COMPATIBILITY OF SELENITE CRYSTAL DIGGING WITH BREEDING ECOLOGY OF LEAST TERNS AND SNOWY PLOVERS AT SALT PLAINS NATIONAL WILDLIFE REFUGE IN OKLAHOMA

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Bachelor of Science

Lake Superior State University

Sault Ste. Marie, Michigan

1991

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1993

OKLAHOMA STATE UNIVERSITY

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WITH BREEDING ECOLOGY OF LEAST TERNS
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Thesis Approved:

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ACKNOWLEDGMENTS

Before I began my graduate career at Oklahoma State University, I had no idea what was in store for me. Being a Michigander, I envisioned Oklahoma as a land of tumbleweeds, duststorms, and shriveled up lizards. Upon arrival at my study site, I found this to be the case. However, the harshness of the salt flat made it an extremely fascinating place to me, and one I will NEVER forget. The rest of Oklahoma proved to be more lush and diverse than I had ever imagined. This experience assuredly broadened my perspectives and my appetite for further travel.

First, I would like to extend thanks to my major advisor, David Leslie, countless graduate students, and the rest of the Unit staff for a warm welcome. I also thank David Leslie for help with writing, insightful ideas, and sound advice concerning my future as a wildlife biologist. I especially thank him for allowing me freedom to work without undue hassle. Al Zale and Stan Fox were extremely helpful as committee members. I thank Bill Fisher and Noble Jobe for help with computer problems that occasionally arose (all of which, of course, were the fault of the computer). Numerous Unit staff were also instrumental to my research, particularly Judy Gray, Becky Newkirk, and Helen Murray.

Thanks goes to biologists outside of Oklahoma State University for help with my academic career and interest in my research. Patrick Brown, Tom Allan, and other Lake Superior State University professors helped prepare me for graduate studies. Pat Brown was largely responsible for my acceptance at Oklahoma State and Tom Allan provided me with rewarding and challenging work experience and a strong friendship. I also thank Laura Hill (Tulsa Ecol. Serv., U.S. Fish and Wildl. Service) for helpful advice on this study.

Without the help and concern of the refuge staff, none of my research would have been possible. I thank refuge manager Rod Krey for helpful ideas, suggestions, and an occasional pat on the back. Gratitude is extended to refuge biologist Ron Shepperd for help in the field, to assistant manager Harold Beierman, and to Lloyd Hill, Roger Hill and Margaret Gregory. I thank Ken Brown and his YCC crews for all their efforts in nest searches of the dig site, electric fence repairs, and chasing cows off the flats. Many thanks go to Wayne Miller and Tom Ogburn for countless repairs of the 4-wheelers after I repeatedly ravaged them in the harsh, salty environment of the flats. Because of their mechanical expertise, I always had a vehicle at my disposal to get mired knee-deep in the black, greasy ooze that I frequently managed to find. Without their help, I would have been walking or crawling instead of driving. I also thank Wayne and Tom for many of my best memories of Oklahoma; they took me quail hunting and provided comic relief to many otherwise dull days. I especially thank Wayne for introducing me to the regal art of noodling and letting me deer hunt on his property. Without these latter mental diversions, this thesis would have been impossible.

Special thanks are due to fellow graduate students and their families who were always there for moral support and some great times. I especially thank John and Lisa Hausbeck; Rob, Shelley, and Christopher Simmonds; Chris Wilson; Marvin Shutters; Larry Martin; and Bruce Corley. I thank Sara Schweitzer and technicians Bill McAbee and Charles Anderson for countless hours of help in the field.

I also thank my parents, Gerald and Mary Ann, for their love and support through all of my endeavors, no matter what they have been.

Lastly, I give my sincerest thanks to my fiancée Tabitha. Since the first time I met her at Lake Superior State University, she has always provided love and understanding through good times and bad. Her love is felt even more now despite the 1,200 miles between us. Thank you for everything. I'll be home soon!

My research would have been impossible without funding and logistical support from many sources. This project was funded by the

U.S. Fish and Wildlife Service (Region 2 and Salt Plains NWR) and the Oklahoma Cooperative Fish and Wildlife Research Unit (Okla. State Univ., Okla. Dep. Wildl. Conserv., U.S. Fish and Wildl. Serv., and Wildl. Manage. Inst., cooperating). Salt Plains National Wildlife Refuge also provided a house (plus utilities) on the refuge to live in, 4-wheelers, access to shop facilities and equipment, and gasoline for vehicles in 1991.

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CHAPTER I

INTRODUCTION

Chapters in this thesis, except the INTRODUCTION, are written in manuscript format suitable for submission to selected scientific journals. Manuscripts are complete without supporting materials. Chapter II follows the format of the Journal of Field Ornithology and Chapter III, the Wildlife Society Bulletin.

Two annual reports (1991 and 1992) resulting from this project were submitted to the U.S. Fish and Wildlife Service. These reports cover results of: 1) an assessment of compatibility of the annual harvest of selenite crystals near Clay Creek in Salt Plains NWR 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. Individuals interested in obtaining copies of these reports should contact the Oklahoma Cooperative Fish and Wildlife Research Unit, Oklahoma State University, Stillwater, Oklahoma 74078 (telephone 405-744-6342).

CHAPTER II

COMPATIBILITY OF THE ANNUAL HARVEST OF SELENITE CRYSTALS WITH BREEDING ACTIVITIES OF LEAST TERNS AND SNOWY PLOVERS AT SALT PLAINS NATIONAL WILDLIFE REFUGE

Abstract.--The effect of a selenite crystal dig site on breeding activities of Least Terns (*Sterna antillarum*) and Snowy Plovers (*Charadrius alexandrinus*) was studied in north-central Oklahoma in 1991 and 1992. Mean distances from Least Tern nests to the center of the 87/92 functional dig unit in 1991 and 1992 were significantly different north of Clay Creek (t = 2.12, P = 0..039) but were not significantly different south of Clay Creek (t = 0.78, P = 0.443). Mean distances from Snowy Plover nests north of Clay Creek (t = 1.16, P = 0.248) and south of Clay Creek (t = 0.04, P = 0.970) to the center of the 87/92 functional dig unit in 1991 and 1992 were not significantly different. Daily mortality rates of Least Tern and Snowy Plover nests far from and close to digging activities in 1991 (P = 0.072, P = 0.166, respectively) and 1992 (P = 0.211, P = 0.410, respectively) were not significantly different. In 1991, 24 Least Terns and 157 Snowy Plovers used the dig site; 1 Least Tern and 293 plovers used the site in 1992. Dig units with mounds in 1991 (X^2 = 53.59, P < 0.001) and 1992 (X^2 = 4.92, P = 0.027) were used by Snowy Plovers significantly more than units without mounds. Plovers used units closed to digging more than open units. The selenite crystal dig site probably had little effect on the breeding activities of Least Terns and Snowy Plovers.

The interior population of the Least Tern (*Sterna antillarum*) has been listed as endangered since 1985 (U.S. Fish and Wildl. Serv. 1985*a*), and the Snowy Plover (Charadrius alexandrinus) is a candidate (Category 2 species) for listing as threatened or endangered (U.S. Fish and Wildl. Serv. 1982, 1985b). Our study was designed to determine if human disturbance jeopardizes increasing the adult Least Tern population to levels specified in the Recovery Plan (U.S. Fish and Wildl. Serv. 1990).

Hatching success in undisturbed Herring Gull (Larus argentatus) colonies was significantly higher than in disturbed (picnickers) colonies in each of two years (Hunt 1972). Burger (1981) reported that shorebirds in coastal bay habitats on the Atlantic Coast used sample sites 42% of the time when people (non-investigator) were present, and 72% of the time when people were absent. McGarigal et al. (1991) suggested that non-investigator disturbances can cause changes in spatial use patterns of Bald Eagles (Haliaeetus leucocephalus). In contrast, non-investigator disturbances had no effect on Bald Eagle reproductive success in the Chippewa National Forest, Minnesota (Mathisen 1968, Fraser et al. 1985). However, no work of this kind has been done where significant numbers of Least Terns and Snowy Plovers nest, for example, on the Arkansas River System in the south-central Great Plains (Purdue 1976, Downing 1980, Boyd 1990).

Concern has arisen about possible effects (positive or negative) of selenite crystal digging on the breeding success of Least Terns and Snowy Plovers at Salt Plains National Wildlife Refuge (NWR) in north-central Oklahoma. The refuge allows individuals to drive onto its salt flat, on a well marked road, to dig for selenite crystals in specifically marked units in close proximity to a historic ternary (Boyd 1990). Our objectives were to: (1) assess compatibility of the annual harvest of selenite crystals with breeding activities of Least Terns and Snowy Plovers and (2) assess use of the selenite crystal dig site by Least Terns and Snowy Plovers at Salt Plains NWR.

STUDY AREA

Our study was conducted on the south side of the 4,050-ha salt flat in Salt Pains NWR in Alfalfa County, Oklahoma (Fig. 1). The salt flat is bordered on the east side by the Great Salt Plains Reservoir. Clay Creek traverses the study site and flows through the northwest corner of the northernmost dig unit. The salt flat commonly experiences high winds (>30 km/hr) and hot summer temperatures (>35 $^{\circ}$C). The salt flat is open and sparsely covered with woody debris, which is washed onto it by storms. Scant patches of inland salt grass (Distichlis stricta) and sea purslane (Sesuvium verucosum) occur near creeks (Grover and Knopf 1982), and salt cedar (Tamarix gallica) is dominant around the edge of the salt flat.

