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Reproductive Success in Saginaw Bay
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**ASSESSMENT OF COMMON TERN (*STERNA HIRUNDO*)
REPRODUCTIVE SUCCESS IN
SAGINAW BAY OF EASTERN MICHIGAN**

By

Kelly F. Millenbah

A DISSERTATION

Submitted to
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ABSTRACT

ASSESSMENT OF COMMON TERN (*STERNA HIRUNDO*) REPRODUCTIVE SUCCESS IN SAGINAW BAY OF EASTERN MICHIGAN

By

Kelly F. Millenbah

Once common and widespread in the Great Lakes region, common tern (*Sterna hirundo*) numbers in Michigan are currently estimated to be around 1,400 breeding pairs. Reproductive success of common terns in the Great Lakes is below that on the eastern seaboard suggesting that their continued existence in the Great Lakes region may be severely jeopardized. Two common tern colonies were observed in Saginaw Bay of eastern Michigan in the summers of 1995 - 1997 to determine impacts to reproductive success using a monitoring program that included observations, trapping and banding, and nest checks. Population projection models were developed to determine the long-term survival of the species at these sites. The effectiveness of using nesting platforms to increase reproductive success also was evaluated. Results from this study indicate that the common tern population is declining. Major threats to survival include wave inundation and predation. To reverse this declining trend it will be necessary to increase the survival of common tern eggs and chicks, the primary variables that can be impacted in Michigan. Recommendations for increasing reproductive success include predator control efforts, use of nesting platforms, and manipulation of habitat.

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TABLE OF CONTENTS

LIST OF TABLES	vi
LIST OF FIGURES	ix
INTRODUCTION	1
OBJECTIVES	10
STUDY AREA	11
CHAPTER I: POPULATION ASSESSMENT AND REPRODUCTIVE STATUS OF THE COMMON TERN IN SAGINAW BAY	
INTRODUCTION	19
OBJECTIVES	22
METHODS	23
General Observations	23
Predation	24
Site Characteristics	26
Assessing Reproductive Success and Determining Survival Estimates ..	27
Population Projections	29
RESULTS	33
General Observations	33
Predation	44
Site Characteristics	47
Assessing Reproductive Success and Determining Survival Estimates ..	55
Population Projections	59
DISCUSSION	70
General Observations	70
Duck Island	70
Confined Disposal Facility	71
Predation	72
Site Characteristics	77

Assessing Reproductive Success and Determining Survival Estimates .	79
Population Projections	81

CHAPTER II: USE OF NESTING PLATFORMS TO INCREASE COMMON TERN REPRODUCTIVE SUCCESS

INTRODUCTION	85
OBJECTIVES	89
METHODS	90
RESULTS AND DISCUSSION	99
SUMMARY AND RECOMMENDATIONS	101
LITERATURE CITED	105

LIST OF TABLES

Table 1	Population projection calculations used to predict the long-term survival of common terns on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan. 30
Table 2	Greatest number of active common tern nests on a given day, suggesting the number of breeding pairs, on Duck Island and the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1995 - 1997. 38
Table 3	Mean clutch size (number of eggs per nest) of common tern nests on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1995 - 1997. 39
Table 4	Number of common tern young fledged per pair (out of those that successfully hatched) on the Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan summer 1997. Only values obtained from enclosures in 1997 are reported due to the high rate of censoring in 1995 and 1996 and outside of the enclosures in 1997. 40
Table 5	Number of common tern young surviving to hatching and/or fledging per clutch (%) on the Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summer 1997. Only values from enclosures used in 1997 are presented. 41
Table 6	Number of common tern chicks banded in each age class (aged according to criteria presented by Nisbet and Drury (1972)) on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1996 - 1997. 43
Table 7	Number of dead common tern chicks recovered and last age when known alive in each age class (aged according to criteria presented by Nisbet and Drury (1972)) on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1996 - 1997. 45

Table 8	Mean (SD) vegetation characteristics at common tern nests of combined successful and unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summers 1996 and 1997. 48
Table 9	Mean (SD) vegetation characteristics at common tern nests of successful and unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summer 1997. 50
Table 10	Mean (SD) vegetation characteristics at common tern nests of successful and unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summer 1996. 51
Table 11	Mean (SD) vegetation characteristics at common tern nests of successful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summers of 1996 and 1997. 52
Table 12	Mean (SD) vegetation characteristics at common tern nests of unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summers of 1996 and 1997. 53
Table 13	Mean (SD) vegetation characteristics at common tern nests of successful and unsuccessful fledging (at least one young from a nest fledged) on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summer 1997. 54
Table 14	Daily (S_D) and period (S_P) survival rates (variance; Mayfield 1961) of common tern eggs on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1995 - 1997. 56
Table 15	Daily (S_D) and period (S_P) survival rates (variance; Mayfield 1961) of common tern eggs on Duck Island in Saginaw Bay of eastern Michigan, summers 1995 - 1997. 57
Table 16	Daily (S_D) and period (S_P) survival rates (variance; Mayfield 1961) of common tern chicks on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1996 - 1997. No estimates of chick survival are available for 1995. 58
Table 17	Overall period (S_P) survival rates (variances; Mayfield 1961) of common terns from initiation to fledging on the Saginaw Bay Confined Disposal Facility (CDF) in eastern Michigan, summer 1996 - 1997. 60

Table 18	Combinations of common tern egg survival (Mayfield estimate, Mayfield 1961), chick survival (Mayfield estimate), and mean clutch size on the Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan used in population projections that yielded $\lambda \geq 1$, indicating a stable or increasing population. 61
Table 19	Population projection of common terns on the Confined Disposal Facility (CDF), in eastern Michigan. Projection represents the most representative case scenario using egg survival = 0.4461, chick survival = 0.637, and mean clutch size = 2.34. See Table 1 and associated text for description of calculations. 64
Table 20	Population projection of common terns on the Confined Disposal Facility (CDF), in eastern Michigan. Projection represents the worst case scenario using egg survival = 0.3571, chick survival = 0.598, and mean clutch size = 2.04. See Table 1 and associated text for description of calculations. 66
Table 21	Population projection of common terns on the Confined Disposal Facility (CDF), in eastern Michigan. Projection represents the best case scenario using egg survival = 0.8887, chick survival = 0.932, and mean clutch size = 2.61. See Table 1 and associated text for description of calculations. 67
Table 22	Manipulation of common tern egg survival (S_p), chick survival (S_p), and mean clutch size to generate $\lambda = 1.0$. Mean values generated for egg survival, chick survival, and mean clutch size were used as the basis of the manipulations. 68
Table 23	Supplies, including prices and quantities, for building one common tern nesting platform used near Duck Island in Saginaw Bay, Michigan in summer 1995 - 1997. Prices are given in 1997 dollars. 98

LIST OF FIGURES

- Fig. 1 Location of common tern colonies (Confined Disposal Facility (CDF) and Duck Island) in Saginaw Bay, Michigan in summers 1995 - 1997. 12
- Fig. 2 Aerial view of Duck Island located in Wildfowl Bay State Game Area of Saginaw Bay, Michigan showing location of common tern nesting colony in relation to vegetation and the water's edge. 13
- Fig. 3 Side view of Duck Island in Wildfowl Bay State Game Area in Saginaw Bay, Michigan showing height of island from water line and vegetation height. 14
- Fig. 4 Side view of Saginaw Bay Confined Disposal Facility (CDF), Michigan showing the design of the island including water level, outer retaining wall, interior dike wall, and interior cell. 16
- Fig. 5 Aerial view of Saginaw Bay Confined Disposal Facility (CDF), Michigan showing location of common tern colony and other nesters including ring-billed and herring gulls, black-crowned herons, and caspian terns. 17
- Fig. 6 Diagrammatic representation of infra-red camera system connected to time lapse recorders used on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan to record predation activities within the CDF common tern colony summer 1996 - 1997. 25
- Fig. 7 Number of common tern clutches, eggs, and chicks on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan summer 1997. 34
- Fig. 8 Number of common tern clutches, eggs, and chicks on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan summer 1996. 35
- Fig. 9 Number of common tern clutches and eggs on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan summer 1995. 36

- Fig. 10 Location of Duck Island and other islands of Wildfowl Bay State Game Area in Saginaw Bay, Michigan. 87
- Fig. 11 Duck Island in Saginaw Bay, Michigan and placement of common tern nesting platforms in summer 1995 - 1997. 91
- Fig. 12 Diagrammatic representation of one common tern nesting platform used near Duck Island in Saginaw Bay, Michigan summer 1995 - 1997. Illustration depicts platform completely assembled and installed but lacking substrate. 92
- Fig. 13 Diagrammatic representation of one common tern nesting platform used near Duck Island in Saginaw Bay, Michigan summer 1995 - 1997. Illustration depicts platform partially disassembled. 96

INTRODUCTION

The common tern (*Sterna hirundo*) breeds throughout a wide band of latitudes in the Northern Hemisphere (Morris et al. 1980). In Michigan, nests can be found on all of the Great Lakes with a few birds nesting on inland lakes (Scharf 1991). A notable gap in their distribution in Michigan occurs along the western shore of the state, where preferred nesting habitat is lacking. Terns nest in highest numbers on human-made islands in the Saint Mary's River, in northern Lake Michigan, and in Saginaw Bay of Lake Huron (Scharf and Shugart 1985, Shugart and Scharf 1983, F. Cuthbert, University of Minnesota, pers. commun.).

Throughout their range common terns are colonial nesters and require three features for colony nest site selection including physical isolation from predators, a constant supply of food nearby, and flat and relatively open habitat with good visibility and sparse vegetation (Austin 1929, Palmer 1941, and Burger and Gochfeld 1991). Terns prefer nest sites on peninsulas or islands presumably to limit or prevent access by ground predators (Courtney and Blokpoel 1983, Scharf 1981). Colonies are typically located in estuaries, bays, lakes, rivers, and occasionally marshes (Bent 1921, Palmer 1941). Colony sites located throughout the Great Lakes have included sandbars, shoals, breakwaters, and artificial islands. Selected nests sites are usually located on well

drained substrate including gravel, sand, dredge spoil, chipped concrete, iron slag, bare rock, and rocky spits. Nest sites can be characterized by early plant succession with 10 - 30% vegetation cover (Burger and Gochfeld 1991). If vegetation is widely scattered throughout the colony site common terns will select a nest site near an individual plant to provide shade for chicks after hatching. Additionally, terns often use objects that protrude from the substrate as focal points when returning to the nest site. Unobstructed vision also is an important factor in site selection (Blokpoel et al. 1978, Burger and Gochfeld 1991). If colony members can not easily see or hear each other, then fear reactions (i.e., panic flights) cannot be communicated among individuals within the colony (Blokpoel et al. 1978). Although too much vegetation can negatively impact survival, some vegetation provides refuge from predators and needed thermal cover (Palmer 1941).

Palmer (1941) stated that a constant food supply nearby is influential in colony site selection. Terns display a tendency to return to the same colony each year if reproductive efforts have been successful at the site (Austin and Austin 1956, Courtney and Blokpoel 1983). Site tenacity in common terns increases as birds age (Austin 1942). Because food availability influences reproductive success and common terns are site tenacious, especially when reproductive efforts have been successful, food availability should influence site selection.

Colony size can be quite variable with colonies as small as 10 nests or as large as several thousand nests (Burger and Gochfeld 1991). Inter-nest distance for common terns has been reported to vary between 45 - 300 cm (Burger and Gochfeld 1991). Common

terns may nest with other species [e.g., black skimmers (*Rynchops niger*); Burger and Gochfeld 1991] or with other species nearby [i.e., ring-billed (*Larus delawarensis*) and herring gulls (*Larus argentatus*) in Saginaw Bay; Winterstein and Millenbah 1996].

Two or three eggs are commonly laid by common terns with the third egg being the smallest and least likely to survive (Ehrlich et al. 1988). Common terns have been observed with up to 5 eggs in a nest, but this is rare. Typically common terns produce a single brood and may attempt to raise a second brood but are rarely successful (Hays 1984, Wiggins et al. 1984). Initial nest loss is frequent and may be compensated by second nesting. Common terns are monogamous within a breeding season and hatching within a colony is synchronous. Food availability and precipitation determine the timing of initial nesting (Becker et al. 1985, Burger and Gochfeld 1991) with most egg-laying commencing in mid- to late-May and ending by early June (Austin 1932, Nisbet 1973). In highly disturbed sites, initiation of egg laying may continue into late July (Winterstein and Millenbah 1996).

Once abundant and widespread in the Great Lakes and many inland lakes (Barrows 1912), common terns were first threatened with extinction in the early 1900's due to plume and feather trade. After passage of the Migratory Bird Treaty Act, the common tern population in Michigan rebounded, but has never recovered to previous levels (Brewer 1991). Currently, common terns in Michigan are designated as a State threatened species. Other states in the Great Lakes region that provide designation to common terns as threatened or endangered include Ohio, Illinois, Wisconsin, Minnesota, and New York. Additionally, the entire Great Lakes population of common terns is

currently undergoing a status assessment for possible listing as Federally endangered (S. Lewis, U. S. Fish and Wildlife Service (USFWS), pers. commun.)

