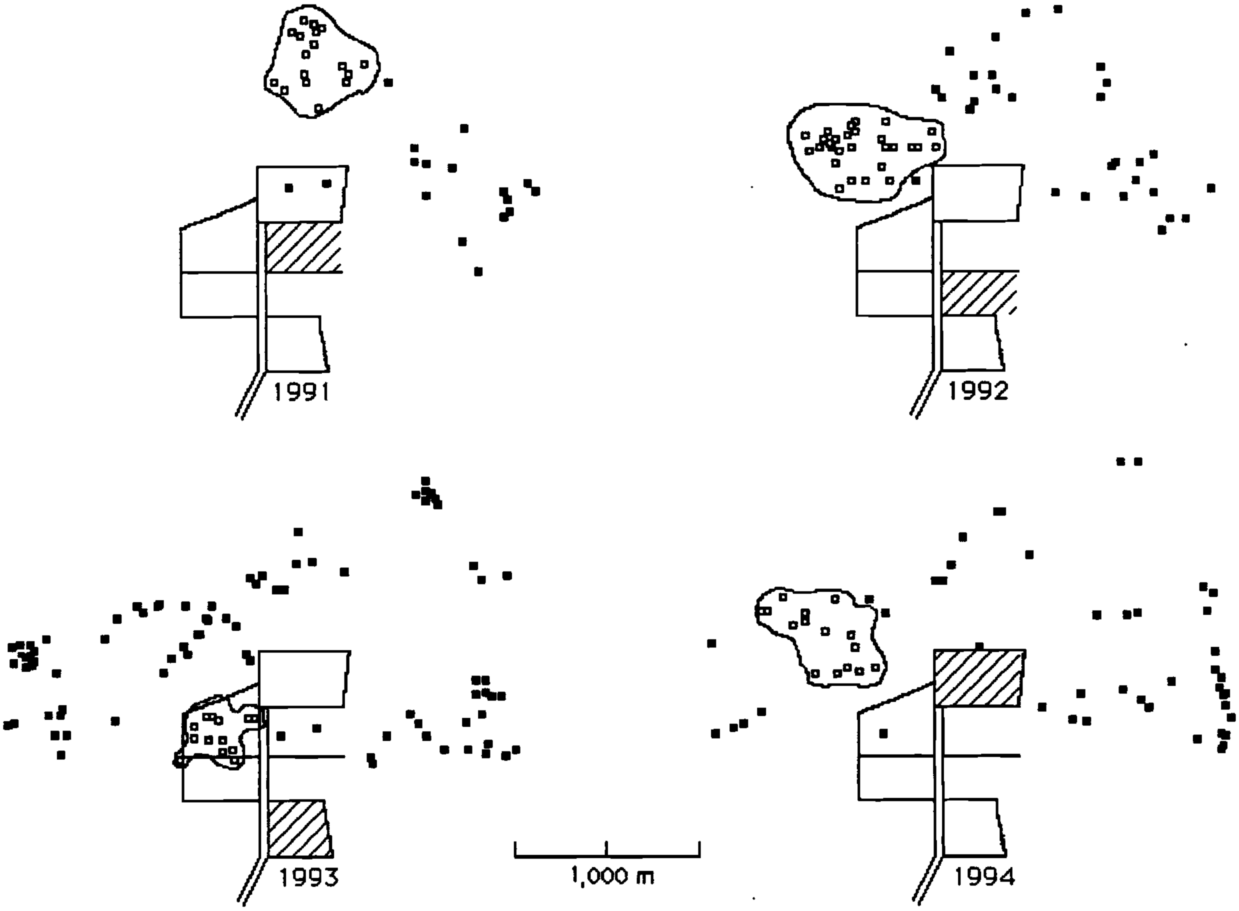

Fig 3. Locations of least tern nests within core colonies defined by 60% harmonic mean isoclines (▫) and outside of core colonies (▪) near the crystal dig area for 1991-1994; slashed area designates each year's active dig unit.

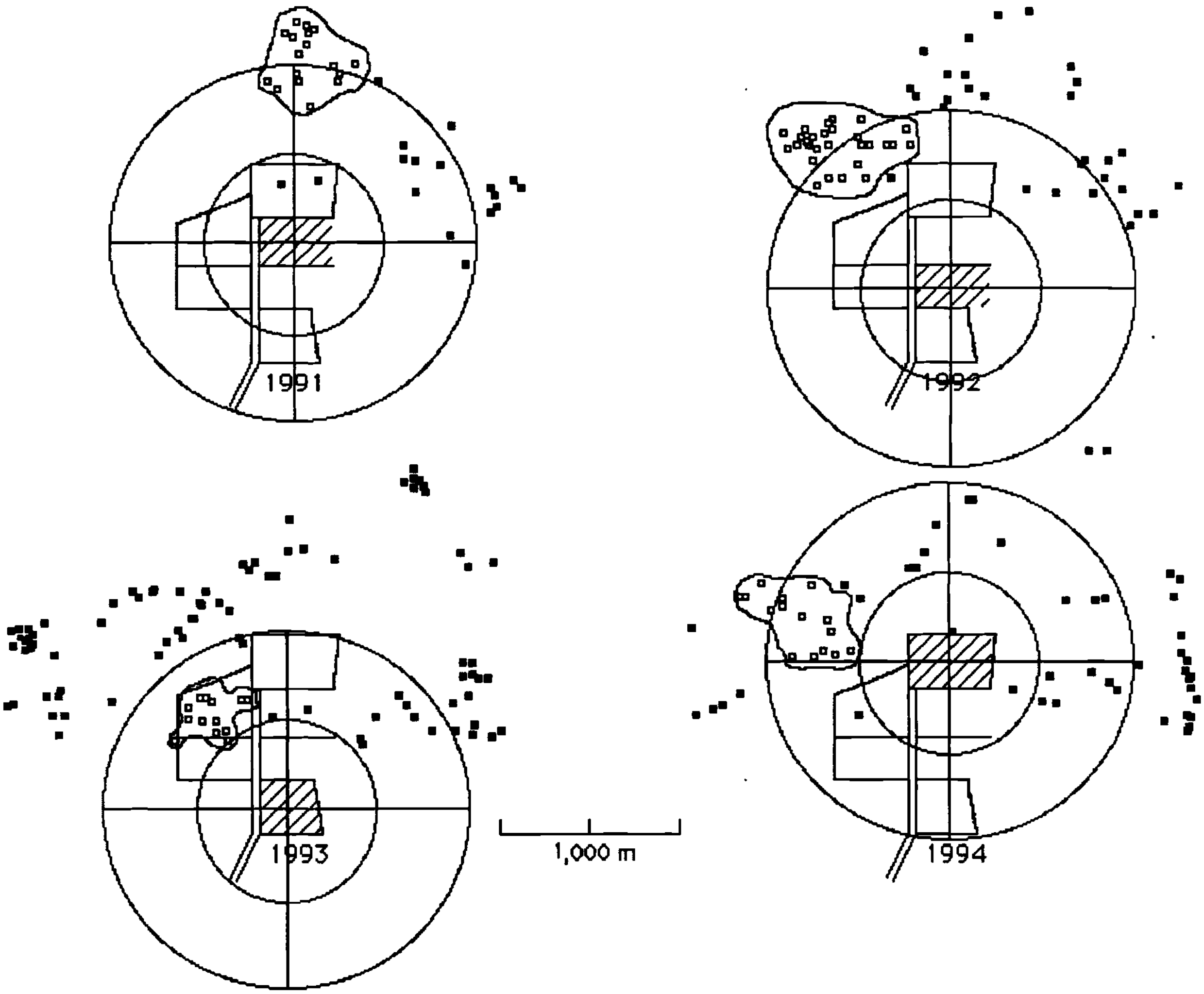

Fig 4. Locations of least tern nests (▪) near the crystal dig area within 500- and 1,000-m radii buffer areas from the center of each year's dig unit, 1991-1994, Salt Plains National Wildlife Refuge, Oklahoma.

Chapter II

NEST RIDGES AND ELECTRIC FENCES TO INCREASE LEAST TERN AND SNOWY PLOVER PRODUCTIVITY ON AN ALKALINE FLAT

ABSTRACT

Abstract: A 4-year study was initiated in summer 1991 to evaluate methods applied at Salt Plains National Wildlife Refuge, Oklahoma, to increase reproductive success of endangered interior Least Terns (*Sterna antillarum*) and Category 2 Snowy Plovers (*Charadrius alexandrinus*). Nest ridges were designed to provide habitat safe from sheet flooding, and electric fences were built to reduce the threat from mammalian predators. Least Tern and Snowy Plover nests were located and monitored every 3-4 days to determine nest success and causes of nest failure. Nest ridges did not reduce nest losses due to flooding ($P > 0.05$). Electric fences can reduce nest predation but currently contain only a small part of the nesting Least Tern and Snowy Plover population. Management recommendations include a review of nest ridge construction and expansion of electric fences to include more nests or the use of temporary fences placed around existing colonies.

The interior population of the Least Tern (Sterna antillarum) has been listed as endangered since 27 June 1985 (U.S. Fish and Wildlife Service 1985). The inland population of the western Snowy Plover (Charadrius alexandrinus) is currently listed under Category 2 (U.S. Fish and Wildlife Service 1991), and the coastal population of the western Snowy Plover was federally listed as threatened 5 March 1993 (U.S. Fish and Wildlife Service 1993). The Least Tern recovery plan objectives include: (1) protection and enhancement of essential breeding habitat and (2) maintenance of 300 adults at Salt Plains National Wildlife Refuge (NWR) for at least 10 years (U.S. Fish and Wildlife Service 1990).

Flooding and predation are the main causes of Least Tern and Snowy Plover nest losses on salt flat habitat at Salt Plains NWR (Grover and Knopf 1982, Hill 1985, Utych 1993). Rain storms from May through August can cause sheet flooding and wash eggs out of nests or completely submerge nests. Water may remain on the flats for several hours to several days after rain events. Coyotes (Canis latrans) have been the only mammalian nest predator identified on the salt flats (Grover and Knopf 1982, Hill 1985, Utych 1993); known avian predators include ring-billed gulls (Larus delawarensis) and cattle egrets (Bubulcus ibis).

The refuge built experimental nest ridges in spring 1990 and electric fences in 1991 to decrease nest losses and boost Least Tern and Snowy Plover breeding populations. Nest pads constructed from 2 5-gallon buckets of sand and gravel have been used in Kansas to enhance nest sites for Least Terns (Boyd 1990), but nest ridges have not been evaluated for their efficacy. Predator fences have been extensively used to protect nesting Least Terns (Boyd and Rupert 1991, Minsky 1980, Rimmer and Deblinger 1992), piping plover (Charadrius melodus) (Mayer and Ryan 1991), and other ground nesting birds (Lokemoen et al. 1982, Sargeant et al. 1974) from mammalian predators. Nest ridges and mounds were constructed within electric fence exclosures to test their effectiveness at increasing nest productivity of Least Terns and Snowy Plovers. We hypothesized that: (1) nest ridges provide stable substrate and reduce nest loss due to flooding, and (2) electric fences reduce risk of nest exposure to mammalian predators.

STUDY AREA AND METHODS

Salt Plains NWR is located in Alfalfa County in northcentral Oklahoma (Fig. 1) and contains a 4050-ha salt flat that serves as a breeding ground for Least Terns and Snowy Plovers (Grover and Knopf 1982, Hill 1985, Schweitzer 1994, Utych 1993). The flats are nearly level and poorly drained. The altitude ranges from approximately 340-350 m. Most surfaces are bare, but vegetation includes sea purslane (Sesuvium verrucosum), inland salt grass (Distichlis stricta), and saltmarsh bulrush (Scirpus paludosis). Exotic salt cedar (Tamarix spp.) is invading on the boundary of the salt flats, particularly along waterways. The salt flats consist of reddish brown salorthid soil series with a thin (approximately 0.01-3.00 cm) layer of white crystalline salt crust that forms on the surface (Williams and Grover 1975). The salt is the result of brine upflows from underlying Permian rock (Johnson 1972).

Salt Plains NWR receives an average annual rainfall of 68 cm; almost 60% of that occurs in spring and summer. Creeks flow across the flats into the Great Salt Lake, a reservoir built in 1941. They are ephemeral and multibranched by nature and tend to dry up by late July and early August. In 1994, creeks on the salt flats were dry throughout most of the Least Tern breeding season from May to August (Hill 1985). Average wind speed is 21 kph, but southwesterly winds of 48-72 kph are common in spring (Williams and Grover 1975). The salt flats are closed to the general public, except for a rotating 9-15 ha public use area on the southwestern corner of the salt flats that is open between 1 April and 15 October for selenite crystal collecting.

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 may range from 5 m to >500 m. Snowy Plovers may nest among Least Tern colonies or in scattered patches throughout the salt flat habitat.

Prior to the 1990 breeding season, the refuge plowed 14 experimental nest ridges (approximately 10 m long x 1 m wide x 0.5 m high) on the northeastern side of the salt flats (Fig. 1). Ridges were placed approximately 20-30 m apart in an area where Least Terns had not previously nested (Hill pers. comun.) to minimize possible disturbances to the birds. Wind and rain eroded the ridges to a height of 10-20 cm in 1992, 3-6 cm ridges in 1993, and 0-3 cm ridges in 1994. In fall 1990, a 400- x 400-m (16-ha) electric fence exclosure was built around the experimental ridges. Two additional 250- x 150-m (3.75-ha) electric fence exclosures were built in April 1992 without nest ridges. In 1993, spring floods damaged all 3 exclosures prior to the Least Tern breeding season. The 2 3.75-ha exclosures were subsequently removed and the 16-ha exclosure was partly rebuilt, resulting in a 150- x 300-m (4.5-ha) exclosure. A second 300- x 800-m (24-ha) electric fence exclosure was established in 1993 approximately 1,000 m south of the 4.5-ha exclosure. Eight sand and gravel nest pads, as described by Boyd and Rupert (1991), were placed in the exclosure after fence completion. 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 (sticks 20-150 cm) were constructed in fenced areas. Mounds were approximately 2 m wide at the base and 0.5 m high.