Selenite crystals are formed from hydrous calcium sulfate just below the surface (<0.5 m) of the salt flat when the concentration of calcium and sulfate in brine becomes so great that the mineral is precipitated (Johnson 1972). At Salt Plains NWR, crystals contain a brown, hour-glass inclusion of sand, silt, and clay particles, which makes them unique and prized by rock collectors from around the world. The dig site attracts about 25,000 people in the digging season (April through October) and is therefore economically important to the surrounding towns of Cherokee and Jet, Oklahoma. It takes 5 years for the crystals to form, and therefore they can be harvested on a sustainable basis.

The total dig site (306 ha) is divided into 6 units (Fig. 2). Digging occurs in only 1 unit per year (except that in 1 year 2 units are dug); i.e., dig units are rotated on a 5-yr schedule to allow the renewable selenite crystals to form. The 2 units on the west side of the access road have boundaries marked with signs supported by wooden fenceposts. The 4 units east of the road are similarly marked on the north, west, and south sides and the east end is bounded by the reservoir. Most (>90%) crystal diggers use the area within 350 m of the access road, although the east boundary extends about 1.5 km to the reservoir.

Selenite crystals are dug with trowels or shovels. Shallow (10-50 cm) holes are dug, and excavated materials are piled in mounds beside the holes. Mounds left by crystal diggers require 1-2 yrs to completely erode. Crystal diggers are requested to leave the holes unfilled, which allows crystals to reform faster. Due to the high water table, holes usually fill with water within days. People remain relatively still while digging and tend to dig in an individual hole for long periods (1-3 hrs).

METHODS

Compatibility of digging activity with breeding of birds.--The selenite crystal dig site and habitat extending 1.5 km north of the site were searched for Least Tern and Snowy Plover nests from May through August, 1991 and 1992. Systematic searches were made every 2-4 days in a manner similar to Hill (1985). Individual nests were serially numbered, plotted on a map, and rechecked every 3-4 days to determine nest success and egg success (Mayfield 1961, 1975). Apparent nest success (number of successful nests/total found) would be a serious overestimate of the true value because many nests were found after incubation had begun (Mayfield 1961, 1975). Nests were considered successful if ≥1 egg hatched. Hatching success of Least Terns was indicated if chicks and/or fecal droppings of chicks were observed close to the nest; tiny shell fragments found in Snowy Plover nests indicated successful hatching (Hill 1985). More frequent nest checks were not made because observer-induced disturbance can decrease nest success (Henry and Ralph 1975, Bart and Robson 1978, Ellison and Cleary 1978, Tremblay and Ellison 1979, Shugart and Fitch 1981, MacIvor et al. 1990).

Individual nests were marked with 30-cm wooden dowels protruding 10 cm above the substrate and placed about 10 m north of the nest. Hill (1985) reported no evidence of markers cueing predators to nests. A grid system consisting of wooden 1 x 2s driven into the substrate about 100 m apart in a checkerboard configuration was established to facilitate nest searches and mapping of individual nests. Nests were plotted on maps of the dig site and surrounding habitat to measure distances between nests and the center of a functional dig unit to determine if nesting locations changed in relation to dig site use by humans. A functional dig unit was the area that extended 350 m east of the access road. We did not consider entire dig units east of the access road (Fig. 1) as receiving significant human use because >90% of digging took place within 350 m of the road. Burger and Gochfeld (1990: pg. 13) define a colony as "an aggregation of breeding birds." Least Terns are a colonial species (Burger 1984), and Terres (1991) described Snowy Plovers as occasionally nesting in loose colonies. Therefore, we considered aggregations of nesting terns and plovers as belonging to colonies.

To evaluate digging activities on nesting Least Terns and Snowy Plovers, we mapped respective breeding colonies in 1991 and 1992 and compared mean distances, from each year, between nests north of Clay Creek and the center of the functional dig unit in 1992. The same comparison was made for birds that nested in a disjunct colony south of Clay Creek and east of the functional dig unit. We reasoned that such a comparison would maximize our ability to demonstrate significant movement of colonies relative to the movement of digging activities between 1991 and 1992. If digging activities did not influence colony location, we expected terns and plovers to nest in the same area in 1991 and 1992, and therefore, mean distances from nests in each year to the center of the 87/92 functional dig unit would be the same. Conversely, if digging activities did influence colony locations we expected that the mean distance between nests and the 87/92 functional dig unit would decrease (if colony moved toward), or increase (if colony moved away). If terns and plovers were negatively influenced by digging activities, we would expect them to move their nesting locations in response to the annual rotation of dig units and thereby maintain a given distance between them and digging activities. We used a t-test (Steel and Torrie 1980) to evaluate this hypothesis. Additionally, median nesting dates were calculated by methods outlined by Hill (1985) to map colonies pre- and post-median nesting to illustrate changes in nesting locations within years, possibly caused by flooding of habitat.

Median distances between nests (on both sides of the creek) and centers of functional dig units for both species were determined in 1991 and 1992. Nests beyond the median distance were labelled "far nests" relative to digging activities; nests closer than the median distance were labelled "close nests." As a further test of the effects of digging activities on breeding terns and plovers, nest success, daily mortality rates of nests, and egg success (Mayfield 1961, 1975) were estimated for far and close nests in 1991 and 1992. Daily mortality rates of far and close nests were compared with a 1-tailed _t_-test (Steel and Torrie 1980). Test statistics were derived from the ratio of the difference between the daily mortality rates of far nests and close nests to its standard error (Johnson 1979). Nests lost to flooding in 1991 and 1992 were excluded from these analyses to lessen any effect that Clay Creek had on daily mortality rates. Habitat on both sides of Clay Creek was the same, and it was unlikely that weather or predation differentially affected daily mortality rates of far and close nests. If human activities associated with crystal digging affected mortality of either species, we hypothesized that daily mortality rates of close nests would exceed that of far nests.

Least Tern and Snowy Plover use of dig site.--Least Tern and Snowy Plover use of all functional dig units was monitored with weekly scan surveys in the 1991 (n = 8) and 1992 (n = 10) breeding seasons. Surveys were conducted from about 0800-0900 hr from the center of each functional dig unit by the same observer to minimize observer biases (Reynolds et al. 1980, Verner and Ritter 1985). A 5-min waiting period after observer arrival preceded surveys of each unit to allow birds to resume normal activity. Surveys covered all habitat 360° around the observer. Ten x 50-mm binoculars were used to detect all birds in the 350-m diameter plot. Surveys were 5 min in duration to decrease chances of counting birds twice (Granholm 1983, Tomialojc and Verner 1990). Only feeding, nesting, or loafing birds were counted.

Personal observation and observations by refuge personnel indicated that snowy plovers used mounds left by crystal diggers for nesting platforms and fed in excavated holes. Mounds could provide protection to nests from flooding, and the holes (once filled with water) could serve as collecting reservoirs for insects. We hypothesized that crystal digging and presence of mounds did not affect bird use of dig units, and therefore each species would be observed equally in all dig units regardless of human digging activity. Chi-square analyses (Steel and Torrie 1980) were used to detect differences in bird use of dig units. Expected values were calculated from the proportional area available in each category multiplied by the total of birds using all sites. Bird use of dig units with mounds still present was compared with units without mounds in 1991 and 1992 to determine if units with mounds were used preferentially. Use of the current dig unit was compared with units without digging in 1991 and 1992 to determine if digging affected bird use. The current dig unit was compared to units with mounds but no digging in 1991 and 1992 to determine if digging affected bird use.

RESULTS

Compatibility of digging activities with breeding of birds.--Least Terns (Figs. 2, 3) and Snowy Plovers (Figs. 4, 5) nested on both sides of Clay Creek in 1991 and 1992. Mean distances from Least Tern nests in 1991 and 1992 to the center of the 87/92 functional dig unit were significantly different north of Clay Creek (t = 2.12, P = 0.039) but were not significantly different south of Clay Creek (t = 0.78, P = 0.443) (Table 1). Mean distances from Snowy Plover nests north of Clay Creek (t = 1.16, P = 0.248) and south of Clay Creek (t = 0.04, P = 0.970) in 1991 and 1992 to the center of the 87/92 functional dig unit were not significantly different (Table 1). Shifts in nesting locations of Least Terns (Figs. 2, 3) and Snowy Plovers (Figs. 4, 5) within years were observed on both sides of Clay Creek.

Daily mortality rates of far and close Least Tern nests in 1991 (t = 1.51, P = 0.072) and 1992 (t = 0.81, P = 0.211) were not significantly different (Table 2). Similarly, daily mortality rates of far and close Snowy Plover nests in 1991 (t = 0.98, P = 0.166) and 1992 (t = 0.23, P =

0.410) were not significantly different (Table 2).