Recent population estimates for common terns in Michigan number around 1,200 - 1,400 breeding pairs (Evers 1992, F. Cuthbert pers. commun.). Banding records indicate that the Great Lakes population is fairly discrete with little movement to and from other areas (Austin 1953, Haymes and Blokpoel 1978), thus the size of the population and its persistence will largely be determined by natality and mortality. Unfortunately, the reproductive success of the common tern in the Great Lakes is below that of colonies on the eastern seaboard of North America (Nisbet and Drury 1972, Morris et al. 1976), suggesting that their continued existence may be severely jeopardized. Several factors have been identified that may negatively impact reproductive success and survivorship, including loss of habitat, competition with gulls, predation, and contaminant effects.

Loss of available beaches in Michigan to high waters in the 1980's, plant succession, and human disturbance have caused a dramatic decline in the number of common tern breeding pairs (Scharf and Shugart 1985). Elevated lake levels have eliminated much of the natural island nesting habitats where many long-time colony sites have been washed away (Morris and Hunter 1976, Scharf 1991). Because terns require nest sites with sparse, low vegetation that are isolated from mammalian predators (Courtney and Blokpoel 1983), they often nest on bare sandy, gravelly parts of islands or peninsulas highly susceptible to wave damage and erosion (Dunlop et al. 1991). This situation has been exacerbated during the past several decades by large populations of

ring-billed gulls which have forced common terns into marginal habitat close to the water line (Blokpoel and Scharf 1991).

Loss of habitat also can be attributed to residential and commercial development along the Great Lakes shoreline. This loss of natural habitat has resulted in a shift to the use of human-made islands (Scharf 1991). Other human activities that adversely affect common tern nesting success include recreation in or near colonies and egg collection. Birders and photographers cause disturbances at nest sites and may keep brooding adults off nests thus exposing eggs and chicks to thermal stress and/or opportunistic predators (Courtney and Blokpoel 1983, Burger and Gochfeld 1991).

Vegetation encroachment also reduces the amount of area available for nesting. Terns prefer to nest in locations with sparse vegetation (Palmer 1941), however, as plant growth progresses and increases in density, terns may be forced to abandon nest sites (Courtney and Blokpoel 1983, Shields and Townsend 1985). For example, seasonal growth of sandbar willow (*Salix exigua*) forced terns to abandon nests at a Minnesota colony (McKearnan and Cuthbert 1989) while terns along the Maumee River colony in Ohio were physically unable to reach their nests as a result of seasonal grass growth in 1980 (Shields and Townsend 1985).

As indicated previously, available nesting sites for common terns also have been depleted due to the expanding ring-billed gull population (Courtney and Blokpoel 1983, Shugart and Scharf 1983, Ludwig 1991). Morris and Hunter (1976) suggest that the widespread decrease in common tern numbers has been related to the occupancy of nesting areas by ring-billed gulls which results in terns nesting in less preferred sites that

may be more vulnerable to human disturbance, pollution, and predation. Because gulls arrive on their breeding sites 2 - 3 weeks prior to terns, out-competing terns for nesting sites is not difficult (Morris and Hunter 1976). In addition to the physical displacement of common tern colonies, the vegetation structure within a colony can be damaged due to nesting gulls. Vegetation can be killed or removed by acidic gull fecal matter and pulling and/or trampling of plants within the colony (McBrayer et al. 1995).

Predation also contributes to the declining common tern population. Although some authors (Hatch 1970, Burness and Morris 1992) indicate that ring-billed gulls often have a large impact on the reproductive success of terns in terms of predation, Courtney and Blokpoel (1980) found that ring-billed gulls have little to no effect on common tern reproductive success. Rather, ring-billed gulls posed more of a threat by excluding terns from otherwise quality nesting habitat (Morris and Hunter 1976).

Herring gulls also are known to cause declines in common tern reproductive success. In Maine, herring gull predation on common tern eggs and chicks was suggested as the major factor in lowered reproductive success of a colony (Hatch 1970).

Additionally, black-crowned night herons (*Nycticorax nycticorax*) have been identified as a nocturnal predator of common tern colonies preying primarily on eggs and 1 - 3 day-old chicks (Collins 1970, Morris and Hunter 1976). Similarly, great horned owls (*Bubo virginianus*; Morris and Wiggins 1986) and ruddy turnstones (*Arenaria interpres*; Faraway et al. 1986, Morris and Wiggins 1986) are known to prey on tern chicks. Great horned owls have removed over 100 common tern chicks from a single colony in a given breeding season (Courtney and Blokpoel 1983). Other avian predators include American

crows (*Corvus brachyrhynchos*; LaBarr 1995) and Canada geese (*Branta canadensis*; Courtney and Blokpoel 1983).

Mammalian predators also have been documented to have significant impacts on common tern reproductive success. Norway rats (*Rattus norvegicus*) have been identified preying on common tern eggs, chicks, and adults in colonies along the Atlantic coast (Austin 1932, Palmer 1941). Feral cats (*Felis cattus*) have interrupted incubation by preying on eggs (Shields and Townsend 1985) while mink (*Mustela vison*) have been observed preying on eggs and half-grown chicks (Courtney and Blokpoel 1983, Penning and Cuthbert 1993). Racoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and red foxes (*Vulpes vulpes*) also have been identified as predators of common tern eggs and chicks in colonies in Ohio (Stricker 1995), Lake Ontario (Courtney and Blokpoel 1983), Minnesota (McKearnan and Cuthbert 1989), and along the Atlantic coast (Palmer 1941).

Avian and mammalian predation of common terns is most often described in the literature but reptilian and invertebrate predation also have been reported. Predation by garter snakes (*Thamnophis* spp.) has been recorded at New England colonies (Lyon 1927) while Stricker (1995) found evidence of fox snake (*Elaphe vulpina*) predation on common terns in Ohio. Additionally, ants have been reported entering pipping common tern eggs as well as preying upon newly hatched chicks (Austin 1932). Newly hatched chicks have been killed and/or blinded by ants in a Massachusetts common tern colony (Shields and Townsend 1985). Many ant predations coincide with predations by owls and subsequent nocturnal desertion of the colony by adult common terns (Nisbet 1972). Nisbet and Welton (1984) suggested brooding adults are able to keep ants out of pipping

eggs and away from chicks, but nocturnal desertion allows enough time for ants to access eggs and chicks and kill them.

Contaminants have also been identified as a possible cause of the declining common tern population. High concentrations of some contaminants were reported in common tern eggs from the Great Lakes in the 1970's (Gilbertson and Reynolds 1972, Morris et al. 1976). Additionally, a study conducted from 1969 - 1973 by the Canadian Wildlife Service showed that the eggs of common terns nesting in the Great Lakes contained relatively high levels of several organochlorine contaminants (Weseloh et al. 1989). This coincided with a high incidence of chick deformities and a lower reproductive success. However, common terns may be exposed to various chemical contaminants not only on their breeding grounds but also on wintering grounds and along migration routes. Fox (1976) reported low concentrations of some contaminants in the summer food of common terns and assumed that bioaccumulation in these birds resulted from the intake of contaminated food on wintering grounds. Although high concentrations of some contaminants were reported in the 1970's, a study conducted in 1989 indicated that organochlorine pollution levels had been reduced in the Great Lakes suggesting that they are no longer an important factor in the population dynamics of the Great Lakes common tern (Weseloh et al. 1989).

From previous research it is obvious that one or many factors may be impacting the continued survival of the common tern. To make the most appropriate management recommendations for promoting the continued existence of the species, information must be collected at each colony to understand those factors that either threaten or may

potentially threaten their survival. In Michigan, two common tern colonies in Saginaw Bay, located in Lake Huron, have been monitored by the USFWS for several years. In 1994, a human-made island in Saginaw Bay (Confined Disposal Facility; CDF) supported approximately 100 breeding pairs of common terns. Few if any young were believed to have fledged from the site (L. Williams, USFWS, pers. commun.). A second island in Saginaw Bay, Duck Island, was observed in 1993 to fledge few if any young from the 75 - 100 breeding pairs at the site (D. Best, USFWS, pers. commun.). In each case, USFWS biologists were uncertain as to the cause of the poor reproductive success. Thus it was necessary and imperative that investigations be undertaken to identify potential causes of declines at these sites so that appropriate steps could be taken. The purpose of this research was to determine the factors affecting the reproductive success of the common tern in Saginaw Bay, Michigan and to make appropriate management recommendations that could ensure the continued existence of the species.

OBJECTIVES

Specific objectives of this study were to:

- 1) **determine the reproductive success of common terns in Saginaw Bay;**
- 2) **determine the frequency and impacts of mammalian and avian predators on common tern reproductive success;**
- 3) **predict the long term success of common terns using population projection models;**
- 4) **determine the effectiveness of nesting platforms in increasing common tern reproductive success; and**
- 5) **make recommendations for managing common terns for increased reproductive success on natural and human-made islands.**

STUDY AREA

Common tern colonies were observed at two locations in Saginaw Bay, Michigan during the summers of 1995 - 1997: 1) Duck Island and 2) Saginaw Bay CDF. Duck Island (< 0.5 ha) is located in Wildfowl Bay State Game Area between Heistermann and Maisou Islands (43°50'30"N 83°27'30"W; Figure 1). Due to the location (nearest landform > 400 m away) and small size of the island, no permanent avian or mammalian residents are found on the island. Common terns nest on the southwest side of the island. No nests are found on the northeast side (Figure 2). Duck Island is surrounded by shallow water (< 1.5 m) but can be easily flooded in storm events or completely submerged in high water years. Vegetation is clumped near the center of the island with common species including aspen (*Populus* spp.; < 4 m in height) and reed canary grass (*Phalaris arundinacea*; Figure 3).

The CDF is an artificial kidney shaped island (118.5 ha) near the mouth of the Saginaw River (43°40'N 83°50'30"W; Figure 1). This structure was built around the Channel and Shelter Islands by the Army Corps of Engineers in 1978 to house contaminated dredge material (fine silt, sand) from the Saginaw River and Saginaw Bay shipping channel (Hodgkins 1993). From 1978 - 1996 disposal of all hydraulically dredged material occurred in late summer and early fall to avoid impacting breeding bird

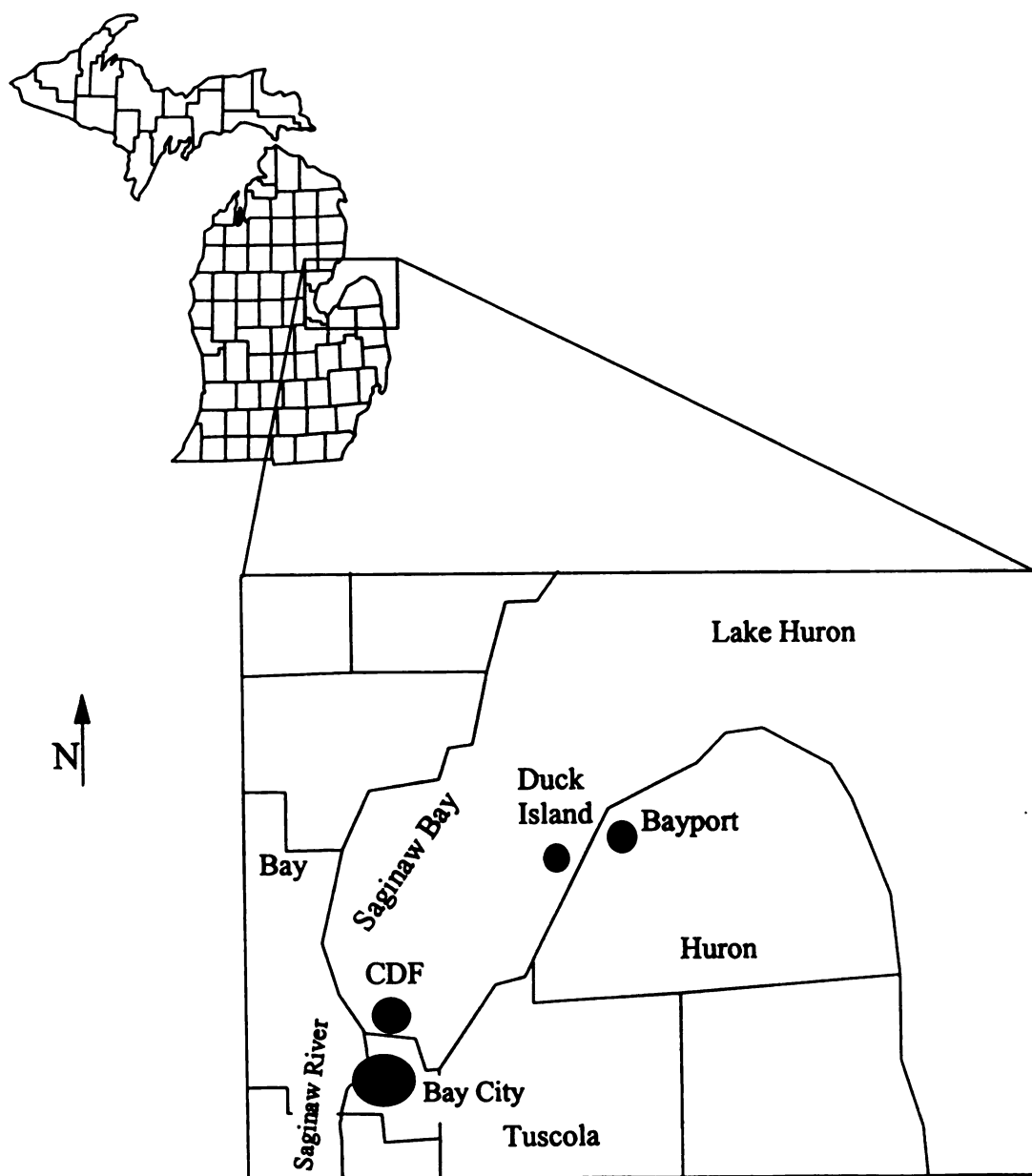


Fig. 1. Location of common tern colonies (Confined Disposal Facility (CDF) and Duck Island) in Saginaw Bay, Michigan in summers 1995 - 1997.