All fences were powered by a deep cycle 12-volt marine battery supported by a Gallaghar B-150 solar energizer resulting in a 1,000-6,000 volt charge. Wire strands were spaced approximately 14, 28, 42, 62, and 86 cm from the ground to prevent coyotes from entering enclosures. Wires were fastened with plastic insulators to steel posts that were spaced at 6-m intervals. Costs were estimated at $0.85/m (Utych 1993).

Least Tern and Snowy Plover nests were located by systematic searches of the salt flats between May and August 1991-1994. Nests were marked with 30-cm dowels placed at least 10 m from the nest cup and monitored every 3-4 days. We monitored nesting Least Terns and Snowy Plovers in all fenced exclosures and at control areas within approximately 2 km from the fences that included nesting terns and plovers. We generated random points on a grid laid over a diagram of the experimental ridge area to determine the expected number of points on or off a ridge. A chi-square test compared the expected points to the observed nests on and off ridges to determine if nests were placed on ridges more than would be expected by chance.

Least Tern and Snowy Plover nest success was calculated in 1991 through 1994 for nests on ridges, nest pads, and mounds and off of ridges, nest pads, and mounds inside the electric fences. All nests in fenced exclosures were pooled each year and compared to the nests in the control area. A contingency table was not used to compare nest losses because nests that were lost to predation would have a decreased chance of being flooded; likewise nests that were flooded would have a decreased chance of being lost to predation. Therefore, nest success was determined for the incubation period as discussed by Mayfield (1975), with a slight modification to compare effects of flooding and predation. 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 predator mortality rate. Likewise, only nests lost to flooding were considered failed nests when calculating daily flooding mortality rate. The number of days that ≥ 1 eggs remained in nest scrapes were used to determine exposure. We assumed a 21-

day incubation period for Least Terns and a 24-day period for Snowy Plovers (Hill 1985). Predator and flooding mortality rates were used to determine nest success and 95% confidence intervals (Johnson 1979) to compare productivity.

A nest was considered successful if ≥1 egg hatched. Hatched eggs were determined by (1) the presence of chicks in or near the nest, (2) chick fecal material, and/or (3) small eggshell fragments resulting from the hatching process. Nests were considered lost to predators if crushed eggs, large shell fragments, and/or predator footprints were located at the nest site and eggs were missing before the expected hatch date. Nests were considered flooded if found under water, or without eggs after a rain event but before the expected hatch date. 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 from the center of the experimental ridge area increased from 2 in 1990 to 15 in 1994 (Table 1). Snowy Plover nests increased from 1 in 1990 to 11 in 1994. Numbers of both Least Tern and Snowy Plover nests peaked in 1993.

Least Terns ($\underline{X}^2$ = 71.590, $\underline{P}$ < 0.001) and Snowy Plovers ($\underline{X}^2$ = 61.495, $\underline{P}$ < 0.001) selected nest sites on ridges significantly more than expected in the fenced exclosure with ridges from 1991 to 1994. Nest pads were selected for a nest site by 1 Least Tern and 1 Snowy Plover in both 1993 and 1994. Nest ridges built in fall 1993, however, were not selected significantly more by Least Terns ($\underline{X}^2$ = 0.138, $\underline{P}$ = 0.711) and plovers ($\underline{X}^2$ = 0.301, $\underline{P}$ = 0.583) in 1994 than expected. In 1994, only 1 Least Tern nest and 2 Snowy Plover nests were found on the new ridges. Mounds were not used by either species in 1994. Least Terns ($\underline{X}^2$ = 18.540, $\underline{P}$ < 0.001) and Snowy Plovers ($\underline{X}^2$ = 7.325, $\underline{P}$ = 0.007) nested more on old ridges (built in 1990) than expected in 1994.

Overall nest success for terns on ridges ranged from 0.23 to 1.00 (Table 2). There was no significant difference (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).

Coyotes entered the fence exclosures on 5 occasions during 1991 and 1992, but no nests were predated. At least 1 coyote also entered the fence exclosures in 1993 and 1994 and predated 1 and 3 Least Tern nests, respectively. Unidentified avian predators took 1 Snowy Plover nest in 1992 and 1 in 1994 in the fenced exclosures. One Least Tern nest was lost to avian predation in the fenced exclosure in 1993. One Least Tern nest and 1 Snowy Plover nest in the control area were lost to avian predators in 1993 and 1994, respectively.

Least Tern nests in the fenced exclosure had higher nest success (P < 0.05) in 1991 than nests outside of fenced exclosures (Table 3).

There was no significant difference between Snowy Plover nest success inside and outside the exclosures in 1991. From 1992 to 1994, there were no significant differences in Least Tern and Snowy Plover nest success inside and outside of the exclosures.

DISCUSSION

Nest Ridges.--Nest ridges, mounds and pads were designed to offer elevated nesting platforms safe from sheet flooding, which commonly occurs during and after rain events on the salt flats. Least Terns began to use the experimental ridge area within 1 year after being built. Least Tern nests within 500 m of the center of the ridge area increased from 2 in 1990 to 15 in 1994. Least Terns and Snowy Plovers preferred nest sites on ridges; however, neither species selected nest ridges built ≤6 months before the breeding season. Boyd (1990) suggested that terns will not nest on pointed or new ridge tops as built within our fenced exclosure in 1990 and 1993. Weathering rounds ridge tops, and Least Terns are more likely to nest on them. Ridges built in 1993 may not have weathered enough for nesting Least Terns and Snowy Plovers. Because of no replication of an area like this, we do not know if nest ridges actually drew nesting birds in. 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, Page et al. 1991, U.S. Fish and Wildlife Service 1990), and unknown factors.

Ridges did not consistently decrease nest loss due to flooding for Least Terns and Snowy Plovers nesting on ridges. This may be due, in part, to small sample sizes of terns and plovers nesting in the fenced exclosure (<20 per species) in each year of our study. In 1993, when sample sizes were greatest (n = 28 Least Tern nests), nest ridges had eroded to their shortest 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. Rains also may have been strong enough to push eggs out of nests on ridges or mounds and wash them away by sheet flooding. Further study is clearly needed to increase sample size and identify alternative methods to protect nests from flooding.

Electric fences.--Coyotes are major nest predators of Least Tern and Snowy Plovers (Boyd and Rupert 1991, Grover and Knopf 1982, Page et al. 1985, Utych 1993). Grover and Knopf (1982) attributed 57.7% and 32.8% of combined Least Tern and Snowy Plover nest losses at Salt Plains NWR to coyotes in 1977 and 1978, respectively. Other potential nest predators include rats (Rattus norvegicus) (Burger 1984, Craig 1971), feral cats (Felis domesticus), and dogs (Canis familiarus); however, coyotes were the only mammalian nest predator identified on the salt flats from 1991 to 1994. Overall, Least Tern and Snowy Plover nest success was consistently higher inside electric fences than in the control area, but electric fences increased nest success for Least Terns statistically only during 1991.

Although fences can be effective at reducing predator impact to ground nesting birds (Sargeant et al. 1974, Minsky 1980, Lokemoen et al. 1982, Rimmer and Deblinger 1992), there are a number of problems associated with them. 1) Electric fences can protect only a fraction of the terns nesting on the salt flats. Only 13.6% of all Least Tern and 9.4% of all Snowy Plover nests monitored 1991 to 1994 occurred in fenced areas and not all known nesting areas on the salt flats were monitored. 2) Least Tern colonies shift between years (Burger 1984, chapter I), 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 1 coyote entered an exclosure in 1994 and predated 3 Least Tern nests when debris blew into the fence and temporarily damaged it. Fences need to be checked daily to ensure that they are functioning properly. 4) Coyotes may enter electric fences by squeezing through wire strands (Utych 1993) or jumping over the fences. Thompson (1978) noted that wild caught coyotes could jump over 152 cm fences. 5) Fences do not protect chicks after they leave the fenced areas. There is currently little information about the activities and survival of Least Tern and Snowy Plover chicks on the salt flats. Boyd (1972) recorded Snowy Plover <20 day-old-chicks moving approximately 3.2 km from their nest in Kansas. We have relocated a 15-day-old banded Least Tern chick approximately 1 km from the nest. 6) Avian predators are not hindered by the electric fences. Potential avian nest predators include Cattle Egret, Ring-billed Gulls (chapter III), Great Blue Herons (Ardea herodias), Blackcrowned Night Herons (*Nycticorax nycticorax*) (Nisbet 1984, Kirsch 1992), 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), and Corvids (Burger 1984, Page et al. 1985). Great-horned Owls (*Bubo virginianus*) preyed on Cattle Egrets near the electric fenced area and may have preyed on Least Tern or Snowy Plover chicks (Lingle 1993).

Thompson (1982), Hill (1985), and Page et al. (1983) estimated that 0.5 fledged young/female Least Tern and 0.8 fledged young/female Snowy Plover were required to maintain respective population stability. Least Terns and Snowy Plovers nesting on the salt flats do not produce enough chicks to meet that minimum estimate (Koenen, unpubl. data). Further research is warranted to design effective methods that decrease nest losses due to flooding and protect nests and chicks from predators. Flooding and predation issues must be addressed together, so that nests protected from predation will not be lost to floods or vice versa.

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LITERATURE CITED

Atwood J. L., and B. W. Massey. 1988. Site fidelity of Least Terns in California. Condor 90:389-394.

Becker, P. H., and M. Erdelen. 1987. Die Bestandsentwicklung von Brutvoegel der Deutschen Nordseekueste 1950-1979. J. Ornithol. 128:1-32.

Boyd, R. L. 1972. Breeding biology of the Snowy Plover at Cheyenne Bottoms waterfowl management area, Barton County, Kansas. M.S. Thesis, Kansas State Teachers College, Emporia.

Boyd, R. L. 1990. Habitat management and population ecology studies of the Least Tern in Kansas and Oklahoma, 1990. Kansas Dept. of Wildl. and Parks. Nongame Wildl. Prog., Pratt.

Boyd, R. L., and J. Rupert. 1991. Habitat management and population ecology studies of the Least Tern in Kansas. Kans. Dept. of Wildl. and Parks. Nongame Wildl. Prog., Pratt.

Burger, J. A. 1984. Colony stability in Least Terns. Condor 86:61-67.

Craig, A. M. 1971. Survey of California Least Tern nesting sites. California Dept. of Game and Fish. Special Investigation, project W-54-R-4. Job II-5.1.

Grover, P. B., and F. L. Knopf. 1982. Habitat requirements and breeding success of charadriiform birds nesting at Salt Plains National Wildlife Refuge. J. Field Ornithol. 53:139-148.

Hill, L. A. 1985. Breeding ecology of interior Least Terns, Snowy Plovers, and American avocets at Salt Plains National Wildlife Refuge, Oklahoma. M.S. Thesis, Oklahoma State Univ., Stillwater.

Johnson, D. H. 1979. Estimating nest success: the Mayfield Method and an alternative. Auk 96:651-661.

Johnson, K. S. 1972. Guidebook for geological trips in Oklahoma. Book 2. Univ. Oklahoma Press, Norman.

Kirsch, E. M., 1992. Habitat selection and productivity of Least Terns (Sterna antillarum) on the Lower Platte River, Nebraska. Ph.D. Thesis, Univ. of Montana, Missoula.

Lingle, G. R. 1993. Causes of nest failure and mortality of least terns and snowy plovers along the central Platter River. Pp. 130-134, in K. F. Higgins and M. R. Brashier, eds. Proceedings of the Missouri River and its Tributaries: Piping Plover and Least Tern Symposium. South Dakota State University, Brookings, South Dakota

Lokemoen, J. T., H. A. Doty, D. E. Sharp, and J. E. Neaville. 1982. Electric fences to reduce mammalian predation on waterfowl nests. Wildl. Soc. Bull. 10:318-323.

Mayer, P. M., and M. R. Ryan. 1991. Electric fences reduce mammalian predation on piping plover nests and chicks. Wildl. Soc. Bull. 19:59-63.

Mayfield, H. F. 1975. Suggestions for calculating nest success. Wilson Bull. 87:456-466.

Minsky, D. 1980. Preventing fox predation at a Least Tern colony with an electric fence. J. Field Ornithol. 51:180-181.

Nisbet, I. C. T. 1984. Seasonal variation in breeding success of Common Terns: consequences of predation. Condor 86: 53-60.

Page, G. W., L. E. Stenzel, and C. A. Ribic. 1985. Nest site selection and clutch predation in the Snowy Plover. Auk 102:347-353.

Page, G. W., L. E. Rimmer, and W. D. Shuford. 1991. Distribution and abundance of the Snowy Plover on its western North American breeding grounds. J. Field Ornithol. 62:245-255.

Rimmer, D. W., and R. D. Deblinger. 1992. Use of fencing to limit terrestrial predator movements into Least Tern colonies. Col. Waterbird 15:226-229.

Sargeant, A. B., A. D. Kruse, and A. D. Afton. 1974. Use of small fences to protect ground nests from mammalian predators. Prairie Nat. 6:60-63.

Schweitzer, S. H. 1994. Abundance and conservation of endangered interior Least Terns nesting on salt flat habitat. Ph.D. Thesis, Oklahoma State Univ., Stillwater.

Thompson, B. C. 1978. Fence-crossing behavior exhibited by coyotes. Wildl. Soc. Bull. 6:14-17.