Least Tern and Snowy Plover use of dig site.--Twenty-four Least Terns and 157 Snowy Plovers were observed using (feeding, loafing, or resting) functional dig units in 1991 (Table 3). In 1991, 3 of 6 (50.0%) Snowy Plover nests in the functional dig units were constructed on mounds left by crystal diggers. Only 1 Least Tern nest was observed in a functional dig unit (89/94) in 1991. One Snowy Plover nest was made on a mound in the functional dig unit where digging was currently taking place (86/91) in 1991. One Least Tern and 293 Snowy Plovers were observed using the functional dig units in 1992 (Table 4). In 1992, 8 of 18 (44.4%) Snowy Plover nests were made on mounds left by diggers. No Least Terns nested in the functional dig units in 1992. One Snowy Plover nest was made on a mound in the functional dig unit (87/92) where digging was currently taking place in 1992.

Functional dig units with mounds still present in 1991 (89/94, 86/91, 90A, and 90B) (X^2 = 53.59, P < 0.001) and 1992 (86/91, 87/92, and 90A) (X^2 = 4.92, P = 0.027) were used by Snowy Plovers significantly more than units without mounds (Table 5). Snowy Plover use of the open functional dig unit (86/91) was not significantly different (X^2 = 3.18, P = 0.075) than dig units without digging in 1991 (Table 6). Functional dig units closed to digging were used by Snowy Plovers significantly (X^2 = 11.17, P < 0.001) more than the unit open to digging (87/92) in 1992 (Table 6). Snowy Plover use of units with mounds but no digging (89/94, 90A, and 90B) and the unit with digging and mounds (86/91) was not significantly (X^2 = 0.08, P = 0.776) different in 1991 (Table 7). Dig units with mounds but no digging (86/91, and 90A) were used by Snowy Plovers significantly (X^2 = 21.00, P < 0.001) more than the open functional dig unit (87/92) in 1992 (Table 7).

DISCUSSION

Burger and Gochfeld (1990) reported that humans in the vicinity of or within a colony of nesting Black Skimmers (Rynchops niger) can induce a defensive response. The degree of response was a function of the familiarity, type, and frequency of disturbance. For example, skimmers nesting in a colony with a beach access road running through it showed little response to passing cars. However, fishermen walking (taking a shortcut away from the road) through the same colony elicited a mobbing response and kept birds off their nests for about 1 min. Neck and Riskind (1981) reported that a Least Tern colony at a boat launch on Falcon Reservoir, Texas, was eventually deserted. Disturbance was apparent by mobbing of humans; however, the launch was not heavily used by humans when terns were present because lake levels allowed humans to use a better launch site. The authors contended that desertion of the colony was probably caused by egg predation by Great-tailed Grackles (Quiscalus mexicanus), which were present because of man-made structures. In our study, we saw no mobbing of humans by terns in 1991 or 1992. In 1991, we conducted 24 hrs of behavioral observations (5,760 individual observations) and recorded if Least Terns were incubating, standing off the nest, or defending the nest. Birds were incubating in 98% of the observations, and distances from digging (550 - 1,200 m) had no effect on behavior (Utych, unpubl. data). All defensive behavior by terns was against American Avocets (Recurvirostra americana) and Cattle Egrets (Bubulcus ibis), which were common on the salt flat (Hill 1985).

Importantly, human activity in our study occurred outside the colonies in both 1991 and 1992. Mean distance from Least Tern nests to digging activity was about 1 km. Snowy Plover nests in 1991 and 1992 were more widely dispersed than tern nests, and the plover colony south of Clay Creek encompassed the dig site. However, distribution of plover nests in 1991 and 1992 south of the creek was such that most nests were located at least 700 m northeast of digging activities. It is difficult to see people at this distance on the salt flat due to distortion caused by heat waves.

We hypothesized that nest locations of terns and plovers would not shift between years (i.e., terns and plovers would display a high degree of nest site fidelity), and therefore, the mean distance between nests and the center of the 87/92 functional dig unit would remain the same, suggesting that digging had no effect on nest location. The distance between Least Tern nests south of Clay Creek and the center of the 87/92 functional dig unit did not change between years as digging moved 1 unit south (from the 86/91 functional dig unit), indicating that Least Tern nesting locations south of Clay Creek did not shift. The distance between tern nests north of the creek and the center of the 87/92 functional dig unit decreased between years, indicating that the nesting locations moved south toward the creek, and in the same direction as the shift in digging. The shift in nesting locations between years suggested terns north of Clay Creek maintained a minimum distance between nests and digging. The mean distance between Snowy Plover nests on both sides of the creek from the center of the 87/92 functional dig unit remained the same in 1991 and 1992 indicating that nesting locations did not shift with digging.

Although the shift in nesting locations of Least Terns north of Clay Creek may have been due to human disturbance, we contend that it was probably more influenced by flooding. The salt flat received 35 cm of rain in 1992 compared to 23 cm in 1991. Burger (1984) suggested that Least Terns will shift or relocate colonies when old sites are made unsuitable for nesting by environmental conditions (e.g., flooding) or human disturbance. Least Terns began nesting in early June in both years on the salt flat. The area that terns north of Clay Creek used for nesting in 1991 was flooded when they began nesting in 1992. Terns then shifted their nesting locations south and west to higher ground, which was closer to digging.

Shifts in nesting location due to flooding also were observed as the breeding season progressed. Terns and plovers south of Clay Creek in 1991 shifted their nesting locations away from the creek to higher ground as the creek rose and flooded surrounding habitat. Plovers in 1992 on both sides of Clay Creek shifted their nesting locations due to flooding in May. Terns arrived after the most severe floods in 1992, so a noticeable change in nesting location within the 1992 tern breeding season was not observed.

Safina and Burger (1983) studied effects of daily and weekly human disturbance of Black Skimmer subcolonies within a Common Tern (Sterna hirundo) colony. They found that nest density, late nesting, hatching success, and fledgling success were significantly lower for skimmers in subcolonies with more disturbance. They also observed that many prelaying adults left subcolonies with daily disturbance and settled in subcolonies with weekly disturbance. Hunt (1972) reported that productivity in Herring Gulls (Larus argentatus) was inversely related to disturbance of colonies by picnickers. He suggested that human disturbance caused adults to leave their eggs exposed to the sun (causing addling) and predation by other gulls. We hypothesized that daily mortality rates of Least Tern and Snowy Plover nests closer than and beyond the median distance from digging would be the same. We observed no differences in daily mortality rates between close (to digging) and far Least Tern and Snowy Plover nests in 1991 or 1992, which suggested that digging activity had no effect on mortality.

Burger (1981) reported that non-nesting Common Terns (Sterna hirundo), Herring Gulls, and several shorebird species (e.g., dowitchers [Limnodromus sp.], Dunlins [Erolia alpina], Black-bellied Plovers [Squatarola squatarola], and small sandpipers [Calidris sp.]) in coastal bay habitats on the Atlantic Coast showed no signs of disturbance when close (15 m) to humans engaged in slow activities such as worm or clam digging. The author suggested that distance from disturbance and type of disturbance were important factors in bird response and observed that fast movements of joggers and people mowing grass usually elicited a flush response. Crystal digging is probably similar to worm and clam digging because most crystal diggers remain in 1 spot for 1-3 hrs. We saw no mobbing of crystal diggers by Least Terns in 1991 or 1992.

Snowy Plovers were observed feeding and nesting along Clay Creek, in habitat extending 1.0 km north of the creek and throughout the dig area in 1991 and 1992. However, the highest use occurred closer to Clay Creek northeast of digging activity (>300 m away from functional dig units) and north of Clay Creek where digging is never allowed. Heavier plover use of functional dig units with mounds than those without mounds suggested that plovers preferentially used units with mounds. Plovers sometimes nested on mounds that offered protection from flooding and fed next to holes left by crystal diggers, which filled with water and served as collecting basins for insects. However, the importance of mounds and holes to plovers is probably negligible compared to the proximity of Clay Creek. Heavy use of units closest to Clay Creek in 1991 and 1992 by Snowy Plovers indicated that these areas are probably excellent habitat, regardless of numbers of mounds present. Areas closest to the creek offered an abundance of beetles (Bledius spp. and Cicindela sp.) and flies (Ephydra spp.), and plovers stand in the saline water to aid in thermoregulation (Purdue 1976). Least Terns are opportunistic feeders and consume small fish (2.5-7.5 cm) that swim near the surface (Atwood and Minsky 1983, Atwood and Kelly 1984). Terns seldom were observed in the functional dig units because of lack of aquatic foraging sites. Clay Creek flowed only through the northwest corner of the dig site, and 48.0% of tern observations recorded in the dig site were in this functional dig unit (89/94).

We conclude that the crystal dig site had little effect on the breeding activities of Least Terns and Snowy Plovers in 1991 and 1992 based on the following observations: (1) no shifts in nesting locations were detected for Least Terns south of Clay Creek or for Snowy Plovers on either side of the creek, (2) flooding probably caused the shift in nesting locations between years for Least Terns north of Clay Creek, (3) daily mortality rates for tern and plover nests closer than and beyond median distance from digging did not differ, and (4) plovers preferentially used units with mounds left by crystal diggers. It could be suggested that flooding was only partially responsible for the shift in nest locations for terns north of Clay Creek and that they require some minimum distance (e.g., 500 m) between their nesting location and digging activity.