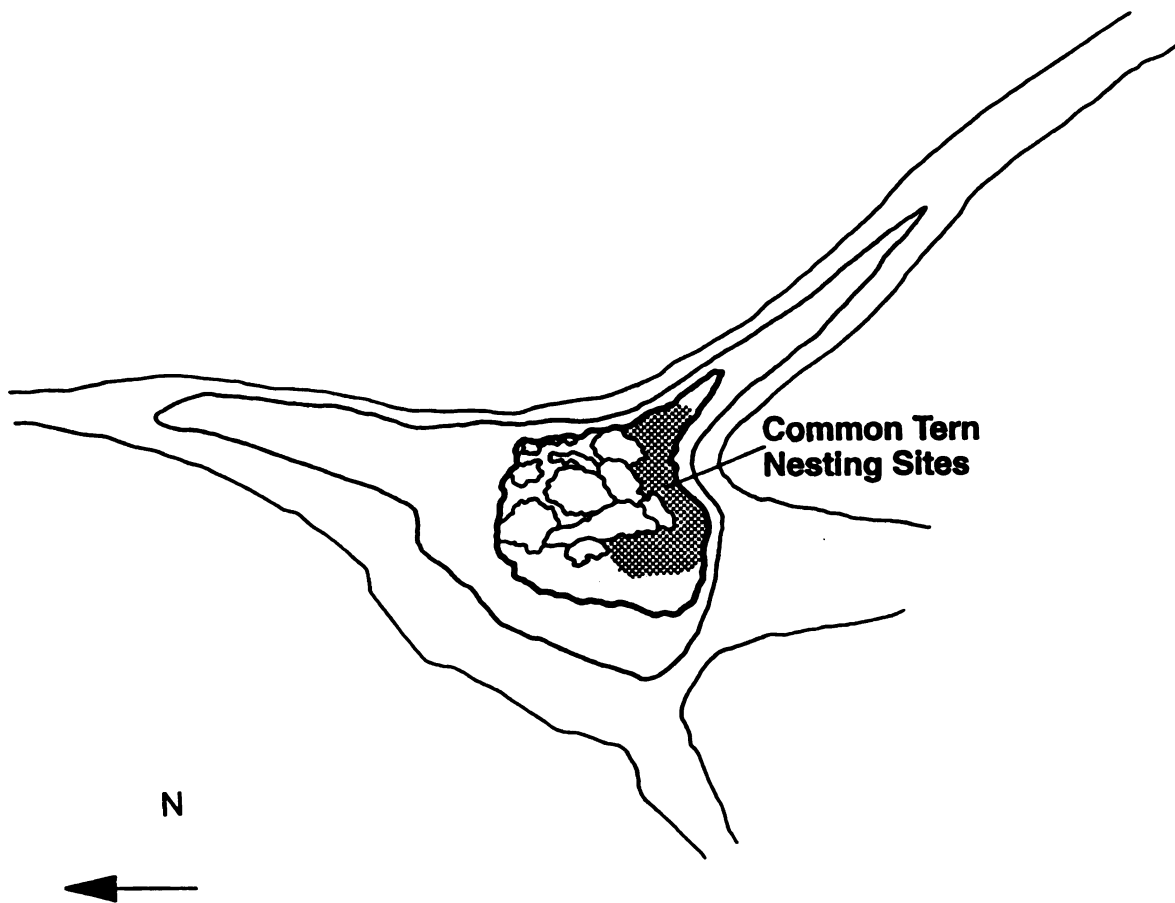


Fig. 2. Aerial view of Duck Island located in Wildfowl Bay State Game Area of Saginaw Bay, Michigan showing location of common tern nesting colony in relation to vegetation and the water's edge.

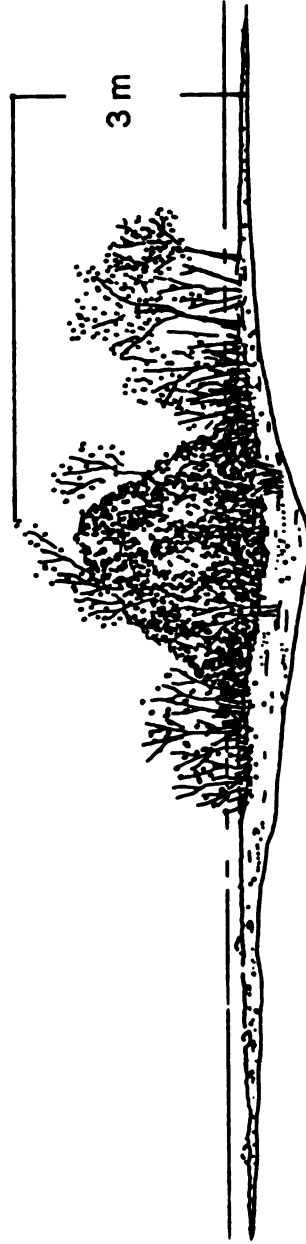


Fig. 3. Side view of Duck Island in Wildfowl Bay State Game Area in Saginaw Bay, Michigan showing height of island from water line and vegetation height.

use of the facility. Since its construction, the CDF has been a haven for migratory birds [i.e. black-crowned night herons, semipalmated plovers (*Charadrius semipalmatus*), spotted sandpipers (*Actitis macularia*), caspian terns (*Sterna caspia*), common terns, red-winged blackbirds (*Agelaius phoeniceus*), ring-billed gulls, herring gulls, great egrets (*Ardea albus*); Hodgkins 1993]. It also supports mammals [white-tailed deer (*Odocoileus virginianus*), muskrat (*Onychomys leucogaster*)] and herptiles [American toad (*Bufo americanus*), unidentified garter snake (*Thamnophis* spp.); Hodgkins 1993].

The outer retaining wall of the CDF rises approximately 3 - 5 m above water level with the interior dike wall, which completely surrounds the periphery of the CDF, approximately 0.5 m below the top of the retaining wall (Figure 4). Dropping steeply 2 - 2.5 m from the interior dike wall is the interior cell where dredge spoil material is deposited (Figure 4). Large boulders constitute the outer retaining wall while coarse packed gravel and rock chips make up the interior dike wall.

Common terns nest in the east-central section of the CDF (Figure 5). Most nests occur on the interior dike wall with few nests occurring in the interior cell and on the outer retaining wall. Common tern colony dimensions are approximately 75 m long by the width of the interior dike (approximately 2 m). During the breeding seasons of this study the colony was bordered on the north by herring and ring-billed gulls and on the south by herring gulls (Figure 5).

Common vegetation species in the CDF colony include bittersweet nightshade (*Solanum dulcamara*), spotted knapweed (*Centaurea maculosa*), field peppergrass (*Lepidium campestre*), field pennycress (*Thlaspi arvense*), rough cinquefoil (*Potentilla*

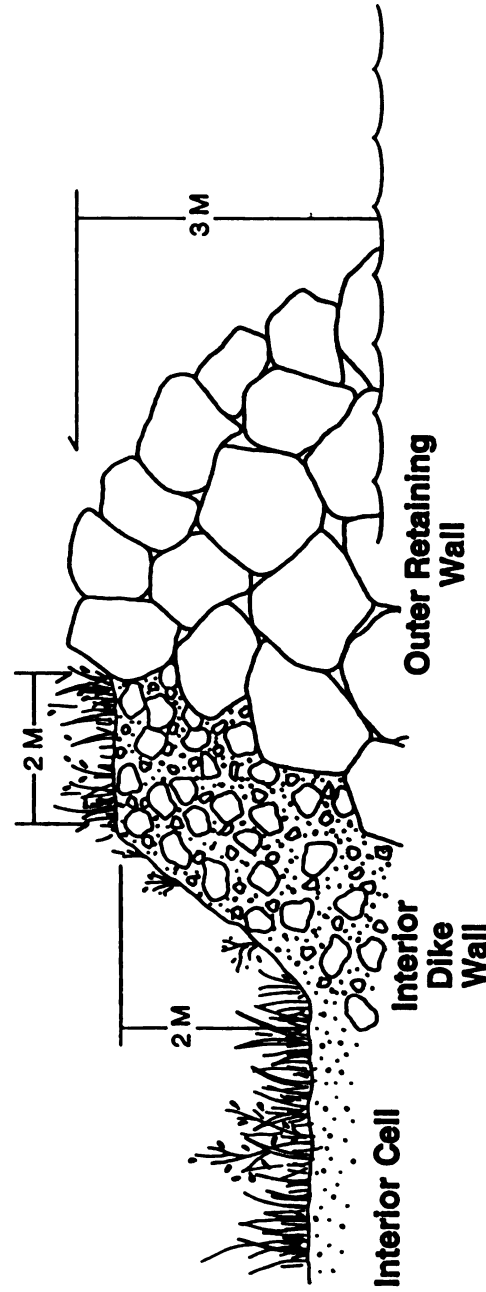


Fig. 4. Side view of Saginaw Bay Confined Disposal Facility (CDF), Michigan showing the design of the island including water level, outer retaining wall, interior dike wall, and interior cell.

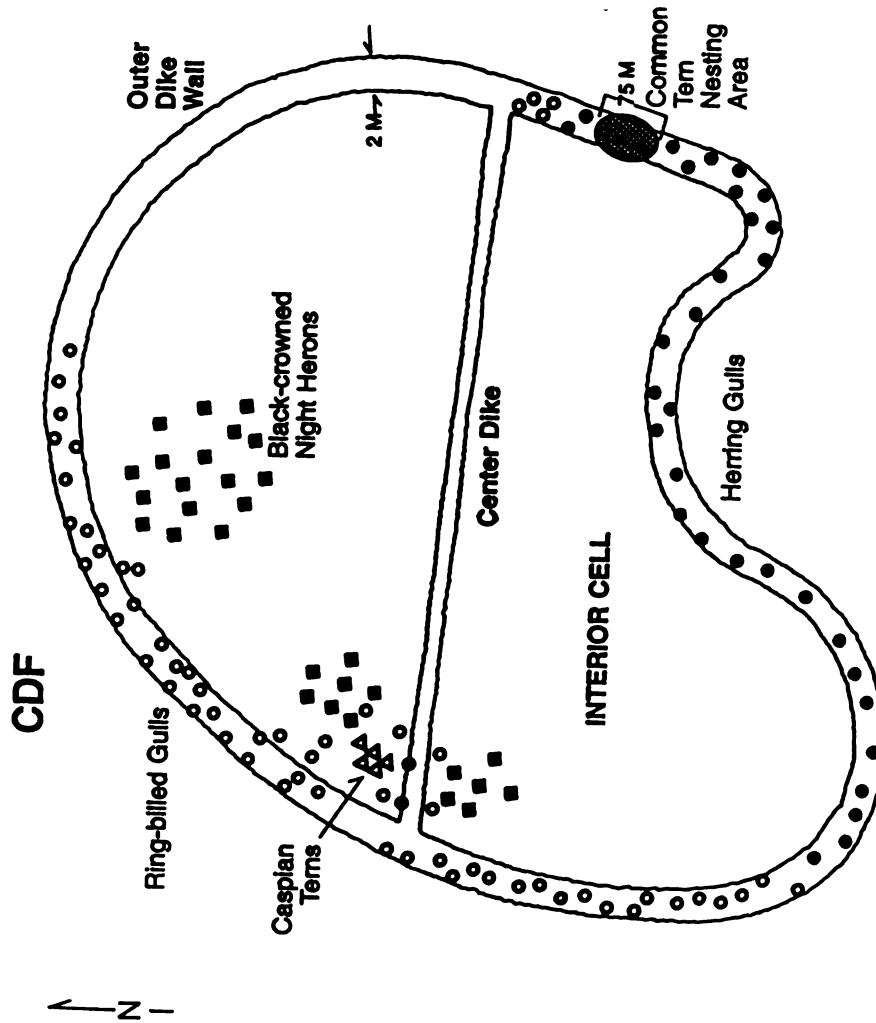


Fig. 5. Aerial view of Saginaw Bay Confined Disposal Facility (CDF), Michigan showing location of common tern colony and other nesters including ring-billed and herring gulls, black-crowned night herons, and caspian terns.

norvegica), and white sweet clover (*Melilotus alba*).

Caspian terns nest in the interior cell on the west-central section of the CDF while black-crowned night herons, great egrets, and great blue herons (*Ardea herodias*) are common nesters in trees on the northwest side of the CDF (Figure 5). Trees in this area are remnants from the original Channel and Shelter Islands. The closest trees supporting these nesters occur no closer than 100 - 150 m from the common tern colony.