U. S. Fish and Wildlife Service. 1985. Interior population of the Least Tern determined to be endangered. Fed. Reg. 50(102):21784-21792.

U. S. Fish and Wildlife Service. 1990. Interior population of the Least Tern (Sterna antillarum): recovery plan. U. S. Fish and Wildlife Service., Twin Cities, Minn.

U. S. Fish and Wildlife Service. 1991. Endangered and threatened wildlife and plants; animal candidate review for listing as endangered or threatened species. Fed. Reg. 56(225):58804-58810.

U. S. Fish and Wildlife Service. 1993. Endangered and threatened wildlife and plants; determination of threatened status for the Delta Smelt and the Pacific Coast population of the Western Snowy Plover. Fed. Reg. 58(42):12864-12874.

Utych, R. B. 1993. Compatibility of selenite crystal digging with breeding ecology of Least Terns and Snowy Plovers at salt plains National Wildlife Refuge. M.S. Thesis, Oklahoma State Univ., Stillwater.

Williams, G. E., and E. S. Grover. 1975. Soil survey of Alfalfa County, Oklahoma. U.S. Soil Conserv. Serv., Stillwater, Okla.

Wood, G. K. 1994. Evaluation of the population and habitat status of the endangered interior Least Tern on the Arkansas River below Keystone Dam, Oklahoma. M.S. Thesis, Oklahoma State Univ., Stillwater.

Table 1. Total number of Least Tern and Snowy Plover nests located and monitored between 1991 and 1994 within 500 m of the center of the experimental ridge area, on ridges, and inside the electric fence Salt Plains National Wildlife Refuge, Oklahoma.

	1990[a]	1991	1992	1993	1994
Least Terns					
N	2	3	11	16	15
On ridges	2	3	7	8[b]	3
In Fence	-	3	10	9	6
Snowy Plovers					
N	1	2	19	20	11
On ridges	1	2	8	4[b]	3[c]
In Fence	-	2	13	9	3

[a] from Boyd (1990)

[b] 1 nest on gravel pile

[c] 1 nest on new ridges built in fall 1993

Table 2. Least Tern and Snowy Plover nest success (Mayfield Method), 95% confidence interval, and losses for all nests on and off of nest ridges, Salt Plains National Wildlife Refuge, Oklahoma.

	1990[a]	1991		1992		1993		1994	
	On	On	Off	On	Off	On	Off	On	Off
Least Terns									
N	2	4	0	7	7	13	15	8	6
Nest Success	0	1.00	-	0.61	0.60	0.23	0.47	1.00	0.62
Confidence Interval (95%)	-	-	-	0.30-1.22	0.29-1.22	0.08-0.64	0.23-0.91	-	0.23-1.59
Predation	2	0	0	0	0	0	3	2	1
Flood	0	0	0	2	2	8	5	0	1
Other nest losses (cr/ab/d-h)[b]	0	0	0	1	0	0	0	1	1
Unknown nest outcome	0	0	0	0	0	2	1	1	1
Snowy Plover									
N	1	2	-	7	13	8	6	5	7
Nest Success	0	1.00	-	0.72	0.63	0.79	0.13	1.00	1.00
Confidence Interval (95%)	-	-	-	0.45-1.14	0.37-1.07	0.50-1.25	0.02-0.92	-	-
Predation	1	0	-	1	0	0	0	0	1
Flood	0	0	-	2	3	1	4	0	0
Other nest losses (cr/ab/d-h)[b]	0	0	-	0	0	2	0	0	0
Unknown nest outcome	0	0	-	0	1	2	0	1	1

a from Boyd (1990)

b cr = nests with cracked eggs/ ab = abandoned nests / d-h = chicks died during hatching process.

Table 3. Least Tern and Snowy Plover nest success (Mayfield Method) and losses for all nests in and out of electric fences, Salt Plains National Wildlife Refuge, Oklahoma.

	1991		1992		1993		1994	
	In	Out	In	Out	In	Out	In	Out
Least Tern								
N	4	11	14	9	28	50	14	59
Nest Success	1.00	0.17	1.00	0.51	0.78	0.75	0.61	0.52
Confidence Interval (95%)	-	0.03-0.78	-	0.23-1.09	0.59-1.04	0.58-0.97	0.34-1.07	0.36-0.74
Predation	0	5	0	3	3[b]	5	3[c]	13
Flood	0	0	4	3	13	23	1	1
Other nest losses (cr/ab/d-h)[a]	0	3	1	1	0	3	2	5
Unknown nest outcome	0	0	0	2	3	9	2	9
Snowy Plover								
N	2	9	20	23	18	67	12	24
Nest Success	1.0	0.99	0.91	0.56	0.88	0.78	0.89	1.00
Confidence Interval (95%)	-	0.56-1.21	0.76-1.09	0.36-0.86	0.67-1.14	0.62-0.97	0.69-1.13	-
Predation	0	1	1[d]	7	1	5	1[e]	0
Flood	0	1	5	7	5	30	0	1
Other nest losses (cr/ab/d-h)[a]	0	1	0	0	0	7	0	2
Unknown nest outcome	0	0	1	3	6	15	2	5

a cr = nests with cracked eggs/ ab = abandoned nests / d-h = chicks died during hatching process.
b 1 nest predated by a gull.
c predated by a coyote on 6/14/1994.
d predated by a cattle egret (Utych 1993).
e predated by a ring-billed gull.

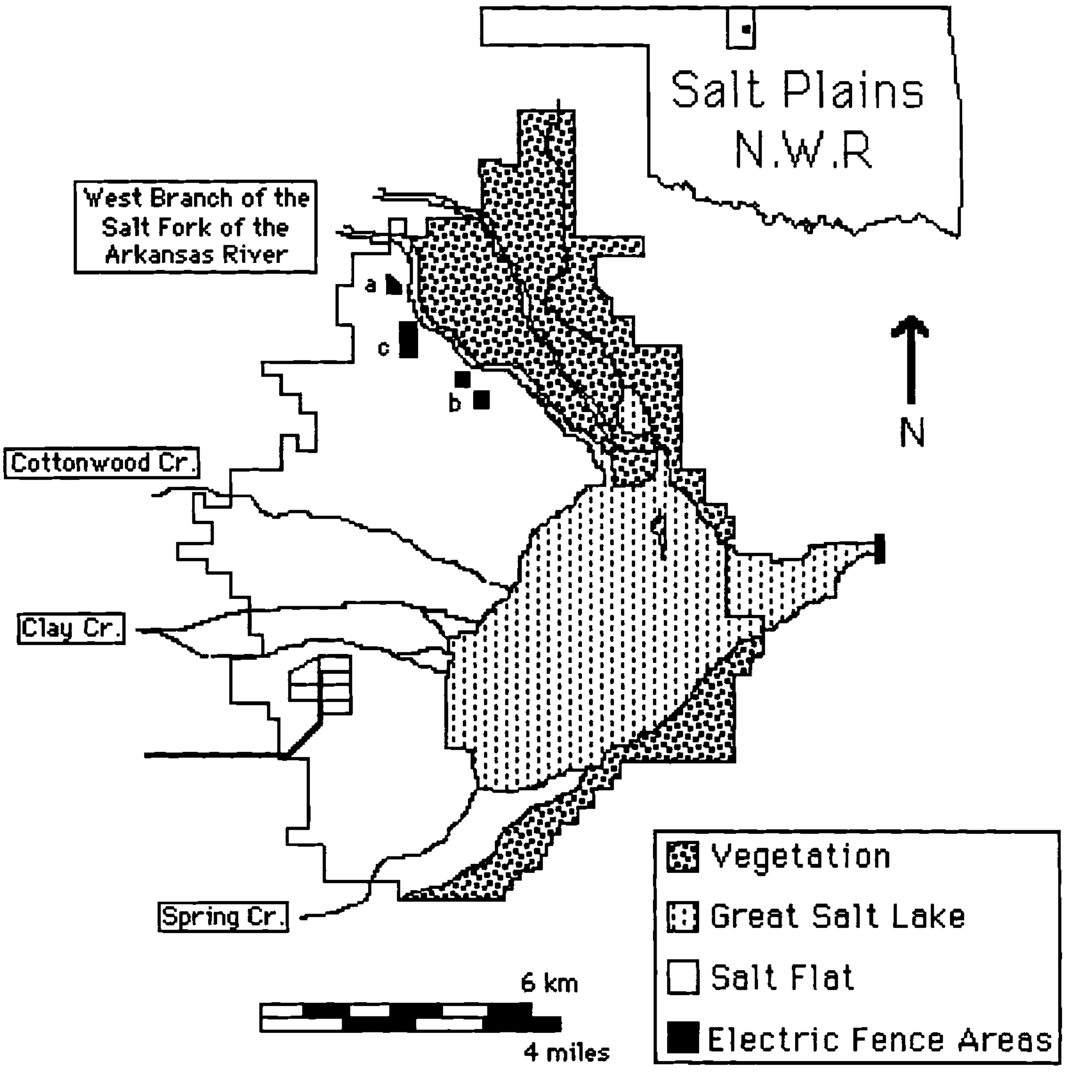

Fig 1. Salt Plains National Wildlife Refuge and locations of fenced areas: a) built in fall 1990; includes 14 experimental nest ridges; washed out and rebuilt in spring 1993; b) built in spring 1992 and washed out in spring 1993; c) built in spring 1993; included 10 preexisting nest ridges and received 8 gravel mounds. Sixty-five nest ridges and 14 nest mounds were built in areas a and c in fall 1993.

Chapter III

HABITAT CHANGES AND PREDATOR IMPACT ON ARTIFICIAL NESTS ON AN ALKALINE FLAT

ABSTRACT

ABSTRACT.--A 2-year study was initiated in summer 1993 to evaluate habitat changes and associated predator impact on artificial nests on an alkaline flat at Salt Plains National Wildlife Refuge (NWR), Oklahoma. Aerial photography of the refuge taken during 1941-1942, 1966, and 1989 were digitized to evaluate habitat changes to an alkaline flat, herbaceous rangeland, and shrub rangeland that was dominated by salt cedar (Tamarix spp.). Vegetation cover increased by approximately 600 ha between 1941 and 1989, and alkaline flat decreased by >240 ha. Field experiments were conducted to determine predator impact on artificial nests that simulated Least Tern (Sterna antillarum) and Snowy Plover (Charadrius alexandrinus) nests. Experimental nest plots were placed adjacent to, 500 m from, and 1,000 m from herbaceous rangeland, shrub rangeland, and stream habitat that was not associated with vegetation. Nests near vegetation had significantly ($P < 0.05$) higher losses to mammalian predators but significantly lower losses to flooding. It is likely that encroaching vegetation

will continue to reduce habitat for ground-nesting birds and increase predation levels.

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 western Snowy Plover was federally listed as threatened on 5 March 1993 (U.S. Fish and Wildl. Serv. 1993). The Least Tern population decline has been attributed largely to loss of breeding habitat due to river channelization and the creation of impoundments (U.S. Fish and Wildl. Serv. 1990). Snowy Plovers use similar habitat and are likely affected by the same habitat changes that caused the Least Tern population decline.

Alkaline flats at Salt Plains NWR contains the largest breeding population of Least Terns in Oklahoma (U.S. Fish and Wildl. Serv. 1990). Nest predation and flooding have been identified as the main causes of Least Tern and Snowy Plover nest losses on these alkaline salt flats (Grover and Knopf 1982, Hill 1985, Utych 1993). Coyotes (Canis latrans) are the main nest predator, and rain causes sheet flooding on the flats, which can wash eggs out of nests.

Flooding and predation are likely consequences of habitat changes occurring at Salt Plains NWR since its creation in the 1930's. Reservoir construction and the spread of saltcedar (Tamarix spp.) stands 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 of artificial bird nests close to forest/prairie or forest/farmland edge habitats than nests further from the edge (Andren and Angelstram 1988, Burger 1988, Paton 1993, Wilcove et al. 1986). No studies have correlated predation rates on Least Terns and Snowy Plover nests relative to vegetated habitat. Proximity to vegetated habitat may make ground nests more susceptible to coyote predation than nests further from vegetation.

The Least Tern recovery plan objectives include: (1) protection and enhancement of essential breeding habitat and (2) maintenance of 300 adults at Salt Plains NWR for at least 10 years (U.S. Fish and Wildl. Serv. 1990). Predators entering Least Tern nesting habitat from adjacent vegetated habitats may be a negative influence on the population density and compromise recovery objectives. In response to recovery plan goals, we assessed habitat changes and evaluated their impact on nest predators and flooding. We hypothesized that because vegetation harbored predators such as coyotes, nests close to vegetation would have higher rates of predation.

STUDY AREA

Salt Plains NWR is located in Alfalfa County in northcentral Oklahoma (Fig. 1) and contains approximately 5,095 ha of alkaline flats that serve as breeding areas for Least Terns and Snowy Plovers (Grover and Knopf 1982, Hill 1985, Utych 1993, Schweitzer 1994). The flats are closed to the general public except for a small public use area on the southwestern corner of the flats that is open between 1 April and 15 October for selenite crystal collecting.

The alkaline flats are nearly level and poorly drained. Altitude ranges from approximately 340 to 350 m above mean sea level. The water table is at the surface of the flats in some areas and up to 1 m deep in others (Williams and Grover 1975). A thin (approximately 0.01-3.00 cm) layer of white crystalline salt crust forms on the salorthid soil surface (Williams and Grover 1975). The salt is the result of brine upflows from underlying Permian rock (Johnson 1972). 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 flats, which can remain for several hours to several days. Such sheet flooding can wash eggs out of nests and submerge entire colonies. Standing water on the salt flats is ephemeral and of variable depth and amount; it contains chloride concentrations of 825-5,156 mEq/l (Purdue and Haines 1977). Average wind speed is 21 kph, but southwesterly winds of 48-72 kph are common in spring (Williams and Grover 1975).