A limitation to this study is that we have collected data only from the first 2 years of a 5-yr study. In 1993, digging will occur in the furthest south unit, and the northernmost dig unit (containing part of Clay Creek) will be open in 1994. Changing the digging location from the 88/93 unit to the 89/94 unit will suddenly move digging >500 m back to Clay Creek. For this reason, we believe that the 1994 breeding season will be the most important one to our assessment of compatibility of breeding activities of Least Terns and Snowy Plovers with crystal digging. Another limitation is that we have no data on bird use of the area prior to the establishment of the dig site. Densities of plover nests in the functional dig units were lower than other colonies on the salt flat, and only 1 Least Tern nested in a functional dig unit. It could be true that this area was more heavily used by terns and plovers prior to the establishment of the dig site.

Our study implies that selenite crystal digging may continue without jeopardizing Least Tern and Snowy Plover productivity. Alternatively, specific areas of the dig site (e.g., within 500 m from colonies) may have to be closed to digging during the breeding season to prevent people from entering the colonies. Due to the large size (306 ha) of the entire dig site, closing certain areas to digging during the breeding season (May-August) may be a practical solution enabling both bird and human use. Further research is needed in the 1993-1995 breeding seasons to determine where birds nest when digging moves to the furthest dig unit south and then, in following years, when it is moved to the units nearest Clay Creek. Hopefully, with more research, we will know if current management practices can be maintained at Salt Plains NWR, or if they must be altered to ensure crystal digging will not compromise the goal of increasing numbers of Least Terns to levels specified in the Recovery Plan (U.S. Fish and Wildl. Serv. 1990) and to prevent possible listing of Snowy Plovers.

ACKNOWLEDGEMENTS

This research was funded by the U.S. Fish and Wildlife Service (Region 2 and Salt Plains NWR) and the Oklahoma Cooperative Fish and

Wildlife Research Unit (Okla. State Univ., Okla. Dep. Wildl. Conserv., U.S. Fish and Wildl. Serv., Wildl. Manage. Inst., cooperating). We thank the very helpful and cooperative refuge staff: R. Krey, H. Beierman, R. Shepperd, W. Miller, T. Ogburn, R. Hill, M. Gregory, and L. Hill. We also thank A. Zale and S. Fox for help with this manuscript, L. A. Hill (Tulsa Ecol. Serv., U.S. Fish and Wildl. Serv.) for advice on this study, and D. Johnson and W. Warde for help with statistics. Excellent field assistance was provided by W. McAbee, C. Anderson, and S. Schweitzer. We also thank the Unit secretarial staff: H. Murray, J. Gray, and R. Newkirk for their assistance.

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Table 1. Mean distances from nests to center of the 87/92 functional dig unit in 1991 and 1992 for Least Terns and Snowy Plovers north and south of Clay Creek at Salt Plains National Wildlife Refuge, Oklahoma.

	North		South	
	1991	1992	1991	1992
Least Tern				
n	19	44	16	13
x	1242.6[a]	1151.8	1072.8	1132.5
SE	29.9	30.7	55.5	50.5
Snowy Plover				
n	24	82	24	62
x	1282.1	1234.1	838.5	835.5
SE	30.7	20.4	67.4	42.9

[a]Indicates 1991 value greater ($P < 0.05$) than 1992 value.

Table 2. Daily mortality rates (DMR), nest success (NS), and egg success (ES) of Least Tern and Snowy Plover nests beyond (far) median distance and closer than (close) median distance from the center of the open functional dig unit at Salt Plains National Wildlife Refuge, Oklahoma.

	1991[a]		1992[b]	
Variable	Far	Close	Far	Close
Least Tern				
n	12	13	21	20
DMR[c]	0.023	0.060	0.043	0.060
SE	0.011	0.022	0.014	0.015
NS[d]	61.5	27.1	39.5	27.3
95% CI	37.7-99.5	9.8-71.1	21.1-72.7	13.8-52.8
ES	49.2	21.7	30.0	20.7
Snowy Plover				
n	19	18	49	48
DMR[c]	0.025	0.041	0.043	0.040
SE	0.010	0.013	0.010	0.009
NS[d]	53.4	34.9	33.4	36.0
95% CI	31.8-88.7	17.1-69.7	20.6-53.6	22.9-56.0
ES	36.8	24.1	29.2	31.5

[a]The open functional dig unit in 1991 was 86/91 in Fig. 2.

[b]The open functional dig unit in 1992 was 87/92 in Fig. 2.

[c]Daily mortality rates were compared using methods described by Johnson (1979).

[d]Nest success (%) and egg success (%) were estimated with methods outlined by Mayfield (1961, 1975).

Table 3. Dig unit use[a] by Least Terns (LT) and Snowy Plovers (SP) at Salt Plains National Wildlife Refuge, Oklahoma, 1991.

	Dig Units											
	89/94[b]		86/91[b,c]		87/92		88/93		90A[b]		90B[b]	
Date	LT	SP	LT	SP	LT	SP	LT	SP	LT	SP	LT	SP
6/11	2	9	0	8	0	3	0	3	0	3	0	0
6/20	0	6	0	7	1	0	0	2	0	15	0	4
6/27	3	13	0	3	0	1	0	0	0	5	0	2
7/1	2	9	0	2	0	0	0	0	0	4	0	4
7/10	0	6	3	5	0	0	0	0	0	4	0	1
7/17	0	4	0	2	0	0	0	0	0	1	0	0
7/22	2	7	5	3	0	0	0	0	0	4	0	2
8/1	2	5	3	5	0	0	0	0	0	5	1	0
Total	11	59	11	35	1	4	0	5	0	41	1	13

[a]Only birds feeding, loafing, or nesting in dig units were recorded.

[b]Dig units had mounds left by crystal diggers in 1991.

[c]Functional dig unit open to digging in 1991.

Table 4. Dig unit use[a] by Least Terns (LT) and Snowy Plovers (SP) at Salt Plains National Wildlife Refuge, Oklahoma, 1992.

	Dig Units											
	89/94		86/91[b]		87/92[b,c]		88/93		90A[b]		90B	
Date	LT	SP	LT	SP	LT	SP	LT	SP	LT	SP	LT	SP
6/4	0	17	0	4	0	0	0	6	0	11	0	2
6/10	0	15	0	3	0	5	0	1	0	15	0	9
6/23	1	15	0	2	0	1	0	1	0	7	0	0
7/3	0	9	0	4	0	4	0	10	0	13	0	3
7/11	0	5	0	7	0	1	0	0	0	3	0	0
7/16	0	10	0	5	0	15	0	2	0	3	0	0
7/21	0	1	0	52	0	1	0	10	0	5	0	0
7/25	0	0	0	0	0	0	0	0	0	0	0	0
7/30	0	5	0	0	0	0	0	0	0	2	0	0
8/12	0	6	0	0	0	0	0	0	0	3	0	0
Total	1	83	0	77	0	27	0	30	0	62	0	14

[a]Only birds feeding, loafing, or nesting in dig units were recorded.

[b]Dig units had mounds left by crystal diggers in 1992.

[c]Functional dig unit open to digging in 1992.

Table 5. Snowy Plover use[a] of functional dig units with mounds and without mounds at Salt Plains National Wildlife Refuge, Oklahoma, 1991 and 1992.

Year	Comparison	Obs	Exp	$\underline{X}^2$	$\underline{P}$
1991	Units w/ mounds[b]	148	104.7	53.59	<0.001
	Units w/o mounds[c]	9	52.3		
1992	Units w/ mounds[d]	166	146.5	4.92	0.027
	Units w/o mounds[e]	127	146.5		

[a]Only birds feeding, loafing, or nesting in dig units were recorded.

[b]Units with mounds in 1991 were 89/94, 86/91, 90A, and 90B in Fig. 2.

[c]Units without mounds in 1991 were 87/92, and 88/93.

[d]Units with mounds in 1992 were 86/91, 87/92, and 90A.

[e]Units without mounds in 1992 were 89/94, 88/93, and 90B.

Table 6. Snowy Plover use[a] of functional dig unit with digging and units without digging at Salt Plains National Wildlife Refuge, 1991 and 1992.

Year	Comparison	Obs	Exp	$\underline{X}^2$	$\underline{P}$
1991	Unit w/ digging[b]	35	26.2		
				3.18	0.075
	Units w/o digging[c]	122	130.8		
1992	Unit w/ digging[d]	27	48.8		
				11.17	<0.001
	Units w/o digging[e]	266	244.2		

[a]Only birds feeding, loafing, or nesting in dig units were recorded.

[b]Unit open to digging in 1991 was 86/91 in Fig. 2.

[c]Units closed to digging in 1991 were 89/94, 87/92, 88/93, 90A, and 90B.

[d]Unit open to digging in 1992 was 87/92.

[e]Units closed to digging in 1992 were 89/94, 86/91, 88/93, 90A and 90B.

Table 7. Snowy Plover use[a] of functional dig unit with digging and mounds and units with mounds but no digging at Salt Plains National Wildlife Refuge, Oklahoma, 1991 and 1992.