CHAPTER I
POPULATION ASSESSMENT AND REPRODUCTIVE STATUS OF
THE COMMON TERN IN SAGINAW BAY

INTRODUCTION

Declining numbers of common terns in the Great Lakes have caused considerable concern over the future of the species. So great is this concern that the USFWS recently ordered a status assessment of common terns for the entire Great Lakes population for possible listing as Federally endangered (S. Lewis, pers. commun.). Regional declines in nesting pairs have been noted in the Canadian region of the southern Great Lakes (Blokpoel et al. 1978) and in northern Minnesota (Penning and Cuthbert 1993). In Michigan, estimates for common terns have declined from approximately 6,000 breeding pairs in the early 1960's (Ludwig 1962) to approximately 1,400 breeding pairs in the 1980's (Scharf and Shugart 1991). More alarming, however, was the noticeable decline in the number of breeding colonies from 31 to 23 in the Great Lakes region during that time period. Those areas that experienced a particular reduction in the number of breeding colonies included Duluth-Superior of Wisconsin and Minnesota, Green Bay of Wisconsin, and Thunder Bay and Saginaw Bay of Michigan (Scharf and Shugart 1991).

The threats that have caused this continuing decline in common terns both in

Michigan and in the Great Lakes region are well documented and include such things as loss of habitat due to vegetation encroachment (Palmer 1941, Courtney and Blokpoel 1983, Shields and Townsend 1985, McKearnan and Cuthbert 1989) and rising water levels (Morris and Hunter 1976, Scharf and Shugart 1985, Scharf 1991), competition for nesting space with ring-billed gulls (Courtney and Blokpoel 1983, Ludwig 1991, Shugart and Scharf 1983), predation (Austin 1932, Collins 1970, Courtney and Blokpoel 1983, Farraway et al. 1986, Hatch 1970, LeBarr 1995, Morris and Wiggins 1986, Penning and Cuthbert 1993, Shields and Townsend 1985, Stricker 1995), and contaminants (Gilbertson and Reynolds 1972, Morris et al. 1976, Weseloh et al. 1989). With this continued decline in common tern numbers many authors have attempted to determine the minimum population parameter values necessary to maintain stable populations of common terns under the given conditions. For example, Austin (1942) and Austin and Austin (1956) used a life table approach to estimate that to maintain a stable common tern population in Massachusetts adult annual survival must be between 71 - 75%.

Additionally, they predicted that at least 20% of the chicks fledged in a year must return to breed at age 4 (common terns do not reach breeding maturity until 3 - 4 years of age) if the population is to maintain itself. Nisbet (1978) pointed out errors in the above calculations and re-calculated required annual survival for adult common terns to be 87% with 10% of the fledged chicks surviving to enter the breeding population to maintain a stable population. However, DiConstanzo (1980) indicated that the above information should be interpreted with care as the estimates were based on populations that were declining and may not be representative of a stable population. DiConstanzo (1980),

therefore, modeled a stable population for common terns in New York and suggested that annual adult survival needed to be 92% with 14% of the fledglings returning to breed at age 4 to maintain a stable population. Penning (1993) developed a deterministic model to explore the population dynamics of common terns in Minnesota. He found that to maintain a stable population of common terns in Minnesota they must have an age-specific birth rate of 1.10, adult survival of 92%, sub-adult survival of 15%, and 12.5% of sub-adults must breed. No estimates of common tern survival or population longevity have been generated for Michigan colonies.

Before estimates of survival or predictions of population longevity can be generated, one must first understand current threats to a colony and how these threats may potentially impact survival. The purpose, therefore, of this research was to determine the reproductive success of two common tern colonies in Saginaw Bay of eastern Michigan and to identify threats to their continued survival. From this, population projections can be generated to predict the survivorship of these colonies under existing threats. Duck Island and the Saginaw Bay CDF (Figure 1) were chosen as sites for this research because of interest from the USFWS in regards to an ongoing Natural Resource Damage Assessment of Saginaw Bay. Additionally, during much of the 1980's, coinciding with high water levels, the Saginaw Bay CDF supported approximately one quarter of Michigan's nesting population of common terns (Evers 1994), making it a potential stronghold for Michigan's breeding population.

OBJECTIVES

Specific objectives of this part of the study were to:

- 1) determine the reproductive success of common terns in Saginaw Bay;
- 2) determine the frequency and impacts of mammalian and avian predators on common tern reproductive success;
- 3) predict the long term success of common terns using population projection models; and
- 4) make recommendations for managing common terns for increased reproductive success.

METHODS

General Observations

Common tern colonies were observed from May - August 1995 - 1997 on the CDF and Duck Island (Figure 1). Observations of sites were conducted to identify potential predators to the colonies. Colonies were monitored approximately every other day to minimize disturbance to the sites. Sites were not visited in inclement weather. Due to the small size of Duck Island, observations were made from a boat anchored approximately 50 m from the island. The CDF colony was observed from the center dike >100 m from the colony in 1995. In 1996 and 1997, observations were made from blinds located 10 m from each end of the colony. Observations were made with either a spotting scope or binoculars.

Researchers randomly selected a group of terns or a nest site for observations. An attempt was made to observe selected sites for a minimum of 2 h. Behavior (e.g., aggression) among and between terns and other species was recorded. Disturbances (e.g., presence of potential predator) and disturbance length were also recorded when possible. No observations were made during the evening hours for any year. In 1995, observations were made randomly from sunrise to sunset. Researchers were attempting to obtain a better understanding of common tern behavior, thus times of visitation varied to provide

the greatest spectrum of different behaviors. Observations in 1996 and 1997 were limited to 2 time periods (representing peak bird activity): 1) sunrise to 4 h after sunrise, and 2) 4 h prior to sunset to sunset.

Predation

Two and four infra-red cameras connected to time-lapse VHS recorders (Figure 6) were placed at selected nests on the CDF in 1996 and 1997, respectively, to record nocturnal predation attempts and other activities. Cameras and recorders were powered with a 12 volt deep cycle marine battery. Batteries operated each system for 2 days before recharging was required. Cameras were placed at nests when at least one egg or young was present in the nest cup. Recorders operated for 12 h from 2000 hr to 0800 hr. Every attempt was made to operate cameras on consecutive evenings until a nest successfully fledged or was abandoned or destroyed. Because of the high incidence of wave inundation at Duck Island, no cameras were placed at this site.

Two infra-red Trail Master trail monitors connected to Olympus 35 mm cameras were placed at both ends of the CDF colony in 1996 and 1997 to record movement of terrestrial predators and other animals into the colony. Cameras and monitors were set to encompass the width of the colony (approximately 2 m). Any motion breaking the infra-red monitor beam signaled the camera to take a picture, thus recording potential predators on 35 mm slide film. Cameras ran for 24 h. Every attempt was made to operate cameras on consecutive days. Because of the high incidence of wave inundation at Duck Island, no cameras were placed at this site.

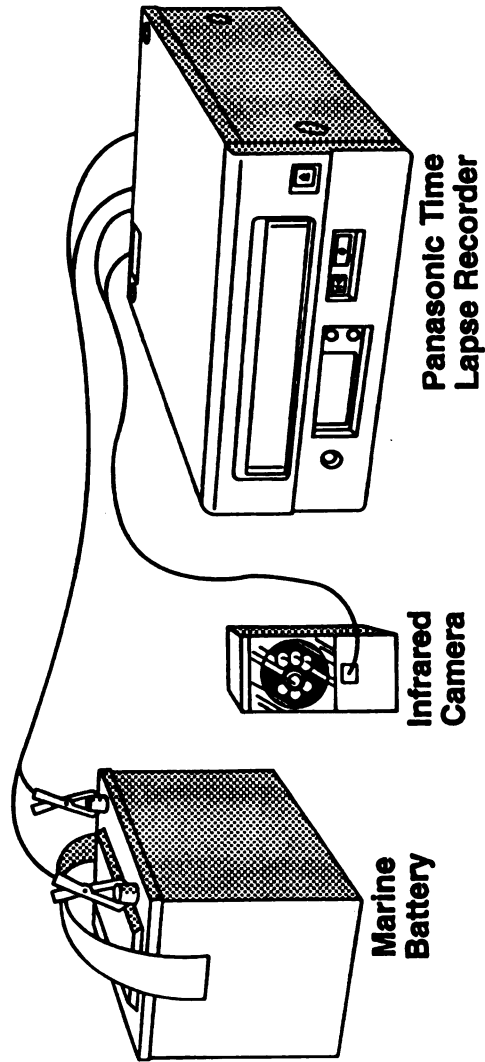


Fig. 6. Diagrammatic representation of infra-red camera system connected to time lapse recorders used on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan to record predation activities within the CDF common term colony summer 1996 - 1997.

Site Characteristics

Vegetation variables were measured at a minimum of 50 nests per year per site to determine if survivorship of eggs or chicks was related to habitat attributes.

Measurements were made as soon as a completed clutch (no additional eggs laid > 5 days after last egg laid) of eggs was present. Vegetation variables were measured in 1996 and 1997 using a modified 50 x 50 cm Daubenmire frame (Daubenmire 1959) centered on the nest and included: percent total, live, dead, grass, forb, and woody canopy; percent bare ground; and percent litter cover. Additional measurements included distance to the closest adjacent tern nest (cm) and distance to the water line (m).

Comparison of vegetation characteristics between 1996 and 1997 for all nests (successful and unsuccessful hatching combined) were made using a Mann-Whitney U test ($\alpha = 0.0125$; adjusted with Bonferroni, Snedecor and Cochran (1980)). Additionally, a Mann-Whitney U test ($\alpha = 0.0125$; adjusted with Bonferroni) was used to compare vegetation characteristics between successful (hatched) and unsuccessful (did not hatch) nests within a year and between years. Nests were considered successful if at least one egg hatched from the nest. Similar comparisons (Mann Whitney U test, $\alpha = 0.0125$, adjusted with Bonferroni) were made for those nests that successfully or unsuccessfully fledged young in 1997. Nests were considered successful if at least one young fledged from the nest.

Assessing Reproductive Success and Determining Survival Estimates

To determine reproductive success and collect data needed for population models, all nests were checked every 2 - 4 days. Nesting variables recorded at each nest included date of egg laying, number of eggs present each day, date of completed clutch, number of eggs lost and reason(s) for loss, hatching date, number of chicks hatched, number of chicks lost and reason(s) for loss, fledging date, and number of chicks fledged. Each nest was given a number using a permanent marker on a nearby rock to allow nests to be followed until hatching, fledging, or until the nest was destroyed or abandoned. An attempt was made to follow all nests to fledging. To facilitate following chicks to fledging, chicks were hand captured and banded using a USFWS #2 steel band and two stripe and one solid celluloid color bands when applicable (leg length is long enough to accommodate four bands). At a minimum chicks received a USFWS steel band and one black/white split band. No color bands were used in 1995 and chicks received an aluminum rather than steel USFWS #2 band. Chicks were banded only after they were completely dry. In 1996 and 1997, chicks were aged according to criteria presented by Nisbet and Drury (1972). Appropriate banding permits were obtained and capturing and banding procedures were approved by Michigan State University's All-University Committee on Animal Use and Care (AUF # 07/95-099-00).

In 1997 three enclosures were erected within the CDF colony to assist in following chicks to fledging. Enclosures were erected not to exclude predators but to enclose chicks which assisted in following chicks to fledging. Large boulders on the CDF served as excellent hiding cover for chicks, making them difficult to follow to

fledging and making survival estimates unreliable, thus enclosures prevented chicks from hiding under the large boulders. Enclosures were constructed of 1.3 cm X 1.5 cm mesh plastic cintoflex E fencing and were evenly distributed throughout the colony.

Dimensions of each enclosure were 1.5 m wide X 10 m long X 1 m high. Enclosures were anchored at the corners and at various locations along the length using 1.5 cm X 1.5 m pieces of conduit. Fencing was attached to conduit using twist-ties. Approximately 20 cm of fencing was rolled to the inside of each enclosure along the bottom edge and covered with rocks and gravel. This prohibited chicks from being able to escape under the enclosure. All enclosures were open on the top to permit adults to enter and leave the area freely.

Daily and period survival estimates for eggs and chicks were calculated using the Mayfield method (Mayfield 1961) to assist with population projections. Survival estimates were made for two time periods: 1) from initiation of incubation to hatching and 2) from hatching to fledging. Nests were used as the experimental unit from initiation of incubation to hatching and individual chicks were used as the experimental unit from hatching to fledging. Nests were considered active if at least one egg or chick was present in the nest cup. Abandoned nests were incorporated into the estimate using a maximum of 12 exposure days for these nests. Period survival rates for eggs and chicks were calculated using 24 days (L; Mayfield 1961) as the mean number of incubation days and 28 days (L) as the mean number of days from hatching to fledging. Chicks were considered fledged if they were ≥ 19 days old at last capture. Any chick < 19 days old at last capture, not found dead in subsequent checks, was considered censored.