Creeks flow across the flats into the Great Salt Lake and are ephemeral and multibranched by nature. They tend to dry up by late July and early August, although they can be dry throughout most of the Least Tern and Snowy Plover breeding season (May-August), as in 1994. The Great Salt Lake was created by a dam built across the Salt Fork of the Arkansas River in 1941. The resulting reservoir flooded about 30% of the original 11,137-ha alkaline flat habitat (Purdue 1976).

The alkaline flats at Salt Plains NWR are about 98% 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, which are frequently dominated by exotic saltcedar (Tamarix spp.). Salt cedar is a fire-adapted tree that was introduced to the southwestern U.S. as an ornamental species near the end of the 18th century (Kerpez and Smith 1987). The north and west sides of the flats are primarily bordered by grazed mixed-grass prairie. The east side of the flats are bordered by thick shrub cover consisting of primarily saltcedar, which has established rapidly along rivers and alkaline flats throughout the Southwest, including Salt Plains NWR.

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 salt flat habitat (Hill 1985, Scweitzer 1994). The average distance between Least Tern nests is 70 m (Schweitzer 1994), but nest distances may range from 5 m to more than 500 m. Snowy Plover nests are widely scattered and can be found in Least Tern colonies and in areas not used by terns. Nests of both species are shallow scrapes (ca. 0.5-4 cm deep x 5-10 cm wide) and typically contain 1 to 3 eggs.

METHODS

Spatial data can be used to evaluate historic habitat changes (Koeln et al. 1994). We identified and manually digitized vegetation habitat from 1:16,000 and 1:20,000 aerial photographs obtained from the U.S. Department of Agriculture Natural Resource Conservation Service using an Altek graphic digitizer board and GRASS4.0 (1991) Geographical Information System (GIS) software. The aerial photographs utilized 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 within Salt Plains NWR's boundary south of Highway 11.

To evaluate the impact of habitat changes and predators on ground nesting birds, we conducted controlled experiments using artificial nests with 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: 1) potential predators; 2) areas sensitive to predation; and 3) areas sensitive to flooding.

In 1993, a 60 x 90-m artificial nest plot was placed 1) adjacent to, 2) 500 m from, and 3) 1,000 m from shrub rangeland and the West Branch of the Salt Fork of the Arkansas River in the northeastern corner of the alkaline flats (n = 3 plots) (Fig. 1). In 1994, the experiment was expanded with 15 new plots. A new plot was established about 1,000 m north of each of the 1993 plots (n = 3 plots) to replicate assesment of proximity to shrub rangeland.

Paired plots were placed about 1,000 m from one another and 1) adjacent to, 2) 500 m from, and 3) 1,000 m from grazed herbaceous rangeland on the west side of the flats (n = 6 plots) (Fig. 1). Similarly, paired plots were placed 1) adjacent to, 2) 500 m from, and 3) 1,000 m from Cottonwood Creek, not associated with vegetation cover (n = 6 plots).

Each plot contained 12 artificial nest scrapes placed approximately 30 m apart, and each nest contained 2-3 quail eggs. Eggs were placed in the nests for 3 21-day trials (17 May-6 June; 16 June-6 July; and 16 July-6 August) in both years to imitate the incubation period of Least Terns and Snowy Plovers (Hill 1985). 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 to 4 days to determine predation rates and other factors causing nest losses.

Nest success was determined for the incubation period as discussed by Mayfield (1975) with a slight modification to compare individually effects of flooding and predation. The Mayfield method determines daily mortality rates and nest success based on nest failure over the number of days that nests were observed (exposure). Nest failure is a general term and may be the result of flooding, predation, abandonment, or other factors. The Mayfield Method was modified to calculate rates of daily predator mortality and daily flooding mortality. Only nests lost to predation were considered failed nests when calculating daily predator mortality rate. Likewise, only nests lost to flooding were considered failed nests when calculating daily flooding mortality rate. The number of days that ≥1 eggs remained in nest scrapes were used to determine exposure. Predator and flooding mortality rates were used to determine nest success and compare categories with 95% 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 between periods.

A nest was considered successful if ≥1 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 found under water, or eggs were 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

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 northeast side of the refuge (Figs. 2-4) where shrub rangeland increased from 1,546 to 1,853 ha from 1941 to 1966 and increased to 2,142 ha between 1966-1989. This represented a vegetation spread of 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 2,901 ha in 1941 (Fig. 2) to

3,492 ha in 1989 (Table 1). This represented a 3.4 ha/yr spread from 1941 to 1966 and a 22.0 ha/yr spread from 1966 to 1989.

The size of the salt flat and lake could not be compared among 1941, 1966, and 1989 because of fluctuating lake levels. Lake levels, however, were 343.0 m in 1941 and 1989 allowing comparisons of net losses and gains over the 48-year period. The salt flat decreased from 5,342 ha in 1941 to 5,095 ha in 1989. The Great Salt Lake decreased 407 ha over the same period. This represented a net loss of 654 ha of salt flat and lake cover that corresponded closely to the 596 ha net increase of shrub rangeland on the northeastern side of the refuge.

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. Canines left distinctive eggshell remains similar to those shown and discussed by Sooter (1946). In late July and August 1993 and 1994, we noted an influx of ring-billed gulls (Larus delawarensis). Footprints, compared to museum specimens, indicated predation of artificial nests by Ring-billed Gulls. These gulls did not leave eggshell remains; however, yolk stains were occasionally found on the sand near predated nests. Angelstram (1986) suggested that single predator species may treat bird eggs in a variety of ways; however, we found very little variation in how coyotes and gulls predated nests.

In 1993, there were no significant differences ($P > 0.05$) in nest success of artificial nests at various distances from shrub rangeland (Table 2). The highest nest success (0.49) occurred adjacent to vegetation, and the lowest nest success (0.33) occurred in plots 1,000 m from vegetation. Mortality specific comparisons of nest success relative to flooding and predation (coyote or gull) also did not differ.

In 1994, highest overall nest success occurred adjacent to shrub rangeland (0.42) and adjacent to Cottonwood Creek (0.47) (Table 3). Lowest nest success occurred 500 m from Cottonwood Creek (0.16). Coyote predation was constant among the 3 trial periods. Comparison of coyote predated plots indicated significant lower nest success for plots adjacent to shrub and herbaceous rangelands and within 500 m of herbaceous rangeland than 500 m and 1,000 m from shrub rangeland, 1,000 m from herbaceous rangeland and all Cottonwood Creek plots. Gull predation did not differ among the sample plots during the first 2 trial periods in 1994 (Table 3). During the third trial period, when ring-billed gulls were noted, nest success relative to gull predation was significantly higher adjacent to shrub rangeland, adjacent to and 500 m from herbaceous rangeland than 500 m and 1,000 m from shrub rangeland and 500 m from Cottonwood Creek.

Comparison of flooded nests indicated significantly higher nest success adjacent to shrub rangeland than on plots located 500 m and 1,000 m from shrub rangeland, 1,000 m from herbaceous rangeland, and all Cottonwood Creek plots. Plots adjacent to herbaceous rangeland also had higher nest success than plots located 500 m and 1,000 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 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 wetlands between 1954 and 1983; shrub dominated wetlands increased from 13% to 46%. Saltcedar tolerates the salt levels found on the alkaline flats at Salt Plains NWR (Ungar 1966) and dominated shrub rangeland vegetation that altered approximately 596 ha of 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. Due to the high water table and often saturated soils on the salt flat, the saltcedar-dominated shrub rangeland is likely to continue spreading away from the West Branch of the Salt Fork of the Arkansas River and onto the salt flats. Dense saltcedar stands can stabilize substrate and alter fluvial processes (Stinnet et al. 1987). Herbaceous rangeland cover fluctuated slightly between periods analyzed; however, it does not appear to be encroaching onto the salt flat habitat.

A variety of studies highlighted negative impacts of saltcedar spread on native wildlife (Anderson et al. 1977, Kerpez and Smith 1987, Hunter et al. 1988). Schulenberg and Ptacek (1984) noted that encroaching salt cedar on sandbanks in Kansas has reduced nesting habitat available for least terns. Typically, vegetation in Least Tern colonies 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).

Encroaching vegetation onto the alkaline flat habitat at Salt Plains NWR also will place ground nesting birds at risk to associated predators. Coyotes have been implicated as major nest predators of Least Tern and Snowy Plover nests at Salt Plains NWR (Grover and Knopf 1982, Hill 1985, Utych 1993, Koenen unpubl. data); about 5-60% of monitored nests have been lost to predators annually.

In this study, there was no significant difference in the rate of coyote predation of real nests and artificial nests (Koenen, Chapter II). Gulls predated artificial nests but rarely predated real Least Tern and Snowy Plover nests. In support of our hypothesis, coyote predation rates were higher adjacent to grazed herbaceous and shrub rangeland than along a stream and >500 m from vegetation. The increase in shrub rangeland over the last 50 years likely increased habitat favorable for coyotes and their predation of tern and plover nests.

Mammalian predators likely locate nests by chance, olfaction, or vision (Page et al. 1983, Gottfried and Thompson 1978, Storaas 1988), and avian predators may rely largely on vision (Angelstram 1986). Nests that are without a protective adult may be easy prey for gulls; however, coyotes are not more likely to find nests with or without adult birds present. Coyotes on the alkaline flats have been observed to pass within 20 cm of nests without predating them, which suggests that they can easily miss nests and find them by chance.

Artificial nest losses due to flooding were lowest near shrub rangeland and highest >500 m from vegetation and along Cottonwood Creek where no vegetation occurred. The saltcedar-dominated rangeland may have encroached into these areas because flooding does not regularly occur there. Once established, vegetation also may have channeled water away from the salt flats or acted as a barrier to sheet flooding. In contrast, accelerated saltcedar growth along the Rio Grande, Pecos, and Gila rivers stabilized channel sediments, reduced stream velocity, accelerated sedimentation and increased flood risks (Blackburn et al. 1982). Saltcedar has not 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 undesirable consequences for ground nesting birds.

Due to the difference in real and artificial nests, it can be difficult to apply results from artificial nest studies to management decisions. Artificial nests may be more or less vulnerable to predation than real nests (Angelstram 1986, Andren and Angelstram 1988, Martin 1987, Willebrand and Marctström 1988, Paton 1993). Incubating terns and plovers provide better cover and protection than artificial nests exposed day and night. However, this study suggests that continued encroachment by vegetation may increase nesting risks to Least Terns and Snowy Plovers by reducing nesting area available for the birds and increasing predator access to ground-nesting birds. Currently, areas near vegetation appear to provide ground nesting birds safety from flooding, but continued spread of saltcedar may further alter fluvial processes.

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LITERATURE CITED

Angelstram, P. 1986. Predation on ground-nesting birds' nests in relation to predator densities and habitat edge. Oikos 47:365-373.

Anderson, B. W., A. Higgins, and R. D. Ohmart. 1977. Avian use of saltcedar communities in the lower Colorado River valley. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. RM-43:128-136.

Andren, H., and P. Angelstram. 1988. Elevated predation rates as an edge effect in habitat islands: experimental evidence. Ecology 69:544-547.

Blackburn, W. H., R. W. Knight, and J. L. Schuster. 1982. Saltcedar influence on sedimentation in the Brazos River. J. Soil and Water Conserv. 37:286-301.

Boyd, R. L., and J. Rupert. 1991. Habitat management and population ecology studies of the Least Tern in Kansas. Kansas Dep. Wildl. and Parks Nongame Wildl. Proj. Rep., Baldwin City.

Brock, J. H. 1994. Tamarix spp. (Salt Cedar), an invasive exotic woody plant in arid and semi-arid riparian habitats of western USA. Pp. 27 - 44 in Ecology and management of invasive riverside plants (L. C. de Waal, L. E. Childs, P. M. Wade and J. H. Brock Eds.). International Centre of Landscape Ecology, John Wiley & Sons, New York.

Burger, J. 1984. Colony stability in Least Terns. Condor 86:61-67.

Burger, L. D. 1988. Relation between forest and prairie fragmentation and depredation of artificial nests in Missouri. M.S. thesis. Univ. Missouri, Columbia.

Gochfeld, M. 1983. Colony site selection by Least Terns: physical attributes of sites. Colonial Waterbirds 6:205-213.

Gottfried, B. M., and C. F. Thompson. 1978. Experimental analysis of nest predation in an old-field habitat. Auk 95:304-312.

GRASS4.0. 1991. Geographic resource analysis support system, U.S. Army Corps of Engineers Construction Engineering Research Laboratroy, Champaigne, Illinois.

Grover, P. B., and F. L. Knopf. 1982. Habitat requirements and breeding success of charadriiform birds nesting at Salt Plains National Wildlife Refuge, Oklahoma. J. Field Ornithol. 53:139-148.

Hill, L. A. 1985. Breeding ecology of interior Least Terns, Snowy Plovers, and American avocets at Salt Plains National Wildlife Refuge, Oklahoma. M.S. Thesis, Oklahoma State Univ., Stillwater.

Hunter, W. C., R. D. Ohmart, B. W. Anderson. 1988. Use of exotic saltcedar (Tamarix chinensis) by birds in arid riparian systems. Condor 90:113-123.

Johnson, K. S. 1972. Guidebook for geological trips in Oklahoma. Book II: Northwest Oklahoma. Univ. Oklahoma Press, Norman.

Johnson, D. H. 1979. Estimating nest success: the Mayfield Method and an alternative. Auk 96:651-661.

Johnson, L. B. 1993. Ecological analysis using geographic information systems. Pp 27-38 in GIS applications in mammalogy (S. B. McLaren and J. K. Braun, eds.). Oklahoma Museum of Natural History, Norman.