Year	Comparison	Obs	Exp	$\underline{X}^2$	$\underline{P}$
1991	Unit w/ digging and mounds[b]	35	37	0.08	0.776
	Units w/ mounds but no digging[c]	113	111		
1992	Unit w/ digging and mounds[d]	27	55.3	21.00	<0.001
	Units w/ mounds but no digging[e]	139	110.7		

[a]Only birds feeding, loafing, or nesting in dig units were recorded.

[b]Unit open to digging in 1991 was 86/91 in Fig. 2.

[c]Units with mounds but no digging in 1991 were 89/94, 90A, and 90B.

[d]Unit open to digging in 1992 was 87/92.

[e]Units with mounds but no digging in 1992 were 86/91 and 90A.

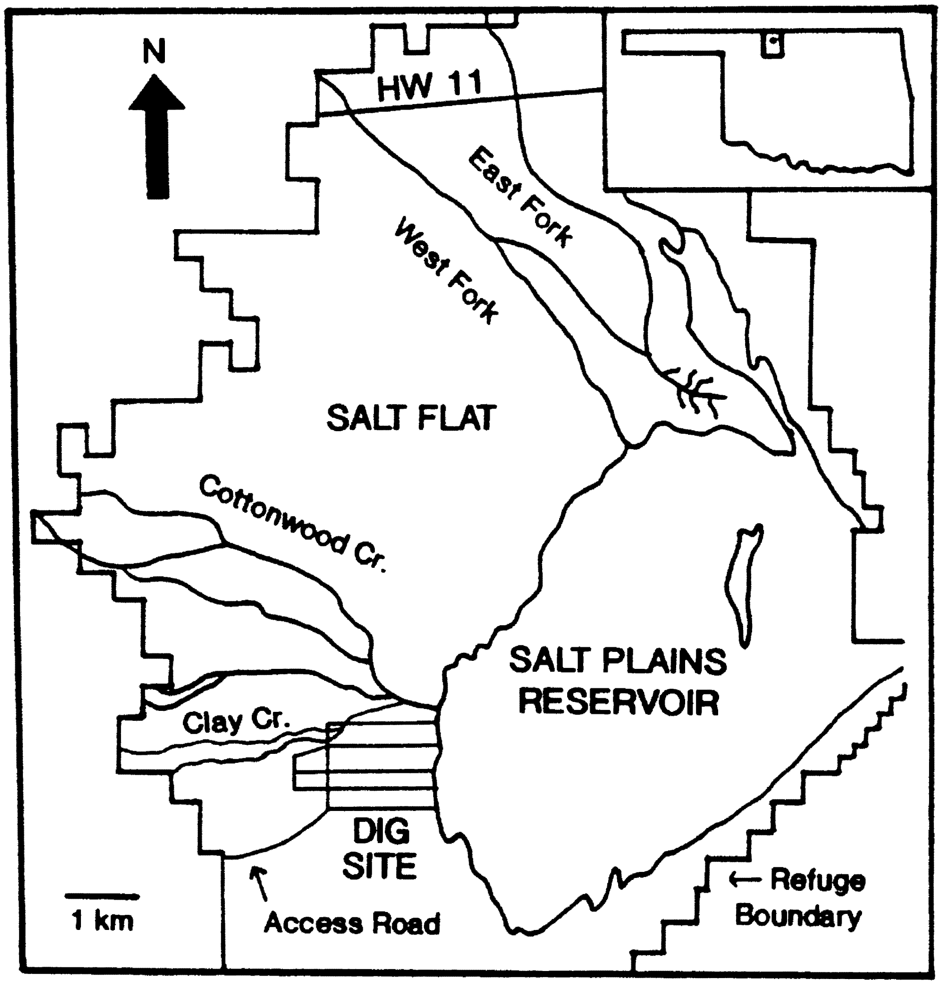

Figure 1. Location of selenite crystal dig site and access road at Salt Plains National Wildlife Refuge, Alfalfa County, Oklahoma.

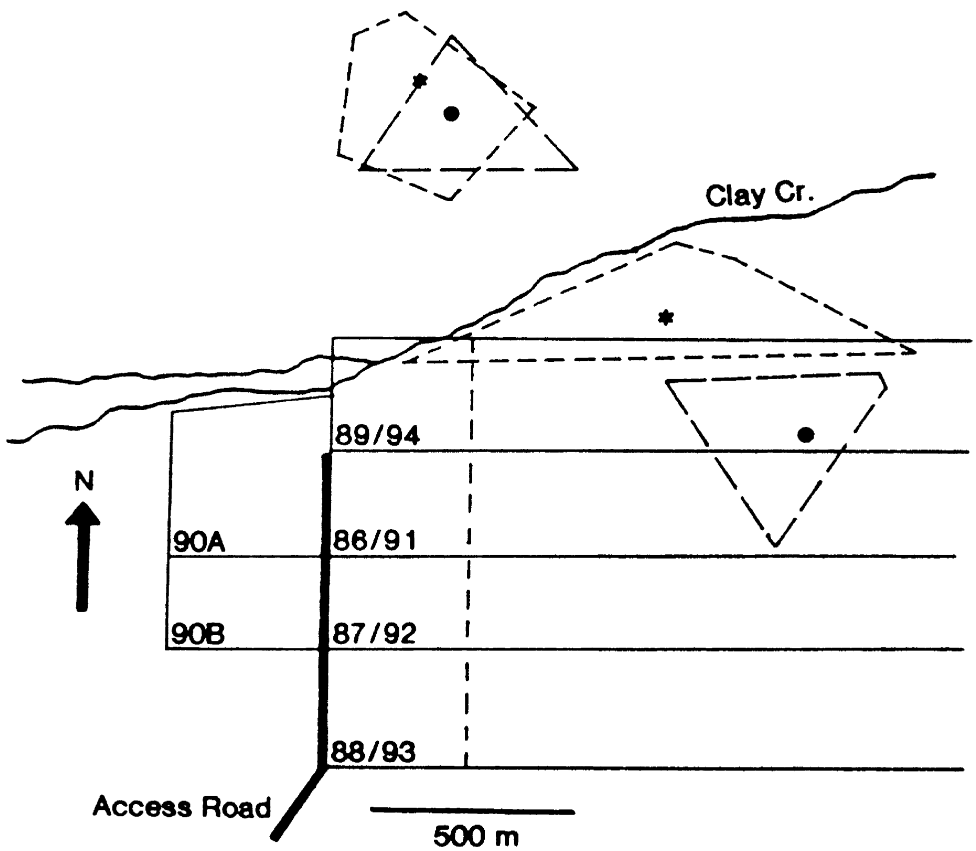

Figure 2. Map of dig units and Least Tern colonies at Salt Plains National Wildlife Refuge, Oklahoma, 1991. Short dashed lines delimit pre-median nesting date colony (✱ = geometric center [Hayne 1949] of colony) and long dashed lines delimit post-median nesting date colony (● = geometric center of colony). Digging occurred in the 86/91 digging unit. Areas to the left of the vertical dashed line through dig area extending to the access road represent functional dig units. Numbers in dig units indicate years the unit was/will be open to digging in April through October. Unit 90A was open 1 April - 31 May and 1 August - 1 October 1990; unit 90B was open 1 June - 31 July 1990.

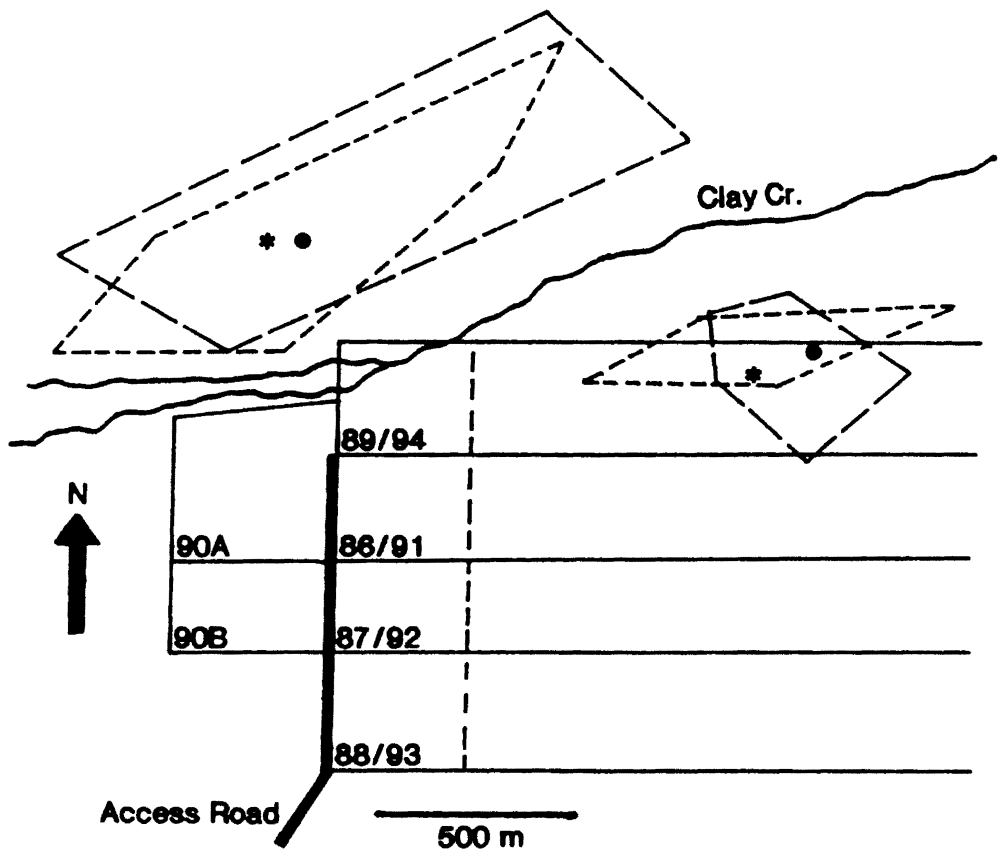

Figure 3. Map of dig units and Least Tern colonies at Salt Plains National Wildlife Refuge, Oklahoma, 1992. Digging occurred in the 87/92 digging unit. Symbols as in Fig. 2.