Population Projections

Populations projections were developed to predict the long-term survival of common terns in Saginaw Bay. Assumptions of the projections were a 1:1 sex ratio and that only females were used in the projections. Only values obtained from the CDF were used in the population projections. Only birds ≥ 4 years of age contributed to age 0 individuals in the projection as birds younger than this have not reached breeding age yet. Although common terns reach breeding age by 3 years of age, research indicates that 3 year-old breeders are rarely successful in nesting attempts and contribute few if any young to the population (Austin and Austin 1956, DiConstanzo 1980, Nisbet 1978). Additionally, no birds were projected to live past 10 years of age. Although common terns have been reported living up to 15 - 20 years, Austin and Austin (1956) suggest that birds > 10 years of age comprise only a small portion of the total breeding population.

Year 0 values for projections were calculated as follows and were used as starting values for all projections generated. Age 0 numbers were generated by calculating the number of young fledged from the three enclosures in 1997 and were extrapolated to the entire colony to determine the total number of young that fledged that year (Table 1). Enclosure data most accurately reflected the actual survival of chicks on the CDF. Under the assumption of a 1:1 sex ratio, this value was divided by 2 so to reflect use of females only in the projection. Although chicks were followed for all three years in this study only estimates from 1997 were included because estimates for other years had such high rates of censoring that survival estimates generated from those numbers would be unreliable. Values in the literature (DiConstanzo 1980, Penning 1993) indicate that a

Table 1. Population projection calculations used to predict the long-term survival of common terns on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan.

Age Class	Year 0	Year 1	Year 2
0	$\bar{x}$ Number of Female Chicks in 1997	n_{10}^a	n_{20}^b
1	$n_{00} * 0.523$	$n_{11} = n_{00} * 0.523$	$n_{21} = n_{10} * 0.523$
2	$n_{01} * 0.523$	$n_{12} = n_{01} * 0.523$	$n_{22} = n_{11} * 0.523$
3	$n_{02} * 0.523$	$n_{13} = n_{02} * 0.523$	$n_{23} = n_{12} * 0.523$
4	x^c	$n_{03} * 0.92$	$n_{13} * 0.92$
5	$x * 0.92^1$	$n_{04} * 0.92$	$n_{14} * 0.92$
6	$x * 0.92^2$	$n_{05} * 0.92$	$n_{15} * 0.92$
7	$x * 0.92^3$	$n_{06} * 0.92$	$n_{16} * 0.92$
8	$x * 0.92^4$	$n_{07} * 0.92$	$n_{17} * 0.92$
9	$x * 0.92^5$	$n_{08} * 0.92$	$n_{18} * 0.92$
10	$x * 0.92^6$	$n_{110} = n_{09} * 0.92$	$n_{210} = n_{19} * 0.92$
N	$\sum \text{Age 0 to Age 10}$	$\sum \text{Age 0 to Age 10}$	$\sum \text{Age 0 to Age 10}$
λ	N_1 / N_0	N_2 / N_1	

$$a \sum_{x=4}^{10} n_{0x} * S_p \text{Eggs} * S_p \text{Chicks} * \bar{x} \text{ Clutch Size}$$

$$b \sum_{x=4}^{10} n_{1x} * S_p \text{Eggs} * S_p \text{Chicks} * \bar{x} \text{ Clutch Size}$$

c where $x = (\bar{x} \text{ number of breeding females from 1995 - 1997}) / (1 + 0.92^1 + 0.92^2 + 0.92^3 + 0.92^4 + 0.92^5 + 0.92^6)$

minimum of 14.3% of nonbreeders must return to breed to maintain a stable population and because no values are available for nonbreeder survival in the 1 - 3 year old age classes, this was the most representative value of nonbreeder survival. Therefore, age 1 values were generated by multiplying the age 0 values by the cube root of 0.143, or 0.523 (Table 1). Age 2 values were generated by multiplying age 1 values by 0.523 while age 3 values were generated by multiplying age 2 values by 0.523 (Table 1). Thus, for nonbreeders (from age 1 - 3), a 14.3% survivorship was modeled (Table 1). Age 4 - 10 year old values were generated from the mean number of greatest active nests from 1995 - 1997 which represented the mean number of females present in the colony. To determine the number of individuals in each of these age classes, the following formula was used:

$$x (1 + 0.92^1 + 0.92^2 + 0.92^3 + 0.92^4 + 0.92^5 + 0.92^6) = \text{mean number of greatest active nests};$$

solving for x, where x was the number of individuals in age class 4. The number of individuals in age classes 5 - 10 was found by multiplying x by powers of 0.92 since the most accurate estimate of adult survival is 92% (DiConstanzo 1980 and Penning 1993; Table 1).

For all other years in the population projection, age 0 values were calculated by summing the number of individuals in age classes 4 - 10 from the previous year and multiplying that value by the period survival rate for eggs, the period survival rate for chicks, and mean clutch size. This yielded the number of young fledged for the entire

colony (Table 1). Multiplying the period survival rate of eggs, period survival rate of chicks, and the mean clutch sizes yields the age-specific birth rate or m_x . The 1 - 3 year old age classes were obtained by multiplying the number of individuals in the 0 - 2 age classes from the previous year by 0.523 (Table 1) representing the age-specific survival rate, or p_x , for all birds in the 1 - 3 year old age classes. Values for age 4 - 10 years old were taken by multiplying the values for the 3 - 9 year olds from the previous year by 0.92 (Table 1) representing the age-specific survival rate, or p_x , for all birds in the 4 - 10 year-old age classes.

Population projections were generated using all possible combinations of egg survival, chick survival, and mean clutch size to predict the population size of common terns on the CDF over time. Projections were generated for a minimum of 11 years to allow for one complete generation cycle. To determine if the population was increasing, decreasing, or staying constant, the finite rate of increase, or λ , was calculated by dividing the total population size at time $t + 1$ (e.g., N_1) by the total population size at time t (e.g., N_0 ; Table 1). A population was considered increasing if $\lambda > 1$, decreasing if $\lambda < 1$, and constant if $\lambda = 1$.

RESULTS

General Observations

Nests were observed in 1997 from 28 May - 1 August on the CDF (Figure 7). No nests were observed on Duck Island as the island was completely submerged for the research period. Nests were observed in 1996 from 22 May - 3 August on the CDF (Figure 8) and 28 May - 11 July on Duck Island. Due to weather and rising water levels in the Saginaw Bay, Duck Island was heavily inundated with waves and standing water throughout the observation period in 1996. Common terns deserted Duck Island on 11 July. Researchers visited the site occasionally after that time, however, no birds were observed using Duck Island after 11 July. Observations at the CDF ended in 1996 and 1997 when nests were no longer present in the colony and researchers were unable to hand capture chicks. Observations in 1995 were made from 25 May - 15 July on the CDF and 24 May - 25 June on Duck Island. No observations were made after this time at either site as encroaching vegetation limited visibility of nest sites. This problem was addressed in 1996 with the use of observation blinds at the CDF. Nest checks on the CDF continued until 7 August 1995 (Figure 9).

Common terns began nesting in 1997 on the CDF on 28 May (Figure 7).

Common terns began nesting on the CDF (Figure 8) and Duck Island in 1996 on 22 May

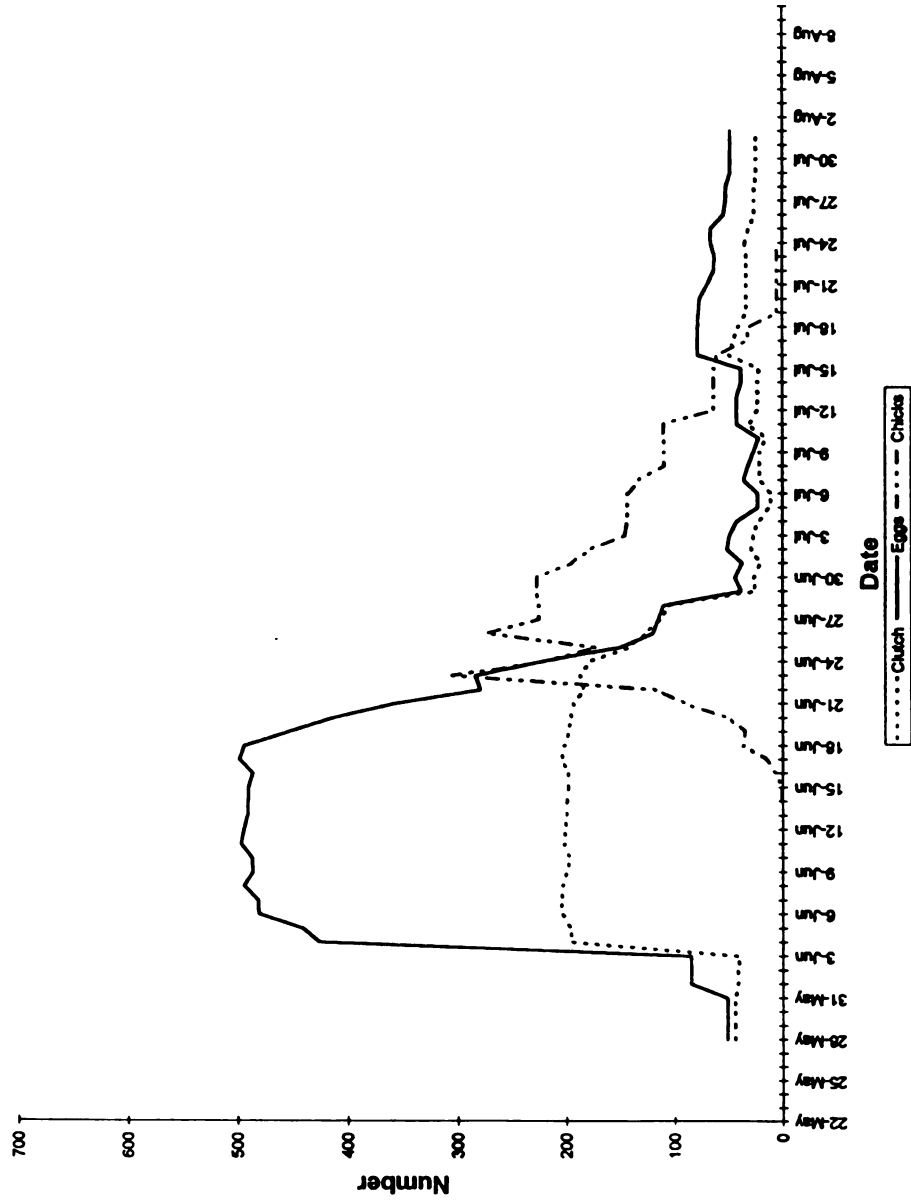


Fig. 7. Number of common tern clutches, eggs, and chicks on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan summer 1997.

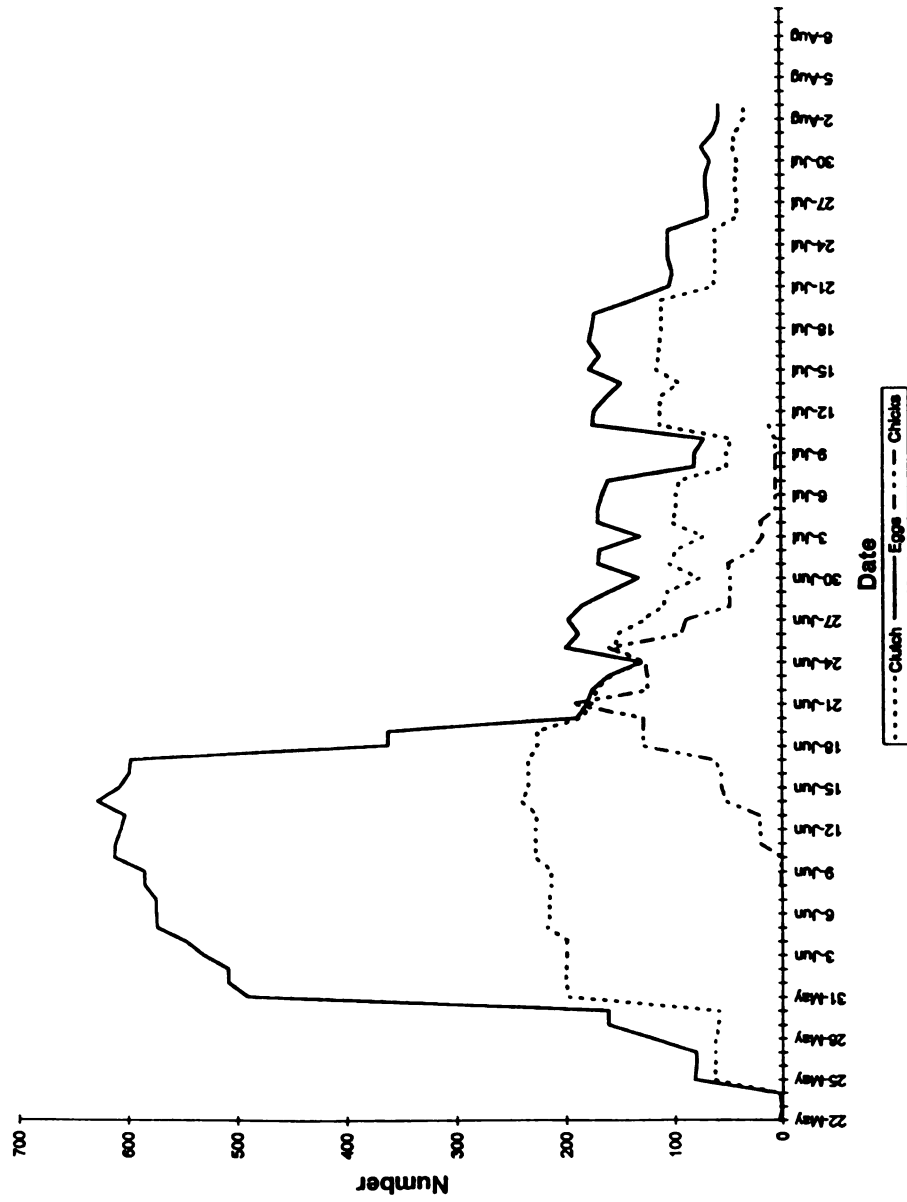


Fig. 8. Number of common tern clutches, eggs, and chicks on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan summer 1996.