Kerpez, T. A., and N. S. Smith. 1987. Saltcedar control for wildlife habitat improvement in the southwestern United States. U.S. Fish and Wildl. Serv. Res. Publ. 169.

Koeln, G. T., L. M. Cowardin, and L. L. Srong. 1994. Geographic information systems. Pp 540-566 in Research and management techniques for wildlife and habitats (T. A. Bookhaut, ed.). Fifth ed., The Wildlife Society, Bethesda, Maryland.

Martin, T. E. 1987. Artificial nest experiments: effects of nest appearance and type of predator. Condor 89:925-928.

Mayfield, H. F. 1975. Suggestions for calculating nest success. Wilson Bull. 87:456-466.

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.

Paton, P. W. 1993. The effect of edge on avian nest success: how strong is the evidence? Cons. Bio. 8:17-26.

Purdue, J. R. 1976. Adaptations of the Snowy Plover on the Great Salt Plains, Oklahoma. Southwest. Nat. 21:347-357.

Purdue, J. R., and H. Haines. 1977. Salt water tolerance and water turnover in the Snowy Plover. Southwest. Nat. 21:347-357.

Schulenberg, J. H., and M. B. Ptacek. 1984. Status of the interior Least Tern in Kansas. Am. Birds 38:975-981.

Schweitzer, S. H. 1994. Abundance and conservation of endangered interior Least Terns nesting on salt flat habitat. Ph.D. Thesis, Oklahoma State Univ., Stillwater.

Sooter, C. A. 1946. Habits of coyotes in destroying nests and eggs of waterfowl. J. Wildl. Manage. 10:33-38.

Stinnet, D. P., R. W. Smith, and S. W. Conrady. 1987. Riparian areas of western Oklahoma. U.S. Fish and Wildlife Service, Ecological Services, Oklahoma City, Oklahoma.

Storaas, T. 1988. A comparison of losses in artificial and naturally occurring capercaillie nests. J. Wildl. Manage. 52:123-126.

Thompson, B. C., and R. D. Slack. 1982. Physical aspects of colony selection by Least Terns on the Texas Coast. Col. Waterbirds 5:161-168.

Ungar, I. A. 1966. Salt tolerance of plants growing in saline areas of Kansas and Oklahoma. Ecology 47:154-155.

U. S. Fish and Wildlife Service. 1985. Interior population of the Least Tern determined to be endangered. Fed. Reg. 50:21784-21792.

U. S. Fish and Wildlife Service. 1990. Interior population of the least tern (Sterna antillarum): recovery plan. Twin Cities, Minn.

U. S. Fish and Wildlife Service. 1991. Endangered and threatened wildlife and plants; animal candidate review for listing as endangered or threatened species. Fed. Reg. 56(225):58804-58810.

U. S. Fish and Wildlife Service. 1993. Endangered and threatened wildlife and plants; determination of threatened status for the Delta Smelt and the Pacific Coast population of the Western Snowy Plover. Fed. Reg. 58(42):12864-12874.

Utych, R. B. 1993. Compatibility of selenite crystal digging with breeding ecology of Least Terns and Snowy Plovers at salt plains National Wildlife Refuge. M.S. Thesis, Oklahoma State Univ., Stillwater.

Willebrand, T., and V. Marctström. 1988. On the danger of using dummy nests to study predation. Auk 105:378-379.

Williams, G. E., and E. S. Grover. 1975. Soil survey of Alfalfa County, Oklahoma. U.S. Soil Conserv. Serv., Stillwater, Okla.

Wilcove, D. S., C. H. McLellan, and A. P. Dobson. 1986. Habitat fragmentation in the temperate zone. Pp 237-256 in Conservation Biology (M. E. Soulé, ed.). Sinauer Associates, INC., Sunderland, Massachusetts.

Ziewitz, J. W., J. G. Sidle, & J. J. Dinan. 1992. Habitat Conservation for Nesting Least Terns and Piping Plovers on the Platte River, Nebraska. Prairie Nat. 24:1-20.

TABLE 1

Aerial coverage of dominant habitat (ha) at Salt Plains National Wildlife Refuge

	1941/42	1966	1989
Herbaceous rangeland	311	197	336
Shrub rangeland (north)	1,546	1,853	2,142
Shrub rangeland (south)	1,044	937	1,014
Salt Flat	5,342	5,688	5,095
Great Salt Lake	3,751	3,281	3,344
Island	60	9	5
Total Area	12,175	12,175	12,175

TABLE 2

Nest success (Mayfield Method) and 95% confidence interval of all nest plots (and replicates) placed at 3 intervals from shrub rangeland in 1993

	Shrub Rangeland		
	Adjacent to	500 m	1000 m
Overall Nest Success (N=36)	0.49	0.37	0.28
Confidence Interval (95%)	0.35-0.68	0.25-0.55	0.21-0.50
Nest Success based on flood mortality (N=36)	0.52	0.43	0.49
Confidence Interval (95%)	0.24-1.09	0.18-0.98	0.23-0.99
Nest Success based on predator mortality (N=36)	0.24	0.31	0.15
Confidence Interval (95%)	0.08-0.69	0.12-0.79	0.02-1.21

TABLE 3

Nest success (Mayfield Method) and 95% confidence interval of all nest plots (and replicates) placed at 3 intervals from 3 treatments in 1994

	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	0.32	0.40	0.29	0.27	0.23	0.47	0.16	0.26
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 flood mortality	0.89	0.59	0.59	0.69	0.64	0.41	0.49	0.26	0.36
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
Nest Success based on coyote predator mortality	0.39	0.83	0.86	0.38	0.31	0.86	0.78	1.00	0.93
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 gull predator mortality	0.40	0.83	0.86	0.38	0.31	0.86	0.78	1.00	0.93
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	0.66-0.93	-	0.85-1.02

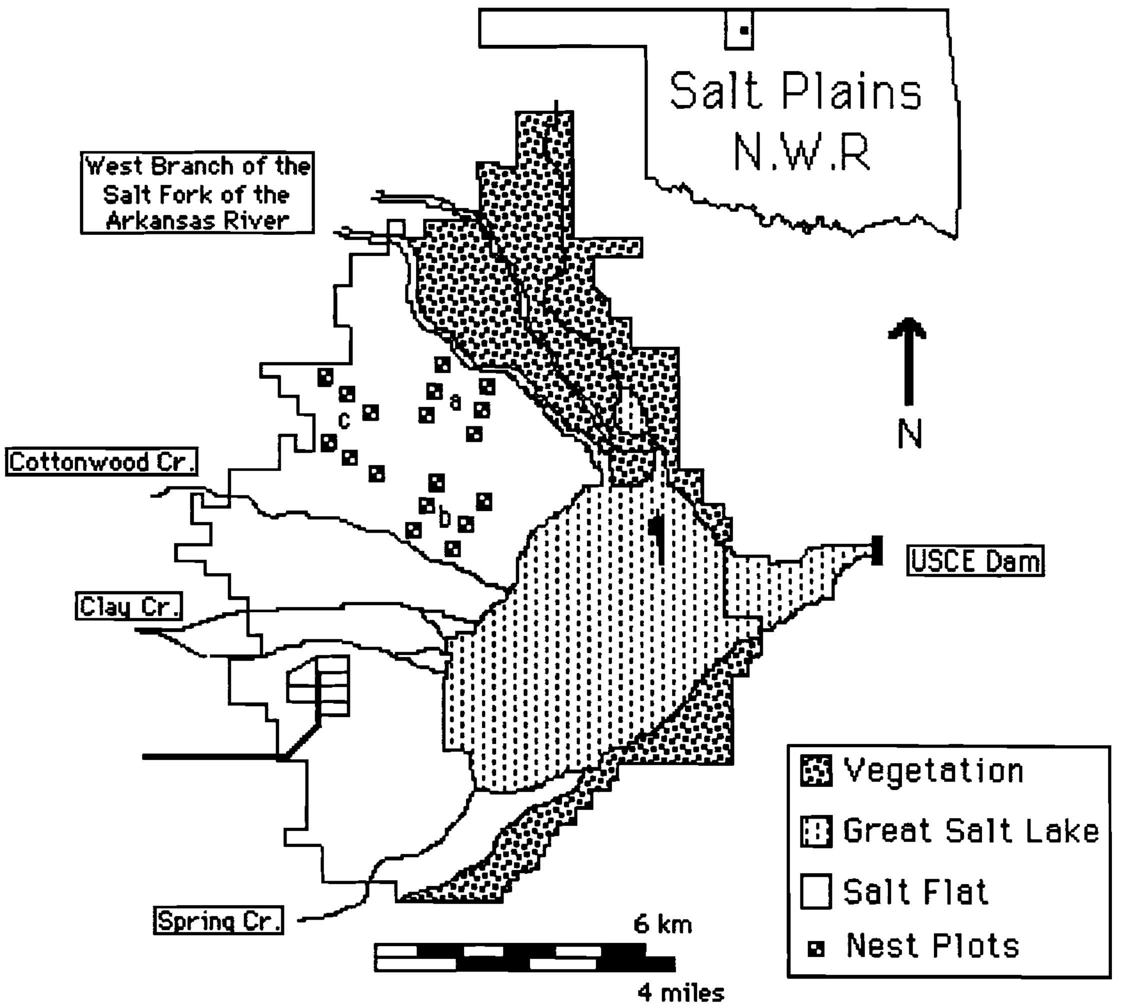

Fig 1. Salt Plains National Wildlife Refuge: a) nest plots placed near shrub/brush rangeland (includes original 3 used in 1993); b) nest plots placed near Cottonwood Creek; c) nest plots placed near herbaceous rangeland.

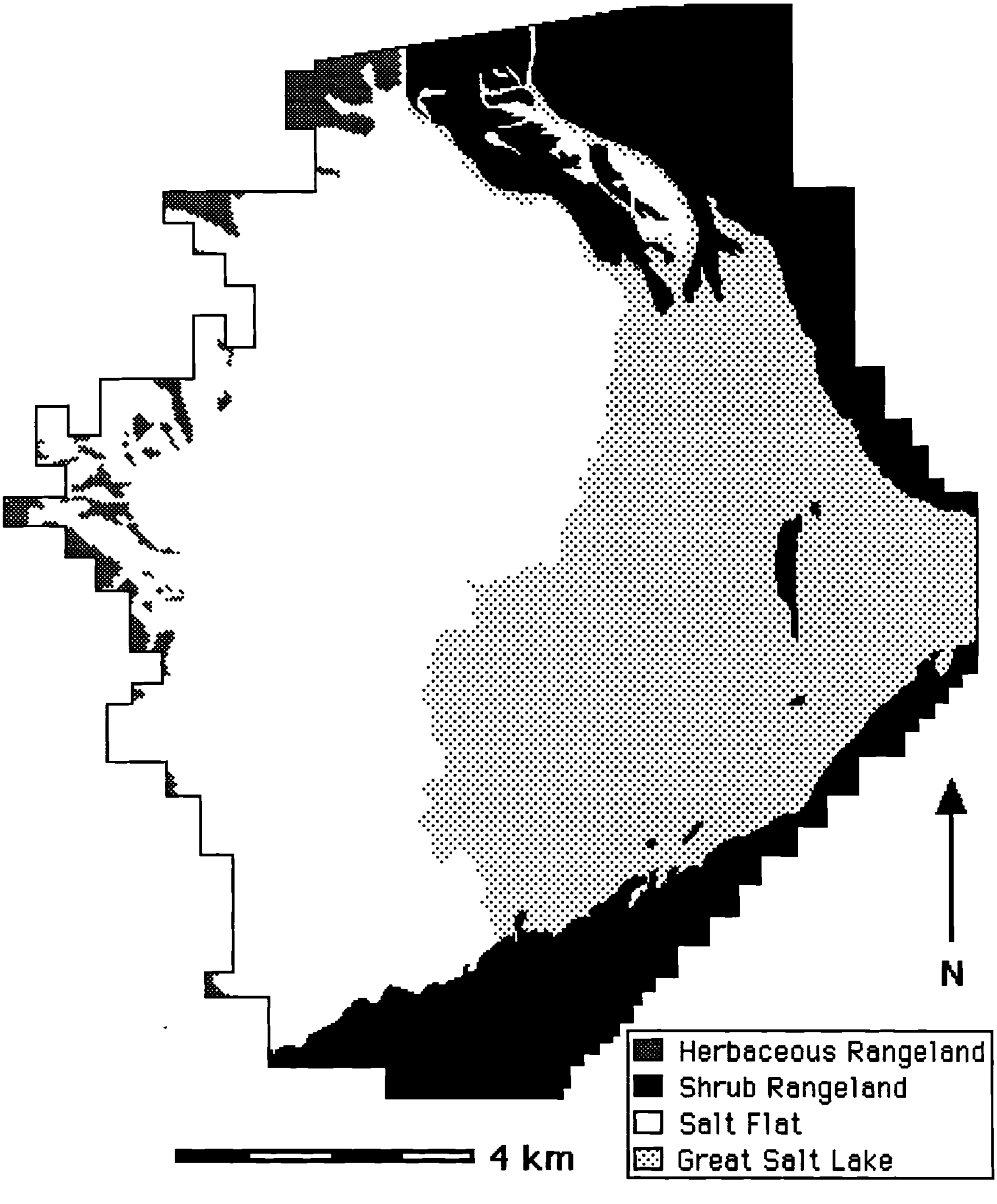

Fig. 2. Salt Plains National Wildlife Refuge in 1941.