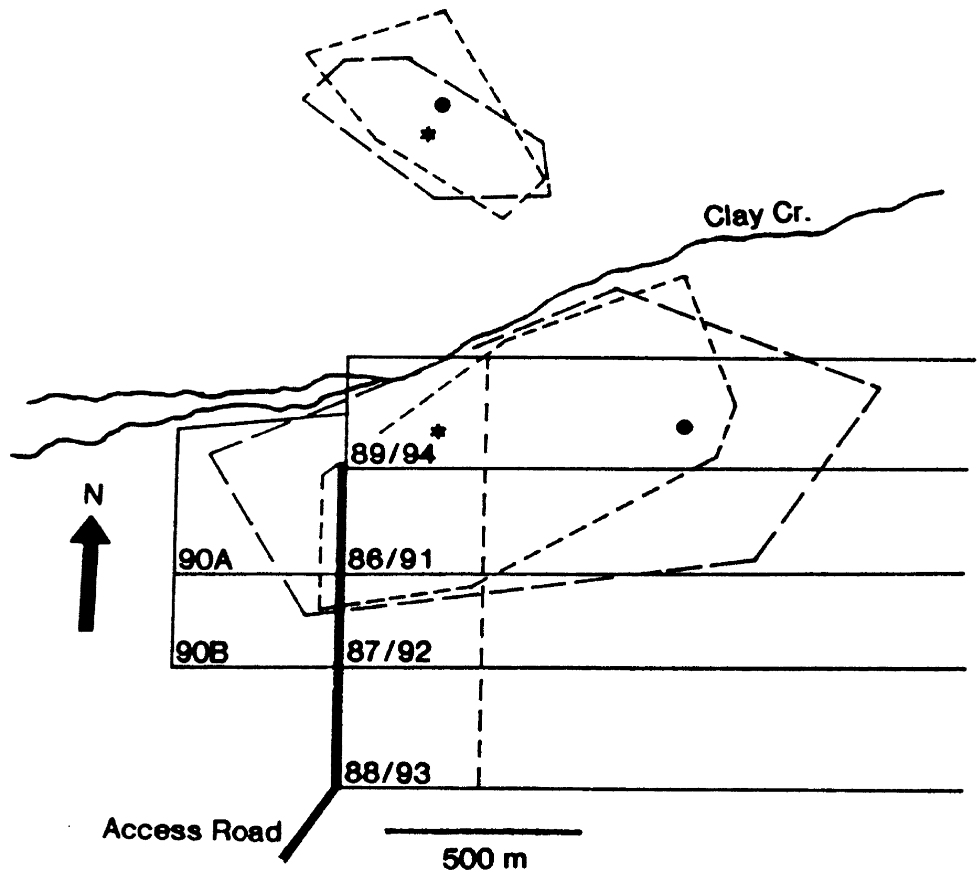

Figure 4. Map of dig units and Snowy Plover colonies at Salt Plains National Wildlife Refuge, Oklahoma, 1991. Digging occurred in the 86/91 digging unit. Symbols as in Fig. 2.

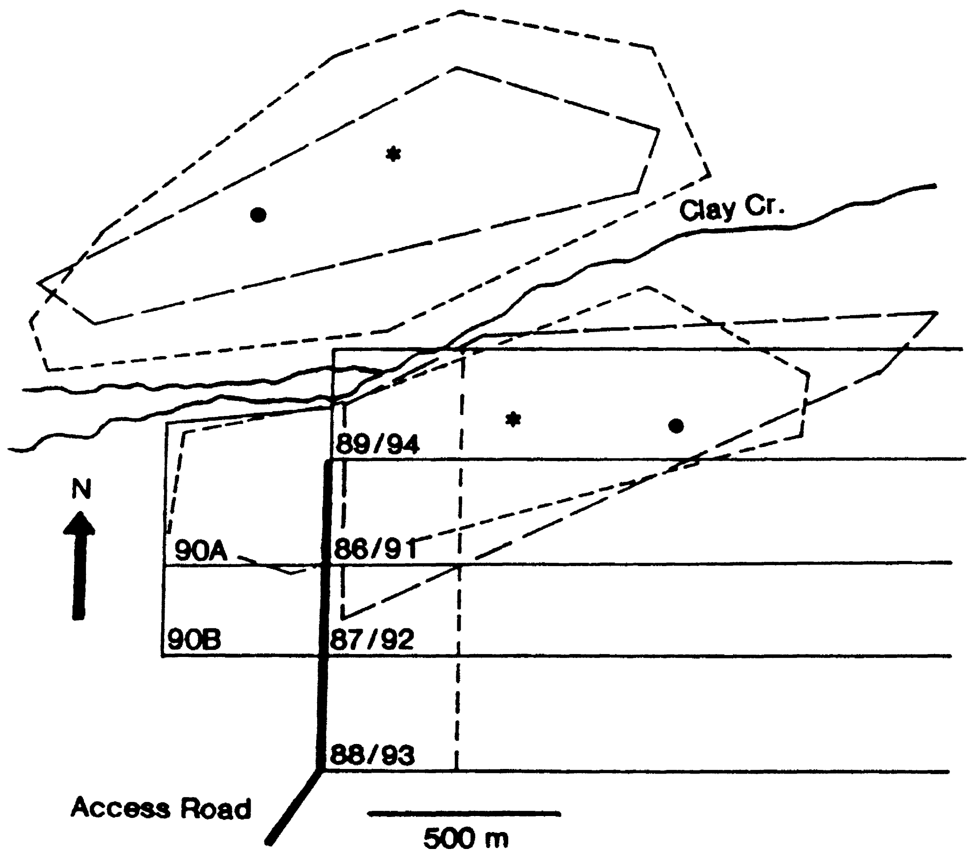

Figure 5. Map of dig units and Snowy Plover colonies at Salt Plains National Wildlife Refuge, Oklahoma, 1992. Digging occurred in the 87/92 digging unit. Symbols as in Fig. 2.

CHAPTER III

EFFICACY OF ELECTRIFIED FENCING TO DECREASE PREDATION OF LEAST TERN AND SNOWY PLOVER NESTS

The interior population of the least tern (Sterna antillarum) has been listed as endangered since 1985 (U.S. Fish and Wildl. Serv. 1985a), and the snowy plover (Charadrius alexandrinus) is a candidate (Category 2 species) for listing as threatened or endangered (U.S. Fish and Wildl. Serv. 1982, 1985b). Our study was designed to increase the adult, breeding population of least terns to levels specified in the priority tasks of the Recovery Plan for Least Terns (U.S. Fish and Wildl. Serv. 1990).

Mayer and Ryan (1991) reported that 909 of 978 egg losses (93%) of ground nesting piping plovers (Charadrius melodus) in North Dakota were caused by predators. Production of ground nesting waterfowl in the Prairie Pothole Region of North Dakota and Minnesota has been limited by severe predation of nests by small carnivores (Lokemoen et al. 1982).

Electrified fencing has been used by wildlife managers for >50 years to control animal movements (McAtee 1939). Previous research has evaluated the efficacy of electrified fencing to decrease predation of shorebird nests and chicks (Forster 1975, Patterson 1977, Minsky 1980, Greenwood et al. 1990). In North Dakota, mean nest survival for piping plovers in fenced areas was 71% greater than in unfenced sites (Mayer and Ryan 1991). Lokemoen et al. (1982) reported that nest success of ground nesting waterfowl in fenced sites was 44% greater than in controls in North Dakota and 109% greater in Minnesota. However, little work of this kind has been conducted where significant numbers of least terns and snowy plovers nest, for example, on the Arkansas River System (Purdue 1976, Downing 1980, Boyd 1990). Our objective was to evaluate electrified fences as protection for least tern and snowy plover nests from mammalian predation.

STUDY AREA

The study was conducted on the north side of the 4,050-ha salt flat in Salt Plains National Wildlife Refuge (NWR) (Alfalfa Co., Okla.). The salt flat is bordered on the east side by the Great Salt Plains Reservoir. The East and West Branches of the Salt Fork of the Arkansas River traverse the area where electrified fences were constructed. The salt flat commonly experiences high winds (>30km/hr) and hot summer temperatures (>35°C). The ground is covered with a thin crust of salt that precipitates as water is evaporated from brine drawn to the surface by capillary action (Johnson 1972). The salt crust usually dissolves after rain and reforms as the surface dries. The salt flat is sparsely covered with woody debris washed onto them during storms. Scant patches of inland salt grass (Distichlis stricta) and sea purslane (Sesuvium verrucosum) occur near creeks (Grover and Knopf 1982), and exotic salt cedar (Tamarix gallica) is abundant around the edge of the salt flat.