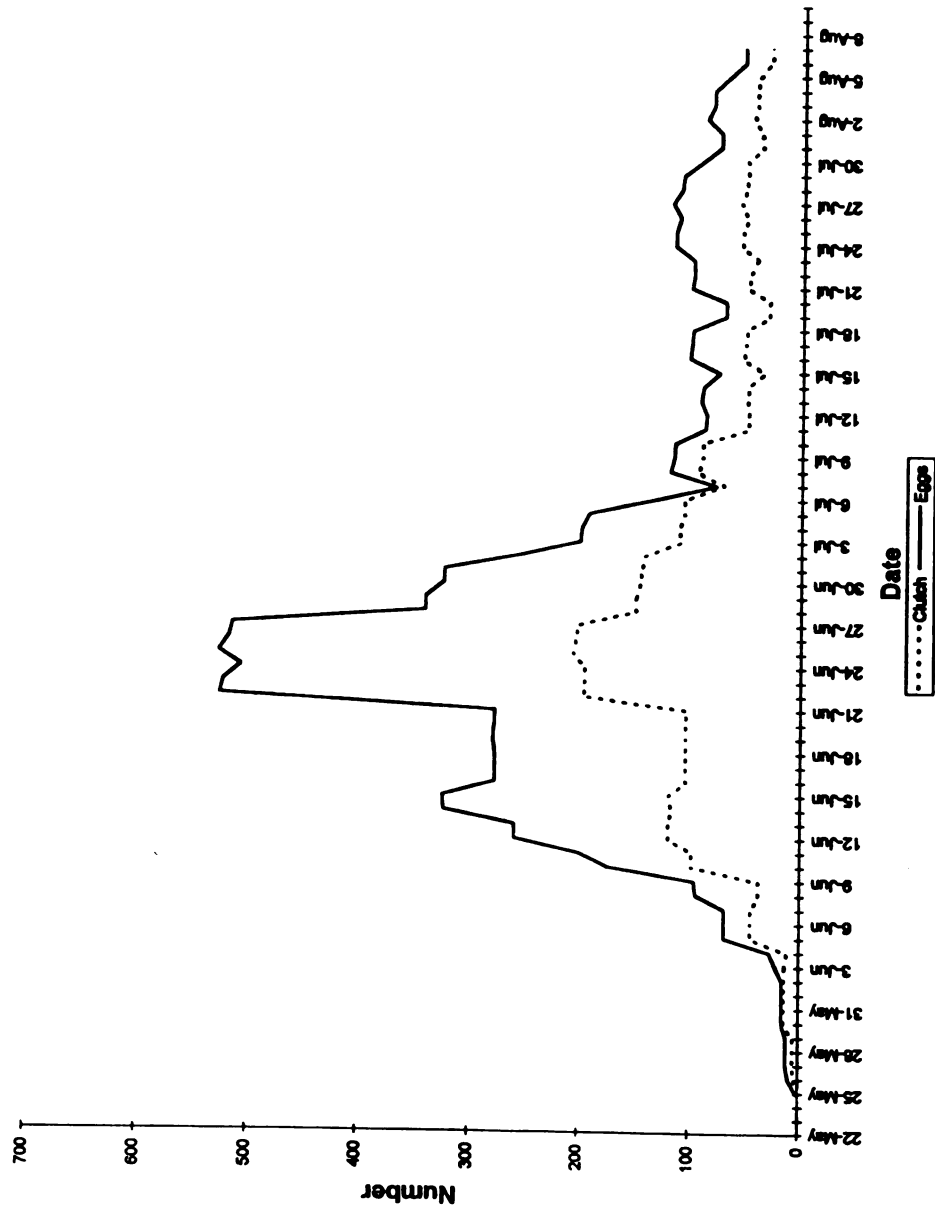


Fig. 9. Number of common tern clutches and eggs on the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan summer 1995.

and 28 May, respectively, and in 1995 on 25 May (Figure 9) and 17 May, respectively. Chicks were first observed on the CDF in 1997 on 14 June (Figure 7). Similarly, chicks were first observed on the sites in 1996 on 8 June (CDF; Figure 8) and 27 June (Duck Island) and in 1995 on 30 June (CDF) and 22 June (Duck Island). The greatest number of active nests on a given day indicating the number of breeding pairs at a colony, varied from 204 nests in 1997 to 239 nests in 1996 on the CDF and zero nests in 1997 to 136 nests in 1995 on Duck Island (Table 2). In 1996 and 1997 the low number of nests at Duck Island was due to the high incidence of wave inundation and complete submersion of the island by rising water levels. Mean clutch size of common terns on the CDF varied from 2.04 eggs per pair in 1997 (enclosure 1) to 2.61 eggs per pair in 1995 (Table 3). Of those nests that successfully hatched chicks in 1997, the mean number of young fledged per pair per enclosure ranged from 0.80 to 1.25 (Table 4). Only values for enclosures used in 1997 were used to determine the number of young fledged per pair due to the high rate of censoring in other years and outside of the enclosures in 1997.

Using data collected from enclosures in 1997, of those nests that supported 3 egg clutches, almost 85% successfully hatched at least one young with 48.1% of 3 egg clutches hatching 2 eggs (Table 5). Of 3 egg clutches that successfully hatched all 3 eggs, 75% successfully fledged at least 2 young while those that hatched 2 eggs successfully fledged at least 1 young approximately 66% of the time (Table 5). Of 3 egg clutches that hatched only 1 young, 83% successfully fledged one young (Table 5). Eighty percent of 2 egg clutches successfully hatched at least one young with 50% of these clutches hatching both eggs (Table 5). Of 2 egg clutches that successfully hatched

Table 2. Greatest number of active common tern nests on a given day, suggesting the number of breeding pairs, on Duck Island and the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1995 - 1997.

Year	CDF	Duck Island
1995	206	136
1996	239	31
1997	204	0

Table 3. Mean clutch size (number of eggs per nest) of common tern nests on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1995 - 1997.

Year	$\bar{x}$ Clutch Size
1995	2.61
1996	2.22
1997 enclosure 1 (n = 22)	2.04
1997 enclosure 2 (n = 27)	2.09
1997 enclosure 3 (n = 27)	2.19
1997 enclosures combined	2.11
1997 outside enclosure	2.24
1997 entire colony	2.20
$\bar{x}$ across 1995 - 1997	2.34

Table 4. Number of common tern young fledged per pair (out of those that successfully hatched) on the Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan summer 1997. Only values obtained from enclosures in 1997 are reported due to the high rate of censoring in 1995 and 1996 and outside of the enclosures in 1997.

	# of Pairs that Successfully Hatched at Least One Young	# Fledged	$\bar{x}$ # Fledged per Pair
Enclosure 1	15	12	0.80
Enclosure 2	16	20	1.25
Enclosure 3	16	15	0.94
All Enclosures	47	47	1.00

Table 5. Number of common tern young surviving to hatching and/or fledging per clutch (%) on the Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summer 1997. Only values from enclosures used in 1997 are presented.

Clutch Size	# from clutch surviving to hatching	Hatch	# from hatching surviving to fledging	Fledge
3 (n = 27)	3	4 (14.8)	3	1 (25.0)
			2	2 (50.0)
			1	0 (0.0)
			0	1 (25.0)
	2	13 (48.1)*	2	3 (25.0)
			1	5 (41.7)
			0	4 (33.3)
	1	6 (22.2)	1	5 (83.3)
			0	1 (16.7)
	0	4 (14.8)		
2 (n = 20)	2	10 (50.0)	2	2 (20.0)
			1	5 (50.0)
			0	3 (30.0)
	1	6 (30.0)	1	2 (33.3)
			0	4 (66.7)
	0	4 (20.0)		
1 (n = 19)	1	2 (10.5)	1	1 (50.0)
			0	1 (50.0)
	0	17 (89.5)		
Total		66		65

* one individual censored from hatching to fledging.

both eggs, 70% successfully fledged at least one young while those nests that hatched only one young successfully fledged one young only 33% of the time (Table 5). Of one egg clutches, only approximately 11% successfully hatched one young with 50% of those nests successfully fledging that young (Table 5).

Four and 36 chicks were banded in 1996 and 1995, respectively, on Duck Island. No chicks were banded on Duck Island in 1997. Three-hundred-fifty-nine, 264, and 166 chicks were banded on the CDF in 1997, 1996 and 1995, respectively. Of the chicks banded in 1997 and 1996, 98.4% and 72.3%, respectively, were banded when they were 0 - 5 days old due to lack of or slow (in relation to the observer) movement of the chicks which aided in capture (Table 6). No birds >21 days old were banded in 1996 or 1997.

One chick with a severely deformed bill was banded by observers at the CDF in early July 1996. The bird was not collected for analysis as procedures for collections had not been previously discussed with the USFWS. In 1997 a 22-day old chick was recaptured (originally banded at approximately 1 day old) and euthanized due to abnormal behavior. The bird was able to stand upright but as it attempted to step forward its' neck would twist to the right side of the body and down so that the top of the head was on the ground with the bill of the bird pointing forward. Additionally, the bird would pull its' right wing from the side of the body over its' head. The bird was immediately sent to the National Wildlife Health Laboratory in Madison, Wisconsin. Laboratory results indicated the bird was infected with *Pasteurella multocida*, or avian cholera.

Forty-nine dead chicks were recovered on the CDF in 1996 and 65 were recovered in 1997. Of these, 38.8% and 18.5% were 0 - 1 day old in 1996 and 1997, respectively

Table 6. Number of common tern chicks banded in each age class (aged according to criteria presented by Nisbet and Drury (1972)) on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1996 - 1997.

Age (days)	1996	1997
0 - 1	115	281
2 - 5	76	43
6 - 9	19	15
8 - 12	36	13
12 - 15	9	4
15 - 18	8	2
17 - 23	0	1
21 +	0	0
Unknown	1	0
Total	264	359

(Table 7). The greatest number of dead chicks (26.2%; Table 7) in 1997 were in the 2A plumage class (Nisbet and Drury 1972), or 2 - 5 days old. Chicks 15 - 18 days old were the next age class most often recovered as dead (22.4%) in 1996 (Table 7). Of those chicks banded in the 0 - 1 day old age group on the CDF, 62 and 91 in 1996 and 1997, respectively, were never recaptured again (Table 7). Over 56% and 40% in 1996 and 1997, respectively, of the chicks banded in the age 0 - 5 day old were never recaptured after 5 days old.

Of the 49 dead chicks recovered in 1996 only 5 had visible signs of injury. One had signs of pecking on the head while the other 4 had openings on the body (i.e., under the right wing, belly, upper right leg) where the skin and feathers were removed exposing muscle tissue or organs. In most instances chicks appeared healthy and had no visible signs of injury. No 2 recovered dead chicks could be assigned to the same nest or parental unit in 1996. Of the 65 dead chicks recovered in 1997, 12 had visible signs of injury ranging from broken necks to pokes in the head to abrasions along the back. Only 6 nests lost two chicks, with 3 nests losing both chicks on the same day.

Predation

Two and four infra-red cameras with time-lapse recorders were operational on the CDF beginning on 28 May 1996 and 3 June 1997. Cameras were removed from the site on 18 July 1996 due to improper functioning of the recording unit. Problems were later attributed to a lack of adequate voltage in the power unit. Cameras were operational until 25 July in 1997. While cameras were operational, no predation was recorded in either

Table 7. Number of dead common tern chicks recovered and last age when known alive in each age class (aged according to criteria presented by Nisbet and Drury (1972)) on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1996 - 1997.

Age (days)	1996		1997	
	Recovered	Last Age Known Alive	Recovered	Last Age Known Alive
0 - 1	19	62	12	91
2 - 5	4	68	17	55
6 - 9	2	33	11	46
8 - 12	2	44	13	26
12 - 15	4	10	7	22
15 - 18	11	7	1	14
17 - 23	4	5	1	40
21 +	3	0	3	65
Unknown	0	0	0	0
Total	49	229	65	359

year. It should be noted that when cameras were operational they produced high quality footage of nest sites. That is, the quality of the footage was sharp enough to detect slight movements of adults (i.e., eye blinking) as well as the presence of eggs and/or chicks. While the nest was the main focus of each frame, background activities (i.e., other birds moving in and out of the area) could also be seen.