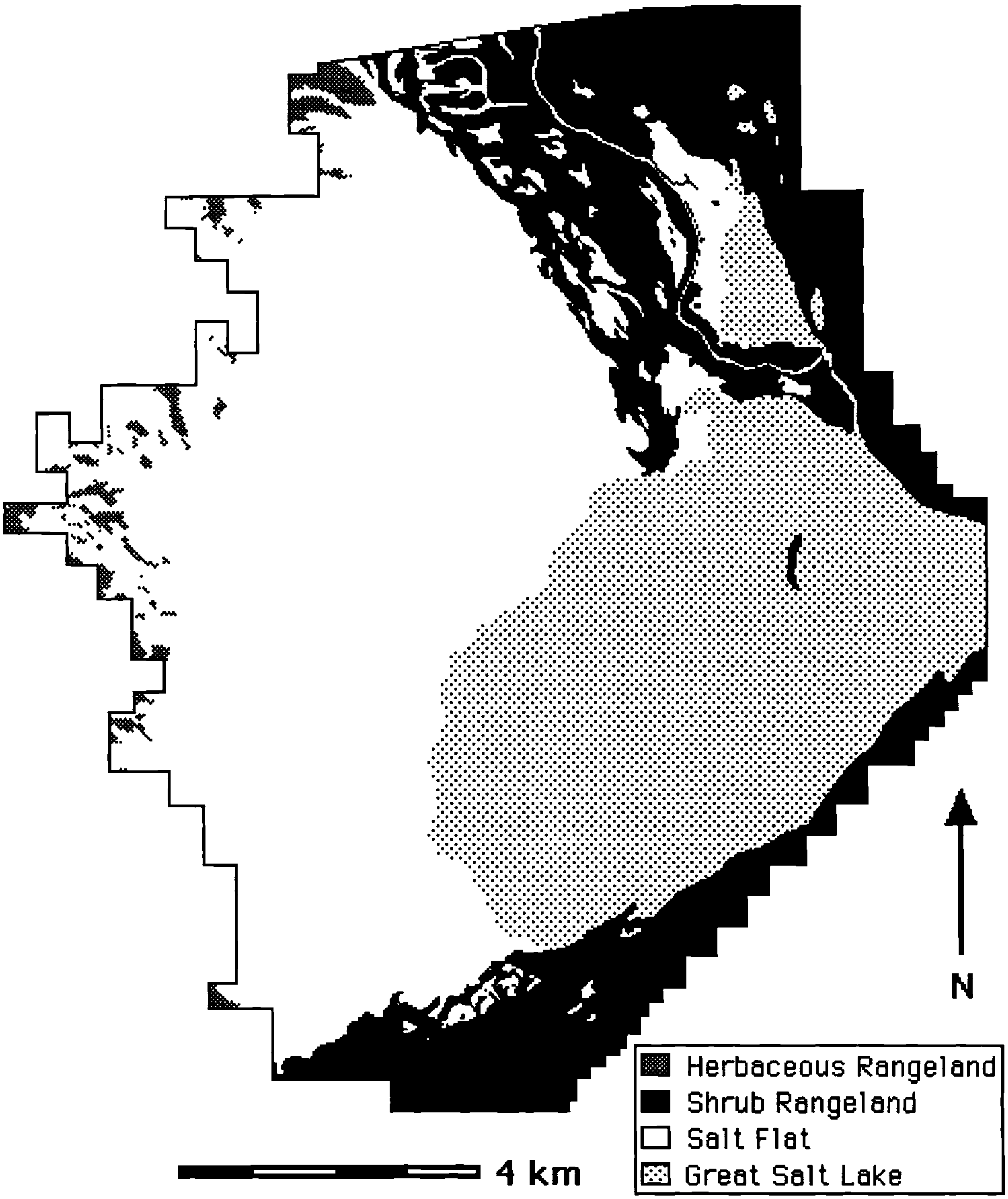

Fig. 3. Salt Plains National Wildlife Refuge in 1966.

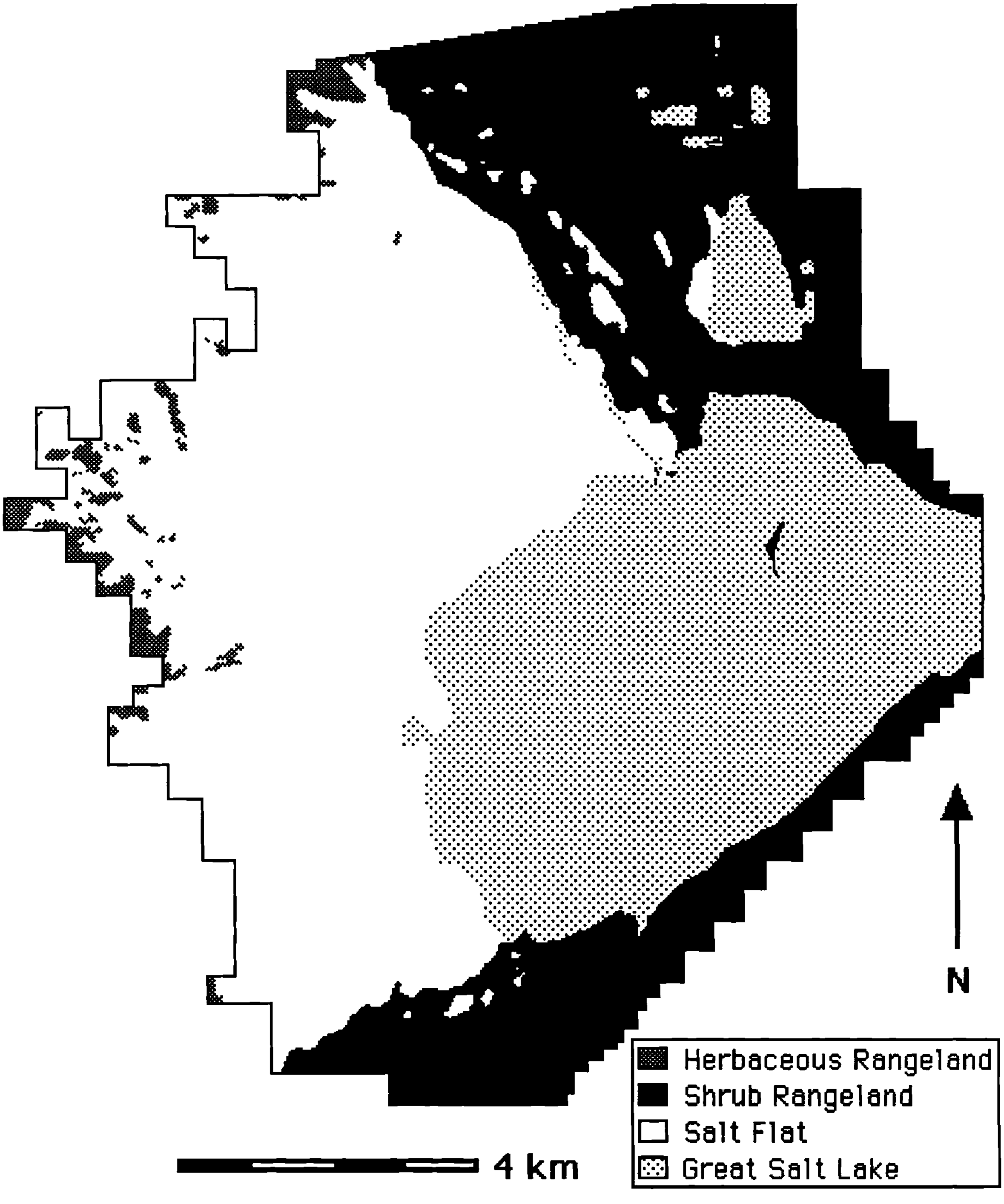

Fig. 4. Salt Plains National Wildlife Refuge in 1989.

Chapter IV

EVALUATION OF INTERIOR LEAST TERN EGGSHELL THICKNESS

Significant decreases in eggshell thickness have been associated with DTT and other organochlorine compounds in many avian species (King et al. 1978, Hickey and Anderson 1968). Organochlorine compounds disturb physiological mechanisms of $CaCO_3$ metabolism and cause eggshell thinning (Ratcliffe 1970). DDT and other organochlorine pesticides are no longer used in the United States, and there has been a significant decrease in organochlorine contamination and eggshell thinning in North American avian species (Blus 1982, Weseloh et al. 1989). However, recent studies of Bald Eagles (Haliaeetus leucocephalus) in Arizona (Grubb et al. 1990) and Peregrine Falcons (Falco peregrinus) in New Jersey (Steidl et al. 1991) indicated thinner eggshells than among pre-DDT era egg samples. In addition, Forster's Terns (Sterna forsteri) and Black Skimmers (Rynchops niger) nesting on the Gulf Coast in Texas had thinner eggshells in 1984 than in 1970 and 1943 (King et al. 1991). This suggests that toxic contamination and eggshell thinning are still a problem for some species in certain breeding areas.

Least Terns (Sterna antillarum) winter in countries known to have higher pesticide use than the United States and are high on the food chain, making them susceptible to environmental contamination. If organochlorine pesticides accumulate in birds on wintering grounds, eggshell thickness and breeding success could be affected on the breeding grounds (Boardman 1988). Several studies have evaluated eggshell thickness for coastal populations of Least Terns, but there is a paucity of eggshell data for the interior Least Tern, which is listed as endangered (U.S. Fish and Wildl. Serv. 1985).

Contamination of Least Terns nesting on the salt flats of Salt Plains National Wildlife Refuge (NWR), Oklahoma, became a concern when 23 of 170 (14%) Least Tern eggs were found addled, crushed, or cracked in 1992 (Utych, unpubl. data). In addition, Dryer and Dryer (1985) reported that 24% of Least Tern nests monitored in North Dakota contained ≥1 addled eggs, and Hill (1985) found that 8-10% of Least Tern eggs at Salt Plains NWR were addled or crushed in the early 1980's. We collected addled Least Tern eggs in 1993 and 1994 at Salt Plains NWR to evaluate shell thickness as a simple way to determine possible contamination problems and to provide baseline data for interior Least Terns.

METHODS

Eighty eggshell samples were available for measurement. We collected 33 Least Tern eggs from flooded nests on the salt flats during the 1993 and 1994 breeding season at Salt Plains NWR. Partial eggshells were gathered from cracked (n=16), hatched (n=9), abandoned (n=8), and predated (n=2) eggs. In addition, 12 partial eggshells were collected, but their cause of failure was unknown.

Contents were removed from 29 of the collected eggs and subsequently frozen in chemically cleaned jars. These have been transferred to U.S. Fish and Wildlife Service for chemical examination.

Eggshells were air-dried for at least 3 months, and the thickness of 80 eggs (membrane and shell) were measured at 3 points around the midline with a Starret Pocket Dial Gage (1010RZ ± 0.002 mm) and averaged. Eggshell thickness was compared among causes of nest failure with 1-way ANOVA and Fisher's least significant difference multiple mean tests. Least Tern shell thickness was compared among samples from coastal and interior areas using 95% Confidence Intervals.

RESULTS AND DISCUSSION

We compared eggshell thickness of the 1993 and 1994 samples among causes of egg failure (Table 1). Eggs that were found cracked ($\bar{x}$ = 0.149) were not significantly thinner than eggs that hatched ($\bar{x}$ = 0.159) ($\underline{P}$ = 0.24). Eggs may crack for a variety of reasons associated with human or other disturbances (Robert and Ralph 1975), which are not related to shell thinning. Abandoned eggs ($\bar{x}$ = 0.139) were slightly thinner than eggs that hatched ($\underline{P}$ = 0.04). Eggshell variation between abandoned and hatched eggs may be associated with food shortages or stress, as noted in captive birds (Ratcliffe 1970).

Thinning of 18-20% was associated with raptor and Brown Pelican (Pelecanus occidentalis) declines (Hickey and Anderson

1968). Blus and Prouty (1979) reported 2-7% Least Tern eggshell thinning from pre-1947 to 1974 on the Atlantic coast of North Carolina. All eggs contained residues of DDE and PCB, but relatively low levels did not appear to affect productivity (Blus and Prouty 1979). Eggs from the Salt Plains NWR ($\bar{x}$ = 0.153 mm, SE = 0.002) were significantly thicker than eggs collected in 1974 by Blus and Prouty (1979) from South Carolina (Table 2) but not significantly different from pre- 1943 and 1947 eggs, and eggs collected in 1970 (King et al. 1978), 1969-1971 (Massey 1972), 1972 (Blus and Prouty) (1979), 1974 (Rahn 1976), 1975 (Blus and Prouty), 1981-1985 (Boardman 1988) in a variety of locations. Similar eggshell thicknesses from Least Tern coastal populations and Salt Plains NWR suggested that excessive thinning is not a problem at the refuge.

Eggshells from all studies were significantly thinner ($P < 0.05$) than samples collected in 1989, 1990 and 1991 by Ruelle (1993) in South Dakota. Least Tern eggs from Salt Plains NWR were 32-40% thinner than eggs from South Dakota. Mean eggshell thickness variation between individuals of the same species may be due to different stages of incubation, clutch size, genes (Klaas et al. 1974), food shortages, or other environmental stress factors that were not accounted for in this study (Ratcliffe 1970). In addition, slight differences in measurement techniques in the different studies also may have influenced variability of eggshell thickness results. Ruelle (1993) made shell measurements after 4 days of drying; whereas, our eggs were air dried approximately 3 months.

Addled Least Tern eggs at Salt Plains NWR may result from other contamination problems. Elevated concentrations of selenium have been found in Least Tern eggs at the refuge (U.S. Fish and Wildl. Serv. 1988) and in North Dakota (Welsh and Mayer 1993), and their effects warrant further examination. Likewise, significant eggshell thickness differences may exist between interior nesting areas; but further study is required to verify this.

LITERATURE CITED

Blus, L. J., and R. M. Prouty. 1979. Organochlorine pollutants and population status of least terns in South Carolina. Wilson Bull. 91(1) 62-71.