The north side of the refuge, bordering the salt flat, is not open to the public except for a limited number of controlled white-tailed deer (Odocoileus virginianus) hunts in autumn, and vegetation consists of >80% salt cedar. Based on direct observations and tracks, coyotes (Canis latrans) frequently venture out onto the salt flat searching for food. Least terns and snowy plovers on the north side of the salt flat nest within 100 m of dense vegetation. As a result, coyotes do not have to journey far from cover to depredate least tern and snowy plover nests.

MATERIALS AND METHODS

A 400- x 400-m (16 ha) electrified fence was constructed by refuge personnel in April 1991 on the north side of the salt flat south of the West Branch of the Salt Fork of the Arkansas River (Fig. 1). The enclosed area was chosen because it was not used by least terns in previous years (Boyd 1990), thereby ensuring that the fence would not have negative effects on an existing colony. Soil from the salt flat was used to make 15 ridges (about 10 m long x 0.5 m wide x 0.2 m high) in the fenced area to serve as nesting platforms and attract adult least terns and snowy plovers in the 1991 breeding season. A 16-ha area south of the creek and about 100 m east of the fence in similar habitat served as a control area.

Additionally, 2 250- x 150-m (3.75 ha) electrified fences were constructed in April 1992. Fences were constructed about 3.0 km east of the experimental fence in an area used by least terns and snowy plovers for nesting in 1991. One fence was constructed on the north side of the West Branch of the Salt Fork of the Arkansas River and the other on the south side of the creek. Habitat was similar inside and outside (controls) of the fenced areas.

Gallagher B-150 energizers (Gallagher Power Fence, Inc., San Antonio, Tex.) with deep cycle 12-V batteries powered the fences. Fences consisted of 5 wires spaced at 14, 28, 42, 62, and 86 cm from the ground. Wires were fastened with plastic insulators to steel T-posts spaced at 6-m intervals. Wooden fenceposts were used at the corners and to support solar power units. One solar unit powered the large electrified fence, and 1 unit powered both of the paired fences. Paired fences were connected with a 50 m long single strand of wire supported about 1.0 m above ground level with steel T-posts. Each fence had 1 gate for entry.

Costs for fence materials were as follows: wire = $16/800 m, solar charger and panel = $200, 12-V battery = $75, steel T-posts = $2.10 each, and plastic insulators = $5/25. We estimated the overall cost at $0.85/m of fence (not including labor). A fence enclosing 16 ha required about 40 person/hrs to construct. Fences were cleared of debris every 1-2 weeks depending upon wind levels. After high winds, fences were checked more frequently. Debris was cleared to ensure that it would not create a visual obstruction to nesting birds or ground the fences.

Fences were checked for predator entry and nests were monitored every 3-4 days. We estimated nest success and egg success using methods outlined by Mayfield (1961, 1975). Daily mortality rates were compared using a t-value resulting from the ratio of the difference between daily mortality rate of nests inside fences and control nests to its standard error (Johnson 1979). A significance level of $P < 0.05$ was used for all comparisons.

It has been suggested that the Mayfield Method (1961, 1975) of calculating nest success should not be used in situations with <20 nests (Hensler and Nichols 1981). We felt justified in using the Mayfield Method, despite small sample sizes, because our population met published assumptions: (1) the period to success (e.g., incubation period) was the same for all nests; (2) there was a constant unknown probability that a nest observed on day j survived to day j + 1; and (3) there was a constant unknown probability that a nest was found first on day j of a nesting period of J days (for j = 1,2,...J) (Hensler and Nichols 1981). In addition, a measure of apparent nest success (number of successful nests/total) would seriously overestimate the true value because many nests were found after incubation had begun (Mayfield 1961, 1975).

RESULTS

Daily mortality rates of least tern nests in 1991 ($t = 2.56$, $P = 0.012$) and 1992 ($t = 1.93$, $P = 0.037$) were significantly higher in the control area than in the large fenced area (Table 1). In 1991, no least tern nests were depredated inside the large electrified fence, but 5 (45.0%) nests were depredated in the control area (Table 1). No least tern nests were depredated inside the large electrified fence in 1992; 3 (42.9%) were depredated in the control area.

Daily mortality rates of snowy plover nests in 1991 ($t = 0.92$, $P = 0.190$) and 1992 ($t = 1.44$, $P = 0.083$) were the same in the control area and large fenced area (Table 2). In 1991, no snowy plover nests were depredated inside the large electrified fence; 1 (10.0%) nest was depredated in the control area. In 1992, 1 (7.7%) snowy plover nest was depredated by a cattle egret (Bubulcus ibis) within the large electrified fence; 2 (22.2%) were depredated in the control area (Table 2).

The salt flat received 35 cm of rain in the 1992 breeding season (compared to 23 cm in 1991), which minimized least tern and snowy plover use in the paired fence area due to flooding of nesting habitat by the rising creek. Due to low nest numbers (n = 27), all nests of the same species found outside fences were treated as control nests, and data from nests of the same species found in both fences were pooled. Daily mortality rates of least tern nests in 1992 (t = 0.91, P = 0.207) were the same in the control area and inside the paired electrified fences (Table 3). Daily mortality rates of snowy plover nests in 1992 (t = 1.73, P = 0.050) were significantly higher in the control area than inside the paired electrified fences (Table 3). No least tern or snowy plover nests inside the paired fences were depredated, but 4 (28.6%) snowy plover nests were depredated in the control area (Table 3).

In the 2-year period, only 5 coyotes entered the fences. In all cases, they squeezed under the bottom wire (14 cm above ground level). In 4 of 5 cases, the coyotes, once inside the fence, walked beside it for 50-200 m before exiting by again squeezing under the bottom wire. No evidence of coyote depredation was found inside any fence.

Weather could have differentially affected nest mortality rates in 1991 and 1992 in the large fenced enclosure because of the ridges. Nests constructed on ridges (not present on control site) would be less prone to flooding; however, we observed no differences in flooding of nests.

DISCUSSION

We attempted to decrease mammalian depredation of least tern and snowy plover nests with the use of electrified fences surrounding nesting areas. Despite small sample sizes, it was apparent that electrified fences did decrease daily mortality rates of nests.

Nest success in our study was similar to that obtained by Mayer and

Ryan (1991) who used electrified fences to protect piping plover nests from mammalian predators on beaches in North Dakota and Lokemoen et al. (1982) who used fences to protect nests of ground-nesting ducks in eastern North Dakota. Greenwood et al. (1990) also showed a significant effect using electrified fences to protect waterfowl nests from mammalian predation.

Lack of a significant difference for daily mortality rates of snowy plover nests inside the large electrified fence and on the control area in 1991 probably resulted from large standard errors associated with the low number of nests (n = 11). Small numbers of nests (n = 5) inside the large electrified fence in 1991 may be attributed to the fence being constructed in an area that was seldom used by either least terns or snowy plovers in the past (Boyd 1990). Numbers of birds nesting inside the large electrified fence increased (n = 23) in 1992, essentially creating a new colony. Additional birds may have nested there because peaks of ridges inside the fence had 2 years to erode. Most ridges (75%) had distinct peaks in 1991 from recently being made (6 mos). All nests in the large fenced area in 1991 were on ridges with less distinct peaks. In 1992, all ridges resembled those used by birds for nesting in 1991.

Only a small number of birds used the paired fence areas in 1992, likely because of flooding. Fences were constructed in an area used for nesting by least terns and snowy plovers in 1991. However, the West Branch of the Salt Fork of the Arkansas River traverses the region and is prone to flooding. Thirty-five cm of rain fell on this area in 1992 compared to only 23 cm in 1991. The fenced areas were flooded 3 times in May and early-June, 1992. Birds did not begin nesting inside the fences until late June 1992 and in smaller numbers than observed in 1991.

Lower mortality rates of nests in fenced areas suggested that mammalian depredation accounts for a large number of unsuccessful nests in these 2 bird species. Of depredated control nests, evidence suggested 90% could be attributed to coyotes. Raccoon (*Procyon lotor*) and striped skunk (Mephitis mephitis) tracks were occasionally observed close to creeks and vegetation, but these species are not believed to be a serious threat to nesting least terns and snowy plovers on the salt flat. Little evidence of avian depredation was observed, which agrees with Hill's (1985) findings. Possible avian predators observed on the salt flat include cattle egrets, ring-billed gulls (Larus delawarensis), turkey vultures (Cathartes aura), and peregrine falcons (Falco peregrinus).

Thompson (1978) observed that coyotes are adept at climbing over, jumping, passing through, and passing under electrified fences. Pass-unders were most common in fences that had a bottom wire >25.4 cm above the ground, and some coyotes could jump 150-cm fences (Thompson 1978). Dorrance and Bourne (1980) suggested that coyotes prefer to crawl under the bottom wires rather than jump over the top or climb through the middle. In our study, coyotes passed under the bottom wire (14 cm above ground) in all 5 cases.