Trail monitors were used beginning 10 July 1996 and 5 June 1997 at the CDF. Both cameras continued to function through the end of the field season. Because cameras were placed at both ends of the CDF colony, information collected only indicates potential predators throughout the colony. No predation attempts were recorded. Species recorded on 35 mm film include herring gull, common grackle (*Quiscalus quiscula*), common tern, European starling (*Sturnus vulgaris*), spotted sandpiper (*Actitis macularia*), and Brewer's blackbird (*Euphagus cyanocephalus*).

Although not recorded on film, observers noted the presence of garter snakes within the CDF colony in 1996 and 1997. In 1997 a garter snake was observed preying upon a 2 day-old common tern chick. Additionally, garter snakes were observed, almost weekly, with bulges in their bodies suggesting they had recently fed, possibly on an egg or chick.

While no mammalian predators were observed within the CDF colony in 1996 and 1997, scat was found within the colony, suggesting the presence of a fox and coyote or feral dog. Scat contained small bone fragments from an avian species suggesting predation by these individuals on common tern chicks. Additionally, in each of 1996 and 1997 evidence of caching of dead chicks was recorded on 2 separate instances, a behavior

commonly attributed to foxes. Observers witnessed 2 separate instances when dead chicks were found in piles of 5 - 10 chicks per pile in each of 1996 and 1997.

Other observations suggest that predation by black-crowned night herons also may have impacted the CDF colony. In 1995 and 1996 when black-crowned night herons were present in large numbers (L. Williams, pers. commun.), several nocturnal predation events at the colony were evidenced with the loss of up to a quarter of the nests within the colony in a given night. In 1997, however, when black-crowned night heron numbers were very low on the CDF, few nocturnal predation events were detected.

Site Characteristics

Vegetation measurements were made at the CDF in June 1996 and 1997. No measurements were made at the CDF in 1995. Additionally, no measurements were made at Duck Island in any year because perpetual flooding of the island did not permit sampling. In 1997, common terns nested significantly closer ($P = 0.003$) to a neighboring common tern nest than in 1996 (Table 8). Additionally, percent grass canopy cover and percent bare ground were significantly less ($P = 0.001$ and $P = 0.002$, respectively) at common tern nesting sites in 1996 than in 1997 while percent forb canopy was significantly greater ($P = 0.009$) in 1997 (Table 8). Although not significantly different, common terns nested closer to the water's edge in 1996 than in 1997 (Table 8). Additionally, although not significantly different, nests in 1997 had greater percent live canopy and less percent total canopy, percent dead canopy, and percent litter cover than in 1996 (Table 8).

Table 8. Mean (SD) vegetation characteristics at common tern nests of combined successful and unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summers 1996 and 1997.

Variable	1996 (n = 50)	1997 (n = 95)
Closest Nest (cm)*	76.8 (45.9)	56.3 (15.9)
Water's Edge (m)	12.8 (0.9)	13.1 (0.6)
% Total Canopy	62.6 (21.8)	61.4 (14.8)
% Live Canopy	59.1 (22.6)	60.5 (15.9)
% Dead Canopy	2.7 (6.1)	0.4 (2.0)
% Grass Canopy*	16.1 (19.7)	27.7 (21.9)
% Forb Canopy*	44.1 (24.1)	33.4 (17.4)
% Woody Canopy	0.0 (0.0)	0.0 (0.0)
% Bare Ground*	26.3 (20.3)	33.1 (14.3)
% Litter Cover	10.1 (14.8)	5.6 (7.4)

* Significantly different between years (Mann-Whitney U test adjusted with Bonferroni, $P < 0.0125$).

Comparison of vegetation variables and distance to closest nest and water's edge between nests that hatched and those that did not yielded no significant differences in 1997 (Table 9). Successful nests were further from the water's edge and had greater percentages of forb canopy cover and bare ground than unsuccessful nests (Table 9).

In 1996, those nests that successfully hatched young were significantly ($P = 0.009$) closer to the water's edge than those that did not hatch young (Table 10). Although not significantly different, successful nesters were further from a neighboring nest than unsuccessful nesters and had greater percentages of forb canopy cover and litter cover (Table 10).

Successful hatchers were significantly closer ($P = 0.006$) to neighboring nest in 1997 than 1996 (Table 11) while no significant differences were found between unsuccessful hatchers between 1996 and 1997 (Table 12). Although not significantly different, successful hatchers were further from the water's edge and had greater percentage of total canopy cover, live canopy cover, grass canopy cover, and bare ground in 1997 than 1996 (Table 11). Unsuccessful hatchers in 1997 were further, although not significantly, from the water's edge and had greater percentages of live canopy cover, grass canopy cover, and bare ground than unsuccessful hatchers in 1996 (Table 12).

No significant differences were found between those nests that successfully fledged young and those that did not successfully fledge young in 1997 (Table 13). However, those nests that did not successfully fledge young were closer to a neighbor and the water's edge and had greater percentage of total canopy cover, dead canopy cover, grass canopy cover, and bare ground (Table 13).

Table 9. Mean (SD) vegetation characteristics at common tern nests of successful and unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summer 1997.

Variable	Successful Hatch (n = 61)	Unsuccessful Hatch (n = 34)
Closest Nest (cm)	55.2 (14.0)	58.4 (18.7)
Water's Edge (m)	13.1 (0.6)	13.1 (0.7)
% Total Canopy	60.3 (14.6)	63.2 (13.6)
% Live Canopy	60.0 (15.7)	61.3 (16.7)
% Dead Canopy	0.3 (1.8)	0.6 (2.4)
% Grass Canopy	26.2 (20.2)	30.3 (24.9)
% Forb Canopy	33.8 (17.5)	32.6 (17.5)
% Woody Canopy	0.0 (0.0)	0.0 (0.0)
% Bare Ground	33.8 (14.5)	31.9 (14.1)
% Litter Cover	5.1 (8.0)	5.1 (6.1)

Table 10. Mean (SD) vegetation characteristics at common tern nests of successful and unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summer 1996.

Variable	Successful Hatch (n = 12)	Unsuccessful Hatch (n = 38)
Closest Nest (cm)	86.6 (66.2)	73.7 (37.4)
Water's Edge (m)*	12.1 (1.4)	13.1 (0.5)
% Total Canopy	57.1 (30.1)	64.3 (18.6)
% Live Canopy	55.0 (28.1)	60.4 (20.8)
% Dead Canopy	2.1 (7.2)	2.9 (5.8)
% Grass Canopy	10.8 (12.9)	17.8 (21.3)
% Forb Canopy	44.2 (24.8)	44.1 (24.2)
% Woody Canopy	0.0 (0.0)	0.0 (0.0)
% Bare Ground	23.3 (26.8)	27.2 (18.1)
% Litter Cover	12.1 (16.2)	9.5 (14.6)

* Significantly different between years (Mann-Whitney U test adjusted with Bonferroni, $P < 0.0125$).

Table 11. Mean (SD) vegetation characteristics at common tern nests of successful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summers of 1996 and 1997.

Variable	1996 (n = 12)	1997 (n = 61)
Closest Nest (cm)*	86.6 (66.1)	55.2 (14.0)
Water's Edge (m)	12.1 (1.4)	13.1 (0.6)
% Total Canopy	57.1 (30.1)	60.3 (14.6)
% Live Canopy	55.0 (28.1)	60.0 (15.7)
% Dead Canopy	2.1 (7.2)	0.3 (1.8)
% Grass Canopy	10.8 (12.9)	26.2 (20.2)
% Forb Canopy	44.2 (24.8)	33.8 (17.5)
% Woody Canopy	0.0 (0.0)	0.0 (0.0)
% Bare Ground	23.3 (26.8)	33.8 (14.5)
% Litter Cover	12.1 (16.2)	5.1 (8.0)

* Significantly different between years (Mann-Whitney U test adjusted with Bonferroni, $P < 0.0125$).

Table 12. Mean (SD) vegetation characteristics at common tern nests of unsuccessful hatching on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summers of 1996 and 1997.

Variable	1996 (n = 38)	1997 (n = 34)
Closest Nest (cm)	73.7 (37.4)	58.4 (18.7)
Water's Edge (m)	13.1 (0.5)	13.1 (0.7)
% Total Canopy	64.3 (18.6)	63.2 (13.6)
% Live Canopy	60.4 (20.8)	61.3 (16.7)
% Dead Canopy	2.9 (5.8)	0.6 (2.4)
% Grass Canopy	17.8 (21.3)	30.3 (24.9)
% Forb Canopy	44.1 (24.2)	32.6 (17.5)
% Woody Canopy	0.0 (0.0)	0.0 (0.0)
% Bare Ground	27.2 (18.1)	31.9 (14.1)
% Litter Cover	9.5 (14.6)	5.1 (6.1)

Table 13. Mean (SD) vegetation characteristics at common tern nests of successful and unsuccessful fledging (at least one young from a nest fledged) on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, in summer 1997.

Variable	Successful Fledge (n = 21)	Unsuccessful Fledge (n = 74)
Closest Nest (cm)	56.5 (14.9)	56.3 (16.2)
Water's Edge (m)	13.2 (0.7)	13.1 (0.6)
% Total Canopy	61.0 (15.5)	61.5 (14.8)
% Live Canopy	61.0 (15.5)	60.3 (16.2)
% Dead Canopy	0.0 (0.0)	0.5 (2.3)
% Grass Canopy	25.0 (21.6)	28.4 (22.1)
% Forb Canopy	36.0 (18.2)	32.7 (17.3)
% Woody Canopy	0.0 (0.0)	0.0 (0.0)
% Bare Ground	33.0 (14.9)	33.1 (14.3)
% Litter Cover	6.0 (6.8)	5.5 (7.6)

Assessing Reproductive Success and Determining Survival Estimates

Daily survival estimates for common tern eggs from initiation of incubation to hatching on the CDF varied from 99.5% in 1997 to 95.8% in 1996 (Table 14). Duck Island daily egg survival estimates varied from 0% in 1997 to 93.7% in 1995 (Table 15). Period survival rates ($L = 24$) from egg laying to hatching for the CDF varied from 35.7% to 88.8% in 1996 and 1997, respectively (Table 14). On Duck Island, period survival estimates ($L = 24$) for eggs varied from 0% in 1997 to 21.1% in 1995 (Table 15). It should be noted that censoring at Duck Island was 21.4% and 32.7% in 1996 and 1995, respectively. Therefore, this data set does not meet the assumption of allowable censoring ($< 10\%$; Mayfield 1961) and care should be taken in interpretation of the results at this site. Censoring of eggs from initiation of incubation to hatching was $< 10\%$ for all years on the CDF.

Due to complete submersion of Duck Island no young were produced from this site in 1997. Only 4 young were known to hatch from the Duck Island site in 1996. All birds were 2 days old at banding. When the site was checked 2 days later, it was completely covered in water and chicks were not old enough to fledge. Also, chicks likely did not make it to dry land as the closest land mass to Duck Island is > 400 m away. Thus, daily and period survival estimates for chicks on Duck Island in 1996 were 0%. Daily and period survival ($L = 28$) rates for chicks on the CDF in 1996 were 98.2% and 59.8% (Table 16), however, censoring of chicks at this site was $> 10\%$ and care should be taken when interpreting the results. Daily survival estimates for chicks from hatching to fledging for the 3 enclosures erected in 1997 varied from 98.3% to 99.8%

Table 14. Daily (S_D) and period (S_p) survival rates (variance; Mayfield 1961) of common tern eggs on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1995 - 1997.

Year	S_D	S_p
1995	0.9644 (<0.0001)	0.4189 (<0.0001)
1996	0.9580 (0.0007)	0.3571 (0.0004)
1997 enclosure 1	0.9798 (<0.0001)	0.6123 (0.0129)
1997 enclosure 2	0.9577 (0.0001)	0.3582 (0.0113)
1997 enclosure 3	0.9951 (<0.0001)	0.8887 (0.0055)
1997 enclosures combined	0.9798 (<0.0001)	0.6123 (0.0043)
1997 outside enclosure	0.9806 (<0.0001)	0.6249 (0.0011)
1997 entire colony	0.9804 (<0.0001)	0.6224 (0.0009)
$\bar{x}$ across 1995 -1997	0.9676 (<0.0001)	0.4661 (0.0023)

Table 15. Daily (S_D) and period (S_P) survival rates (variance; Mayfield 1961) of common tern eggs on Duck Island in Saginaw Bay of eastern Michigan, summers 1995 - 1997.

	1995	1996	1997
S_D	0.9373 (<0.0001)	0.9294 (0.0001)	0.0000
S_P	0.2114 (0.0006)	0.1725 (0.0015)	0.0000

Table 16. Daily (S_D) and period (S_P) survival rates (variance; Mayfield 1961) of common tern chicks on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan, summers 1996 - 1997. No estimates of chick survival are available for 1995.