Blus, L. J. 1982. Further interpretation of the relation of organochlorine residues in Brown Pelican eggs to reproductive success. Env. Poll. (Series A) 28:15-33.

Boardman, C. J. 1988. Organochlorine pesticides in California Least Terns (Sterna antillarum browni). M.S. Thesis, California State University, Long Beach.

Dryer, M. P., and P. J. Dryer 1985. Investigations into the population, breeding sites, habitat characteristics, threats and productivity of the Least Tern in North Dakota. U.S. Fish and Wildl. Serv. Resource Information Paper Number 1, Bismarck, North Dakota.

Grubb, T. G., S. W. Wiemeyer, and L. F. Kiff. 1990. Eggshell thinning and contaminant levels in Bald Eagle eggs from Arizona, 1977 to 1985. The Southwestern Naturalist 35:298-301.

Hickey, J. J. and D. W. Anderson. 1968. Chlorinated Hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162:271-273.

Hill, L. A. 1985. Breeding ecology of interior least terns, snowy plovers, and American avocets at Salt Plains National Wildlife Refuge, Oklahoma. M.S. Thesis, Oklahoma State Univ., Stillwater.

King, A. K., E. L. Flickinger, and H. H. Hildebrand. 1978. Shell thinning and pesticide residues in Texas aquatic bird eggs, 1970. Pesticide Monitoring Journal 12:16-21.

King, K. A., T. W. Custer, and J. S. Quinn. 1991. Effects of mercury, selenium, and organochlorine contaminants on reproduction of Forster's Tern and Black Skimmers nesting in a contaminated Texas bay. Arch. Environ. Contam. Toxicol. 20:32-40.

Klaas, E. E., H. M. Ohlendorf, and R. G. Heath. 1974. Avian eggshell thickness: variability and sampling. Wils. Bull. 86:156-165.

Massey, B. 1972. Breeding biology of the California Least Tern. M.S. Thesis, California State University, Long Beach.

Rahn, H., C. V. Pagnelli, I. C. T. Nisbet and G. C. Whittow. 1976. Regulation of incubation water loss in eggs of seven species of terns. Physiol. Zool. 49:245-259.

Ratcliffe, D. A. 1970. Changes attributable to pesticide in egg breakage frequency and eggshell thickness in some British Birds. J. Appl. Ecolo. 7:67-115.

Robert, H. C. and C. J. Ralph. 1975. Effects of human disturbance on the breeding success of gulls. Condor 77:495-499.

Ruelle, R. 1993. Contaminant evaluation of interior least tern and piping plover eggs from the Missouri River in South Dakota. Pp.

159-171 in: Proceedings of the Missouri River and its Tributaries: Piping Plover and Least Tern Symposium. (K. F. Higgins and M. R. Bashier, Eds.) Brookings, South Dakota: South Dakota State University.

Steidl, R. J., C. R. Griffin, L. J. Niles, and K. E. Clark. 1991. Reproductive success and eggshell thinning of a reestablished Peregrine Falcon population. J. Wildl. Manage. 55:294-299.

U.S. Fish and Wildl. Serv. 1985. Interior population of the Least Tern determined to be endangered. Federal Register 50:21784-21792.

U.S. Fish and Wildl. Serv. 1988. Salt Plains National Wildlife Refuge contaminant survey. Ecological Services, Tulsa, Oklahoma.

Welsh D., and P. M. Mayer. 1993. Concentrations of elements in eggs of Least Terns and Piping Plovers from the Missouri River, North Dakota. Pp. 172-180 in: Proceedings of the Missouri River and its Tributaries: Piping Plover and Least Tern Symposium. (K. F. Higgins and M. R. Bashier, Eds.) Brookings, South Dakota: South Dakota State University.

Weseloh, V., T. W. Custer, & B. M. Braune. 1989. Organochlorine contaminants in eggs of Common Terns from the Canadian Great Lakes, 1981. Env. Poll. 59:141-160.

Table 1. Eggshell thickness (mm) of Least Tern eggs relative to loss from Salt Plains National Wildlife Refuge, Oklahoma, in 1993 and 1994.

	Abandoned	Cracked	Hatched	Predated	Washed Out	Unknown
N	8	16	9	2	33	12
X	0.139[b]	0.149[ab]	0.159[a]	0.135[ab]	0.157[a]	0.148[ab]
SE	0.007	0.005	0.007	0.021	0.004	0.006

Means followed by the same letter are not significantly different

Table 2. Eggshell thickness (mm) of Least Tern eggs from Salt Plains National Wildlife Refuge, Oklahoma, in 1993 and 1994, and other North American studies.

Year	Pre-1947[1]	Pre-1947[2]	Pre-1943[3]	1970[3]	1969-1971[2]	1972[1]	1974[4]	1974[1]	1975[1]	1981-1985[5]	1989[6]	1990[6]	1991[6]	1993-1994[7]
N	61	32	22	15	13	11	12	20	15	16	34	18	47	80
X	0.152[a]	0.152[a]	0.156[a]	0.154[ab]	0.148[ab]	0.145[ab]	0.13[ab]	0.142[b]	0.149[ab]	0.151[a]	0.254[c]	0.226[c]	0.246[c]	0.153[a]
SE	0.002	0.002	0.003	0.004	0.003	0.005	0.01	0.002	0.004	0.001	0.004	0.011	0.003	0.002

Means followed by the same letter are not significantly different
1 South Carolina (Blus and Prouty 1979)
2 California (Massey 1972)
3 Texas (King et al. 1978)
4 Massachusetts (Rahn et al. 1976)
5 California (Boardman 1988)
6 South Dakota (Ruelle 1993)
7 Salt Plains National Wildlife Refuge

APPENDIX A

Compatibility of selenite crystal digging and nesting snowy plovers at Salt Plains National Wildlife Refuge

The inland population of the western snowy plover (Charadrius alexandrinus) is currently listed under Category 2 (U.S. Fish and Wildl. Serv. 1991), and the coastal population of the western snowy plover was federally listed as threatened on 5 March 1993 (U.S. Fish and Wildl. Serv. 1993). Like the least tern, snowy plovers nest in scattered patches on the salt flats of Salt Plains National Wildlife Refuge, including areas in and near the crystal dig area. In concert with the least tern compatibility study, we evaluated impact of recreational crystal digging on snowy plovers at Salt Plains National Wildlife Refuge. To determine the impact of crystal digging, we analyzed: (1) nest success as determined by the Mayfield Method (Mayfield 1975, Johnson 1979); (2) snowy plover spatial use of the dig area for nesting; and (3) area use patterns by snowy plovers. If crystal digging activities at Salt Plains NWR adversely affected snowy plover breeding biology, we hypothesized that: (1) nesting success would be lower than in control nests not associated with digging activities; (2) snowy plovers would avoid nesting near crystal digging activities; (3) snowy plovers would use the dig area less frequently when crystal diggers are present than when absent;

and (4) snowy plovers would use the dig units with mounds less frequently than dig units without mounds.

METHODS

See Methods section for least terns (Chapter I) for a description of data collection and analyses for nest success, spatial use, and area use patterns. In addition, we compared numbers of plovers seen in dig units with mounds and without mounds using Mann-Whitney U tests.

RESULTS

Between 1991 and 1994, 373 snowy plover nests near the dig area (Fig. 1) and 244 nests in the control area were monitored. Snowy plover nests were located in the active dig area during systematic nest searches in 1991, 1992, and 1994 (Table 1). In 1993, 1 snowy plover nest also was located on the edge of the access road to the dig area. Snowy plovers occasionally built nests on mounds left by crystal diggers. Between 1991 and 1994, 32 snowy plover nests were found in dig units with mounds present from previous digging activities; only 5 (16%) of these nests were built on a mound.

Buffers (500- and 1,000-m radius) around the center of each year's active dig unit indicated that significantly more nests occurred near the northernmost dig units (active in 1991 and 1994) than in the southernmost dig units (active in 1992 and 1993) (Table 1). There were significantly more nests within 500 m of the active dig units in 1991 than in 1992 ($\underline{X}^2$ = 7.800, $\underline{P}$ = 0.005) and in 1993 ($\underline{X}^2$ = 3.940, $\underline{P}$ = 0.047). The 500-m radius buffer area also contained more nests in 1994 than in 1992 ($\underline{X}^2$ = 16.973, $\underline{P}$ < 0.001) and in 1993 ($\underline{X}^2$ = 9.789, $\underline{P}$ = 0.002). There were no significant differences between 1991 and 1994 ($\underline{X}^2$ = 0.691, $\underline{P}$ = 0.406) and 1992 and 1993 ($\underline{X}^2$ = 0.453, $\underline{P}$ = 0.057). Chi-square comparisons for the 1,000-m radius buffer revealed similar results. In 1991, 52% of all nests were within 1,000 m of the active dig unit. In 1993, only 22% and in 1992, only 23% of nests were within 1,000 m of the active dig unit. In 1994, 77% of all snowy plover nests were within 1,000 m of the active dig unit.

Success of nests within 500 m of each year's active dig unit ranged from 0.01 to 0.68 (Table 2). Nest success was consistently lower within 500 m of the dig area than in the control area; however, differences were not significant (P > 0.05). Nest losses due to predation were slightly higher in the control area than in the dig area; flooding losses were higher for nests in the dig area. Nest losses due to abandonment or eggs cracking were not consistently higher in either the control or dig area. Combined data (Table 3) indicated that nest success was comparable between nests within 500 m of the dig units and in the control area. Nests within the active dig area appeared to have low nest success (0.04); however, this was not significantly different from nest success in the control area.

Mean number of snowy plovers per 5-min point count in a dig unit ranged from 0 and 6.87 birds (Table 4). Overall, fewer snowy plovers were counted during visitor activities than when no visitors were present. Significantly more plovers were counted during 1993 in the 1990a and 1990b dig units (Mann-Whitney U = 84.5, $P = 0.023$; Mann-Whitney U = 86.5, $P = 0.014$, respectively) and during 1994 in the 1993 and 1990b dig units (Mann-Whitney U = 55.0, $P = 0.038$; Mann-Whitney U = 55.0, $P = 0.055$, respectively) when visitor were absent than when present.

More snowy plovers were seen per point count in the dig areas with mounds than without mounds in 1991 (Mann-Whitney U = 341.0, $P < 0.001$). In 1992 and 1993, there were no significant differences, but in 1994, snowy plovers were seen more in areas without mounds than with mounds (Mann-Whitney U = 795.5, $P = 0.021$).

DISCUSSION

Snowy plovers continue to nest near the dig area and in active dig areas despite digging activities. It is probable that incubating birds were flushed frequently from nests when visitors were present; however, no nests in the active dig areas were known to be lost due to human disturbances (1 nest in the active dig area in 1994 was lost for unknown reasons). The snowy plover nesting on the side of the road in 1993 was occasionally flushed when passed by slow moving vehicles (approximately <10 kph); however, the nest was successful. Snowy plovers nested close to the stream during the 4-year study and did not relocate when crystal digging activities were nearby in 1991 and 1994.

Success of snowy plover nests near the dig area was comparable to nest success in the control area. There was no indication that visitors to the dig area increased nest losses during the 4-year study. Nest losses were primarily due to flooding and predation. In 1991, for example, a 1.0-cm rain washed away 86% of the known snowy plover nests on the salt flats. Snowy plovers occasionally nested on top of dirt mounds left by crystal diggers, but this did not seem to improve nest success.

Mounds and associated dig holes did not appear to influence snowy plover use of the dig area. Snowy plovers did not seem to avoid or be attracted to areas with mounds and associated dig holes. Area use by snowy plovers, however, was affected by crystal digging activities. Fewer plovers used the dig areas when visitors where present than when no visitors were present. Point count differences, however, were significant only in 4 of 12 areas in 1993 and 1994.

Our evidence suggested that crystal digging activities did not reduce snowy plover reproduction at Salt Plains NWR. Nest losses were primarily due to flooding and nest predation. Management efforts should focus on known factors causing the reduction of reproductive success. Further evaluation of methods to improve nest success is warranted and encouraged.

Table 1. Total number of snowy plover nests located and monitored between 1991 and 1994 in the active dig area, within 500- and 1,000-m radii buffers around the active dig area, and in the control area, Salt Plains National Wildlife Refuge, Oklahoma.

	Dig area				
	In active dig unit	Within 500 m	Within 1,000 m	Total	Control
1991	6	9	18	52	9
1992	1	7	26	143	23
1993	0	7	15	101	54
1994	3	18	41	77	24

Table 2. Snowy plover nest success and losses for all nests within 500 m of the active dig area and control area nests, Salt Plains National Wildlife Refuge, Oklahoma.

	1991		1992		1993		1994	
	Dig area	Control	Dig area	Control	Dig area	Control	Dig area	Control
N	10	9	16	23	10	54	26	59
Nest Success	0.04	0.54	0.17	0.29	0.01	0.11	0.68	0.76
95% CI	0 - 0.49	0.27- 1.08	0.06- 0.49	0.15- 0.60	0 - 0.16	0.05- 0.24	0.46- 1.00	0.55- 1.04
Predation (%)	10	11	6	30	8	9	8	0
Flood (%)	40	11	44	30	63	37	4	4
Other (%) (cr/ab/d-h)[a]	10	11	19	0	1	13	4	8
Unknown outcome (%)	0	11	0	13	11	11	15	21

a cr = nests with cracked eggs/ ab = abandoned nests / d-h = chicks died during hatching process.

Table 3. Snowy plover nest success and losses for all nests 1991 to 1994, in active dig area, within 500 m of the active dig area, and the control area, Salt Plains National Wildlife Refuge, Oklahoma.