It has been suggested that the insulating effect of coyote fur, and debris in contact with the fence (especially wet debris) can reduce the effect of electric shock enough to render fences ineffective for excluding coyotes (Gates et al. 1978, Dorrance and Bourne 1980). We observed (from tracks) that most coyotes encountering our fences (90%) received enough of a shock to cause them to jump back from the fence and change direction.

MANAGEMENT IMPLICATIONS

Electrified fences are useful for protecting large areas of nesting habitat where single nest exclosures would be impractible. Fences can be constructed before birds arrive to nest. They require only periodic clearing of debris and power checks once established. We estimated that a fence enclosing 16 ha cost $1,200 and required about 40 person/hrs to construct. We recommend constructing small numbers of large fences instead of many small fences to maximize the area/boundary ratio. Also, a colony may move a bit from year to year; a large fence might still protect it unless the distance moved is great. We also recommend that 1 wire be placed <14 cm above ground to prevent coyotes from crawling under. We suggest that in areas where terrestrial predators are responsible for significant nest losses, electrified fencing can be an effective means to raise numbers of least terns to levels called for in the Recovery Plan for least terns (U.S. Fish and Wildl. Serv. 1990) and prevent snowy plovers from being listed.

SUMMARY

A 16-ha electrified fence was used to protect least tern and snowy plover nests from mammalian predators in 1991 and 1992, and 2 (3.75 ha) additional, paired fences were used in 1992. Daily mortality rates of least tern nests in 1991 (t = 2.56, P = 0.012) and 1992 (t = 1.93, P = 0.037) were significantly higher in the control area than in the large fenced area. Daily mortality rates of snowy plover nests in 1991 (t = 0.92, P = 0.190) and 1992 (t = 1.44, P = 0.083) were the same in the control area and large fenced area. Daily mortality rates of least tern nests in 1992 (t = 0.91, P = 0.207) were the same in the control and paired electrified fence areas. Daily mortality rates of snowy plover nests in 1992 (t = 1.73, P = 0.049) were significantly higher in the control area than inside the paired fences. During our study, only 1 snowy plover nest inside a fenced area was lost to predation, while 8 least tern and 7 snowy plover nests were depredated in controls. Electrified fences are an effective means of decreasing daily mortality rates of least tern and snowy plover nests in areas where mammalian depredation is suspected to limit reproductive success.

Acknowledgments.- This research was funded by the U.S. Fish and Wildlife Service (Region 2 and Salt Plains NWR) and the Oklahoma Cooperative Fish and Wildlife Research Unit (Okla. State Univ., Okla. Dep. Wildl. Conserv., U.S. Fish and Wildl. Serv., and Wildl. Manage. Inst., cooperating). We thank the very helpful and cooperative refuge staff: R. Krey, H. Beierman, R. Shepperd, W. Miller, T. Ogburn, R. Hill,

M. Gregory, L. Hill, and K. Brown. We also thank A. Zale and S. Fox for help with this manuscript, L. Hill (Tulsa Ecol. Serv., U.S. Fish and Wildl. Service) for advice on this study, and D. Johnson and W. Warde for help with statistics. Excellent field assistance was provided by W. McAbee, C. Anderson, and S. Schweitzer. We also thank the Unit secretarial staff: H. Murray, J. Gray, and R. Newkirk for their assistance.

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Table 1. Daily mortality rates, nest success, egg success, and nest losses of least terns in the large electrified fence and control area in Salt Plains National Wildlife Refuge, Oklahoma, 1991 and 1992.

	1991		1992	
Variables	Fenced	Control	Fenced	Control
Successful nests/total	3/3	3/11	6/10	0/7
Nest success[a]	81.0	7.8	50.5	7.1
Egg success	65.4	6.2	38.4	5.4
Daily mortality rate[b]	0.010	0.114[c]	0.032	0.119[c]
Standard Error	0.015	0.038	0.016	0.042
Percentage nest loss:				
Rain/Flooding	0.0	0.0	30.0	42.9
Predation	0.0	45.0	0.0	42.9
Deserted	0.0	27.0	0.0	14.3
Cracked(thin shell)	0.0	0.0	10.0	0.0

[a]Nest success (%) and egg success (%) was estimated with methods outlined by Mayfield (1961, 1975).

[b]Daily mortality rates were compared using methods described by Johnson (1979).

[c]Indicates control value greater ($P < 0.05$) than fenced value.

Table 2. Daily mortality rates, nest success, egg success, and nest losses of snowy plover nests in the large electrified fence and control area in Salt Plains National Wildlife Refuge, Oklahoma, 1991 and 1992.

Variables	1991 Fenced	1991 Control	1992 Fenced	1992 Control
Successful nests/total	2/2	5/9	8/13	2/9
Nest success[a]	77.8	48.7	55.1	22.8
Egg success	54.1	33.9	48.2	20.0
Daily mortality rate[b]	0.010	0.028	0.024	0.057
Standard Error	0.014	0.014	0.010	0.021
Percentage nest loss:				
Rain/Flooding	0.0	10.0	23.1	33.3
Predation	0.0	10.0	7.7[c]	22.2
Deserted	0.0	24.0	7.7	22.2
Cracked(thin shell)	0.0	0.0	0.0	0.0

[a]Nest success (%) and egg success (%) was estimated with methods outlined by Mayfield (1961, 1975).

[b]Daily mortality rates were compared using methods described by Johnson (1979).

[c]One snowy plover nest was assumed to be depredated by a cattle egret (Bubulcus ibis); cattle egret tracks were observed around the nest cup.

Table 3. Daily mortality rates, nest success, egg success, and nest losses of least terns and snowy plovers in paired electrified fences and controls at Salt Plains National Wildlife Refuge, Oklahoma, 1992.

	Least Terns		Snowy Plovers	
Variables	Fenced	Control	Fenced	Control
Successful nests/total	3/4	0/2	5/7	4/14
Nest success[a]	64.9	24.7	56.3	17.2
Egg success	49.4	18.8	49.2	15.1
Daily mortality rate[b]	0.020	0.065	0.023	0.068[c]
Standard Error	0.020	0.044	0.016	0.021
Percentage nest loss:				
Rain/Flooding	25.0	0.0	28.6	35.7
Predation	0.0	0.0	0.0	28.6
Deserted	0.0	100.0	0.0	7.1
Cracked(thin shell)	0.0	0.0	0.0	0.0

[a]Nest success (%) and egg success (%) was estimated with methods outlined by Mayfield (1961, 1975).

[b]Daily mortality rates were compared using methods described by Johnson (1979).

[c]Indicates control value greater ($P<0.05$) than fenced value.

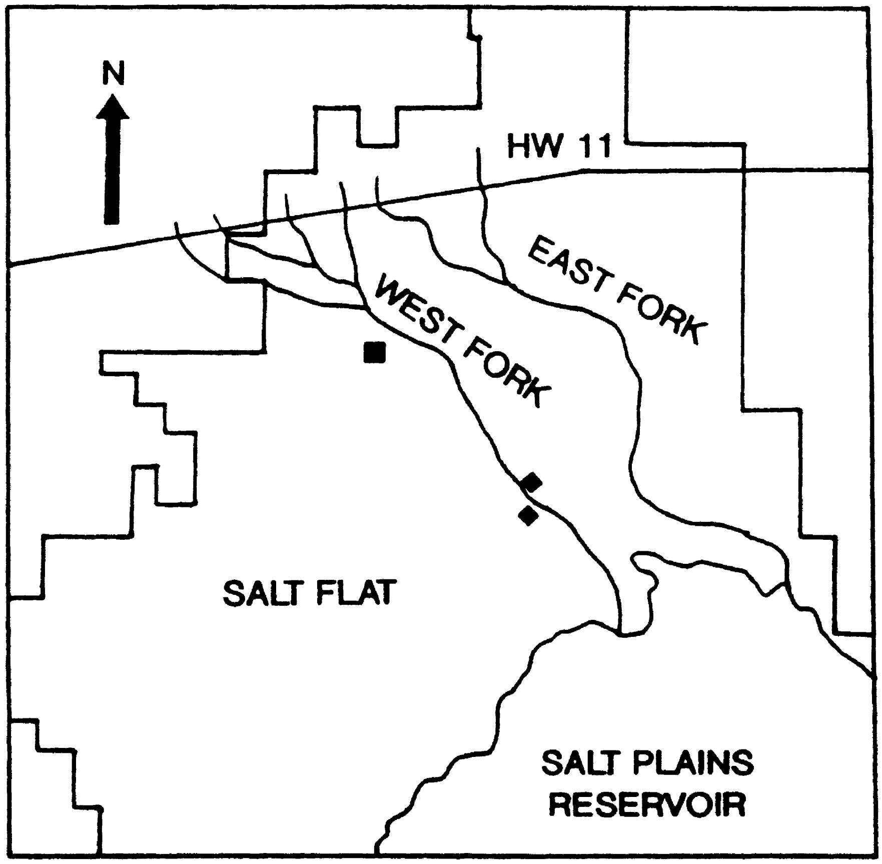

Fig. 1. Location of large electrified fence (■) and paired electrified fences (■) in Salt Plains National Wildlife Refuge, Oklahoma.

VITA

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