	Dig area		
	In active dig area	Within 500 m of dig area	Control
N	9	62	244
Nest Success	0.04	0.22	0.27
Confidence Interval (95%)	0 - 0.62	0.13- 0.88	0.21- 0.58
Predation (%)	11	8	14
Flood (%)	44	34	30
Other (%) (cr/ab/d-h)[a]	0	8	5
Unknown nest outcome (%)	11	6	5

a cr = nests with cracked eggs/ ab = abandoned nests / d-h = chicks died during hatching process.

Table 4. Mean number of snowy plovers seen during 41 5-min point counts in the 6 dig units during 1993 and 1994 when visitors were present and absent, Salt Plains National Wildlife Refuge, Oklahoma. Comparisons were made between visitor and no visitor periods for each dig unit in 1993 and 1994.

	1993		1994	
	Visitors (N=7)	No visitors (N=15)	Visitors (N=5)	No visitors (N=14)
1993 Unit	0.86[a]	1.40[a]	0[a]	1.21[b]
1992 Unit	1.00[a]	2.87[a]	0.40[a]	2.29[a]
1991 Unit	2.71[a]	6.87[a]	0.40[a]	3.21[a]
1994 Unit	2.43[a]	6.87[a]	1.00[a]	3.79[a]
1990a Unit	2.43[a]	7.40[b]	1.60[a]	5.14[b]
1990b Unit	0.43[a]	3.33[b]	0.60[a]	2.79[a]

a Means in each unit with same letter are not different ($\underline{P} > 0.05$) within same year.

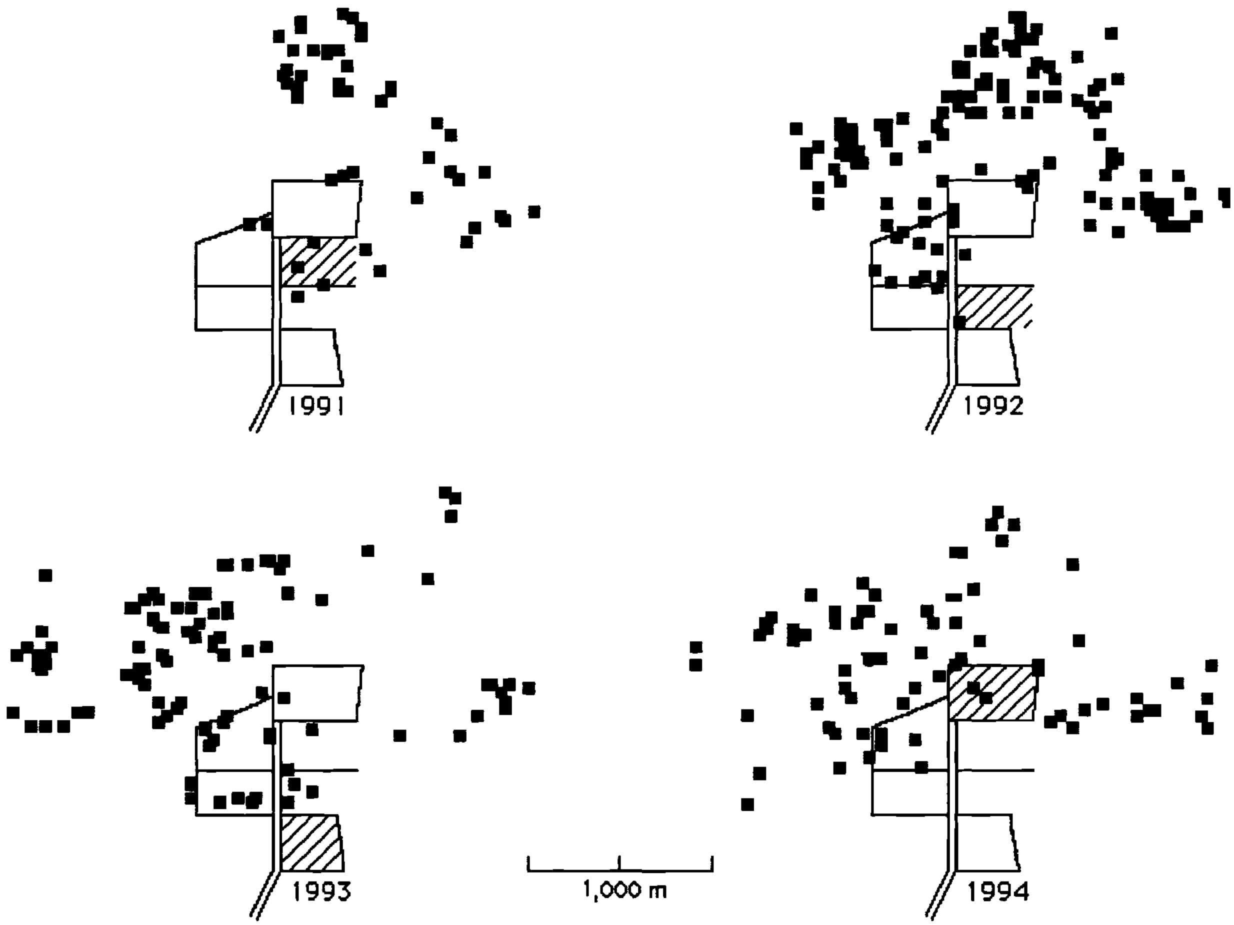

Fig 1. Locations of snowy plover nests (■) near the crystal dig area for 1991-1994; slashed area designates each year's active dig unit.

APPENDIX B

Compatibility of selenite crystal digging and nesting American avocets at Salt Plains National Wildlife Refuge

The American avocet (Recurvirostra americana) inhabits western prairies including the unique salt flats of Salt Plains National Wildlife Refuge. In concert with the least tern compatibility study, we evaluated the impact of recreational crystal digging on the American avocet. To determine the impact of crystal digging, we analyzed: (1) nest success and (2) area use patterns by American avocets. If crystal digging activities at Salt Plains NWR adversely affected American avocet breeding biology, we hypothesized that: (1) nesting success would be lower than in the control area not associated with digging activities and (2) American avocets would use the dig area less frequently when crystal diggers are present than when absent.

METHODS

See Methods section for least terns (Chapter I) for a description of nest success and area use pattern analysis.

RESULTS AND DISCUSSION

Between 1991 and 1994, 50 American avocet nests were monitored at Salt Plains NWR. Nest success ranged between 0 and 1.00 (Table 1). Nest success in the control area was 0.03 between 1991 and 1994; nest success in the dig area was 0.17. Note that all known nest losses (n = 9) in the control area were due to predators. Only 8 (22%) of the nests in the dig area were lost to predators. Most (44%) American avocet nests on the salt flats were lost to flooding from 1991 to 1994. This figure is high because of extensive flooding in 1993 and probable renesting. In 1991, 1992, and 1994, only 24% (n = 5) were lost to flooding. No nests were known to be lost due to direct human disturbances.

In 1991, 4 avocet nests were located 50-200 m from that year's active dig area. From 1992 to 1994, Avocet nests were 650- to 1,760-m from each year's active dig area. American avocets perform distraction displays, displacement sleeping, or mobbing behavior when human intruders approach their nests or chicks (Hamilton 1975, Simmons and Crowe 1951). The avocets may have been flushed from their nests during the incubating period in 1991, although avocets were not flushed from nests by digging activities from 1992 to 1994 due to the distance from the active dig areas.

Avocets were rarely noted in the southernmost dig units during point counts (Table 2). American avocets were seen feeding in Clay Creek and did not typically venture into the dig areas away from the creek. Point counts in 1993 indicated that dig unit use by the avocets was not different when visitors were present compared to when no visitors were present. Avocets were not seen during point counts in 1994, possibly due to shifts of Clay Creek.

In addition to American avocets, Black-necked stilt (Himantopus mexicanus) nests also were found near the dig area in 1993 (1 definite and 1 probable nest) and 1994 (1 definite and 1 probable nest) (Koenen et al. 1994). These nests were >800 m from each year's active dig unit, and incubating birds were not flushed from nests by digging activities. Two nests (1 nest in 1993, and 1 nest in 1994) hatched 8 eggs; the remaining nests were either washed out or the outcome was unknown.

LITERATURE CITED

Hamilton, R. B. 1975. Comparative behavior of the American avocet and the Black-necked stilt (Recurvirostidae). Ornithol. Monogr. 17.

Koenen, M. K., M. Oliphant, J. Key and E. Key. 1994. First nesting record of black-necked stilts for Oklahoma. Bull. Okla. Ornithol. Soc. 27:1-4.

Simmons, K. E. L., and R. W. Crowe. 1951. Displacement-sleeping in the avocet and oystercatcher as a reaction to predators. British Birds 44:405-410.

Table 1. American avocet nest success and losses for all dig area and control area nests, 1991 - 1994, Salt Plains National Wildlife Refuge, Oklahoma.

	1991		1992		1993		1994	
	Dig area	Control	Dig area	Control	Dig area	Control	Dig area	Control
N	8	1	12	3	20	1	2	4
Nest Success	0.49	0	0.07	0.06	0.03	0.05	1.00	0.00
95% CI	0.24-0.99	-	0.01-0.35	0.00-1.24	0.01-0.13	0.00-9.71	-	0.00-0.56
Predation (%)	2	1	4	3	3	1	9	3
Flood (%)	1	0	3	0	13	0	8	0
Other (%) (cr/ab/d-h)[a]	1	0	1	0	0	0	8	0
Unknown outcome (%)	0	0	1	0	4	0	18	1

a cr = nests with cracked eggs/ ab = abandoned nests / d-h = chicks died during hatching process.

Table 2. Mean number of American avocets seen during 22 5-min point counts in the 6 dig units during 1993 when visitors were present and absent, Salt Plains National Wildlife Refuge, Oklahoma. Comparisons were made between visitor and no visitor periods for each dig unit in 1993.

	1993	
	Visitors (N=7)	No visitors (N=15)
1993 Unit	0[a]	0.23[a]
1992 Unit	0[a]	0.08[a]
1991 Unit	0.14[a]	0.15[a]
1994 Unit	2.86[a]	2.84[a]
1990a Unit	0.29[a]	0.62[a]
1990b Unit	0[a]	0[a]

[a] Means in each unit with same letter are not different ($\underline{P} > 0.05$) within same year.

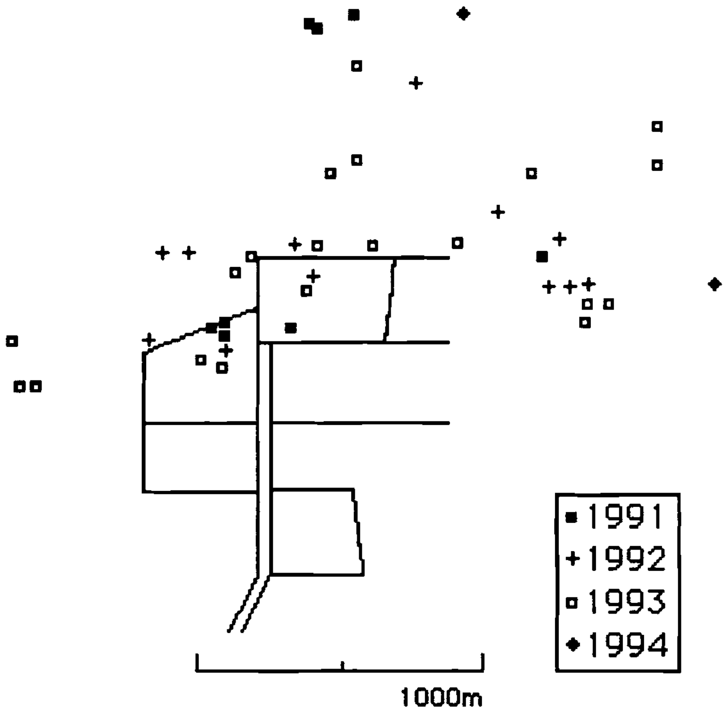

Fig 1. Locations of American avocet nests near the crystal dig area for 1991-1994.

VITA

Marcus Theodor Koenen

Candidate for the Degree of

Master of Science

Thesis: BREEDING ECOLOGY AND MANAGEMENT OF LEAST TERNS, SNOWY PLOVERS, AND AMERICAN AVOCETS

Major Field: Wildlife and Fisheries Ecology

Biographical:

Personal Data: Born in Cologne, West Germany, 8 September, 1966.

Education: Graduated from Pioneer High School, Ann Arbor, Michigan *in June* 1984; received Bachelor of Arts Degree in Cultural Anthropology from University of Michigan, August 1988; completed requirements for Master of Science Degree in Wildlife and Fisheries Ecology at Oklahoma State University, May 1995.

Professional Experience: Graduate Research Assistant, Department of Zoology, Oklahoma State University (1/93-5/95); Bird Bander, G.M. Sutton Avian Research Center (4/92-8/92); Bald Eagle Technician, G.M. Sutton Avian Research Center (3/90-5/90; 12/91-5/91; 12/91-4/92); Peregrine Falcon Technician, Isle Royale National Park (4/90-9/90; 5/91-8/91); Sanitarian Intern, Washtenaw County Environmental Health Department (1/89-4/90; 9/90-11/90); Resource Management Intern, Isle Royale National Park (6/89-10/89); Seasonal Ranger, Mohonk Preserve (9/88-5/89); Research Assistant, Ecology Center of Ann Arbor (5/88-8/88); Taxi Driver, Yellow Cab, Ann Arbor (9/86-8/88); Radio Technician, WCBN, FM Ann Arbor (9/84-9/87); Photographer's Apprentice, Dan Fletcher Photography (6/84-8/86).

Professional Organization: American Ornithologist's Union; Oklahoma Ornithological Society; Society for Field Ornithologists; The Wildlife Society.