	S_D	S_P
1996	0.982 (<0.001)	0.598 (0.003)
1997 enclosure 1	0.998 (<0.001)	0.932 (0.004)
1997 enclosure 2	0.983 (<0.001)	0.619 (0.006)
1997 enclosure 3	0.994 (<0.001)	0.840 (0.005)
1997 enclosures combined	0.991 (<0.001)	0.755 (0.002)
1997 outside enclosure	0.983 (<0.001)	0.615 (0.002)
1997 entire colony	0.986 (<0.001)	0.676 (0.001)
$\bar{x}$ across 1996 -1997	0.984 (<0.001)	0.637 (0.002)

with period survival ($L = 28$ days) estimates varying from 61.9% to 93.2% (Table 16). Daily and period survival ($L = 28$ days) rates for chicks outside of the enclosures on the CDF in 1997 were 98.3% and 61.5% respectively (Table 16). However, censoring of chicks outside of the enclosures was $>10\%$ and care should be taken in interpreting results. Overall (including chicks inside and outside of the enclosure) daily and period survival rates for chicks on the CDF in 1997 were 98.6% and 67.6%, respectively (Table 16).

Overall period survival ($L = 52$ days) rates from initiation of incubation to fledging ranged from 21.4% in 1996 to 74.7% in an enclosure in 1997 (Table 17). No estimates of overall survival from initiation of incubation to fledging are available for 1995.

Population Projections

Five-hundred-seventy-six population projections were generated using all possible combinations of egg survival, chick survival, and mean clutch size. Of those, only 47 combinations of egg survival, chick survival, and mean clutch size yielded $\lambda \geq 1$, indicating a stable or increasing population (Table 18). Based on the mean values calculated for egg survival (0.4461; Table 14), chick survival (0.637; Table 16), and mean clutch size (2.34; Table 3) for common terns at the CDF a population projection (Table 19) was generated yielding a $\lambda = 0.94$, consistently after 12 years, suggesting that the population is decreasing by 6% per year. Use of the mean values for egg survival, chick survival, and mean clutch size provides the most representative scenario of

Table 17. Overall period (S_p) survival rates (variances; Mayfield 1961) of common terns from initiation of incubation to fledging on the Saginaw Bay Confined Disposal Facility (CDF) in eastern Michigan, summer 1996 - 1997.

Year	S_p
1996	0.2135 (<0.001)
1997 enclosure 1	0.5707 (<0.001)
1997 enclosure 2	0.2217 (<0.001)
1997 enclosure 3	0.7465 (<0.001)
1997 enclosures combined	0.4623 (<0.001)
1997 outside enclosure	0.3843 (<0.001)
1997 entire colony	0.4207 (<0.001)
$\bar{x}$ across 1995 -1997	0.4016 (<0.001)

Table 18. Combinations of common tern egg survival (Mayfield estimate, Mayfield 1961), chick survival (Mayfield estimate), and mean clutch size on the Confined Disposal Facility (CDF) in Saginaw Bay of eastern Michigan used in population projections that yielded $\lambda \geq 1$, indicating a stable or increasing population.

Egg Survival	Chick Survival	$\bar{x}$ Clutch Size	λ
0.8887	0.598	2.61	1.007
0.8887	0.932	2.61	1.069
0.8887	0.619	2.61	1.011
0.8887	0.840	2.61	1.054
0.8887	0.755	2.61	1.039
0.8887	0.615	2.61	1.010
0.8887	0.676	2.61	1.023
0.8887	0.637	2.61	1.015
0.8887	0.932	2.22	1.046
0.8887	0.840	2.22	1.031
0.8887	0.755	2.22	1.061
0.8887	0.676	2.22	1.001
0.8887	0.932	2.04	1.034
0.8887	0.840	2.04	1.019
0.8887	0.755	2.04	1.005
0.8887	0.932	2.09	1.037
0.8887	0.840	2.09	1.023
0.8887	0.755	2.09	1.008
0.8887	0.932	2.19	1.044
0.8887	0.840	2.19	1.029
0.8887	0.755	2.19	1.014
0.8887	0.676	2.19	1.000

Table 18. Continued.

Egg Survival	Chick Survival	$\bar{x}$ Clutch Size	λ
0.8887	0.932	2.11	1.038
0.8887	0.840	2.11	1.024
0.8887	0.755	2.11	1.009
0.8887	0.932	2.24	1.047
0.8887	0.840	2.24	1.032
0.8887	0.755	2.24	1.017
0.8887	0.676	2.24	1.003
0.8887	0.932	2.20	1.044
0.8887	0.840	2.20	1.030
0.8887	0.932	2.20	1.015
0.8887	0.676	2.20	1.000
0.8887	0.932	2.34	1.053
0.8887	0.840	2.34	1.038
0.8887	0.755	2.34	1.023
0.8887	0.676	2.34	1.008
0.8887	0.637	2.34	1.001
0.6249	0.932	2.61	1.013
0.6249	0.619	2.61	1.005
0.6249	0.932	2.34	1.004
0.6224	0.932	2.61	1.018
0.6224	0.840	2.61	1.005
0.6224	0.932	2.34	1.004
0.6123	0.932	2.61	1.016
0.6123	0.840	2.61	1.002

Table 18. Continued.

Egg Survival	Chick Survival	$\bar{x}$ Clutch Size	λ
0.6123	0.932	2.34	1.002

Table 19. Population projection of common terns on the Confined Disposal Facility (CDF), in eastern Michigan. Projection represents the most representative case scenario using egg survival = 0.4461, chick survival = 0.637, and mean clutch size = 2.34. See Table 1 and associated text for description of calculations.

Age Class	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
0	108.75	150.06	132.86	117.02	102.46	89.06	80.51	71.07	60.94	59.89	57.69	54.89
1	56.88	56.88	78.48	69.48	61.20	53.59	45.58	42.11	37.17	31.87	31.32	30.17
2	29.74	29.75	29.75	41.05	36.34	32.01	28.03	23.36	22.02	19.44	16.67	16.38
3	15.56	15.55	15.56	15.56	21.47	19.01	16.74	14.66	12.74	11.52	10.17	8.72
4	39.08	14.31	14.31	14.31	14.31	19.75	17.49	15.40	13.48	11.72	10.60	9.35
5	35.95	35.95	13.17	13.16	13.17	13.17	18.17	16.09	14.17	12.41	10.78	9.75
6	33.08	33.08	33.08	12.11	12.11	12.11	12.11	16.72	14.80	13.04	11.41	9.92
7	30.43	30.43	30.43	30.43	11.14	11.14	11.15	11.15	15.38	13.62	11.99	10.50
8	28.00	28.00	28.00	28.00	28.00	10.25	10.25	10.25	10.25	14.15	12.53	11.03
9	25.76	25.76	25.76	25.76	25.76	25.76	9.43	9.43	9.43	9.43	13.02	11.52
10	23.69	23.70	23.70	23.70	23.70	23.70	23.70	8.68	8.68	8.68	8.68	11.98
N	426.91	443.46	425.08	390.58	349.66	309.54	274.15	239.91	219.07	205.75	194.86	184.22
λ	0.91	0.96	0.92	0.90	0.89	0.89	0.88	0.91	0.94	0.95	0.95	0.95

common tern survival across time on the CDF. Using the lowest and highest values for egg survival, chick survival, and mean clutch size, population projections were generated that yielded $\lambda = 0.88$ and $\lambda = 1.08$, respectively, consistently after 12 years. Using the lowest values of egg survival (0.3571; Table 14), chick survival (0.598; Table 16), and mean clutch size (2.04; Table 3), a population projection indicates that the common tern population is decreasing by 12% per year (Table 20). Under the best values for egg survival (0.8887; Table 14), chick survival (0.932; Table 16), and mean clutch size (2.61; Table 3) a population projection indicates that the CDF common tern colony is increasing by 8% per year (Table 21).

If conditions remained constant across years, under the most representative scenario, it would be only 40 years until the common tern colony on the CDF had so few individuals that the colony would be driven to extinction. The end point for the colony to be considered active was determined when < 1 individual was present in each of age classes 4 - 10. Under the worst case scenario, the colony would be driven to extinction in 25 years.

Making the assumption that the mean values for egg survival, chick survival, and mean clutch size are the most representative values for common terns on the CDF from 1995 - 1997 a $\lambda = 0.94$ was obtained (Table 19). To obtain a $\lambda = 1.0$, by manipulating only egg survival and maintaining the mean values for chick survival and mean clutch size, would require the increase of egg survival to 0.90 (Table 22). However, if chick survival were the only variable to be manipulated while maintaining mean egg survival and mean clutch size, a $\lambda = 1.0$ would not be attainable. Increasing chick survival to 1.0

Table 20. Population projection of common terns on the Confined Disposal Facility (CDF), in eastern Michigan. Projection represents the worst case scenario using egg survival = 0.3571, chick survival = 0.598, and mean clutch size = 2.04. See Table 1 and associated text for description of calculations.

Age Class	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
0	108.75	94.09	83.30	73.38	64.24	55.84	47.27	38.77	30.38	28.15	25.63	22.81
1	56.88	56.88	49.21	43.57	38.38	33.60	29.21	24.72	20.28	15.89	14.72	13.40
2	29.74	29.75	29.75	24.74	22.79	20.07	17.57	15.27	12.93	10.60	8.31	7.70
3	15.56	15.55	15.56	15.56	13.46	11.92	10.50	9.19	7.99	6.76	5.55	4.35
4	39.08	14.31	14.31	14.31	14.31	12.38	10.96	9.66	8.46	7.35	6.22	5.10
5	35.95	35.95	13.17	13.16	13.17	13.17	11.39	10.09	8.88	7.78	6.76	5.72
6	33.08	33.08	33.08	12.11	12.11	12.11	12.11	10.48	9.28	8.17	7.16	6.22
7	30.43	30.43	30.43	30.43	11.14	11.14	11.15	11.15	9.64	8.54	7.52	6.58
8	28.00	28.00	28.00	28.00	28.00	10.25	10.25	10.25	10.25	8.87	7.85	6.92
9	25.76	25.76	25.76	25.76	25.76	25.76	9.43	9.43	9.43	9.43	8.16	7.23
10	23.69	23.70	23.70	23.70	23.70	23.70	23.70	8.68	8.68	8.68	8.68	7.51
N	426.91	387.50	346.25	305.71	267.05	229.95	193.54	157.69	136.20	120.23	106.56	93.54
λ	0.91	0.89	0.88	0.87	0.86	0.84	0.81	0.86	0.88	0.89	0.88	

Table 21. Population projection of common terns on the Confined Disposal Facility (CDF), in eastern Michigan. Projection represents the best case scenario using egg survival = 0.8887, chick survival = 0.932, and mean clutch size = 2.61. See Table 1 and associated text for description of calculations.

Age Class	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
0	108.75	466.03	412.60	363.43	318.19	276.58	339.76	382.70	408.25	448.72	474.14	515.46
1	56.88	56.88	243.73	215.79	190.07	166.42	144.65	177.69	200.15	213.52	234.68	247.98
2	29.74	29.75	29.75	127.47	112.86	99.41	87.04	75.65	92.93	104.68	111.67	122.74
3	15.56	15.55	15.56	15.56	66.67	59.02	51.99	45.52	39.57	48.60	54.75	58.40
4	39.08	14.31	14.31	14.31	14.31	61.34	54.30	47.83	41.88	36.40	44.72	50.37
5	35.95	35.95	13.17	13.16	13.17	13.17	56.43	76.96	44.00	38.53	33.49	41.14
6	33.08	33.08	33.08	12.11	12.11	12.11	12.11	51.91	45.96	40.48	35.45	30.81
7	30.43	30.43	30.43	30.43	11.14	11.14	11.15	11.15	47.76	42.28	37.25	32.61
8	28.00	28.00	28.00	28.00	28.00	10.25	10.25	10.25	10.25	43.94	38.90	34.27
9	25.76	25.76	25.76	25.76	25.76	25.76	9.43	9.43	9.43	9.43	40.42	35.79
10	23.69	23.70	23.70	23.70	23.70	23.70	23.70	8.68	8.68	8.68	8.68	37.19
N	426.91	759.43	870.07	869.72	815.98	758.90	800.81	870.78	948.87	1035.27	1114.14	1206.75
λ	0.91	1.15	1.00	0.94	0.93	1.06	1.09	1.09	1.09	1.08	1.08	

Table 22. Manipulation of common tern egg survival (S_p), chick survival (S_p), and mean clutch size to generate $\lambda = 1.0$. Mean values generated for egg survival, chick survival, and mean clutch size were used as the basis of the manipulations.

	S_p Egg	S_p Chick	$\bar{x}$ Clutch Size	λ
S_p Egg	0.9000	0.637	2.34	1.00
S_p Chick	0.4661	1.000	2.34	0.97
$\bar{x}$ Clutch Size	0.4461	0.637	4.50	1.00

would only yield a $\lambda = 0.97$ (Table 22). Thus either egg survival, mean clutch size, or both would also have to be increased to generate a $\lambda = 1.0$. Mean clutch size would need to increase to 4.5 eggs per nest, while maintaining mean egg and chick survival, to obtain a $\lambda = 1.0$ (Table 22).

DISCUSSION

Results from this study indicate that the common tern population in Saginaw Bay of eastern Michigan is declining. Major threats to survival include wave inundation (Duck Island) and predation (CDF). While other factors such as contaminants and site characteristics (e.g., distance to neighboring nest, vegetation cover at nests) may impact survival of common tern eggs and chicks, threats to survival due to these factors were not readily obvious and further investigations of these impacts may be needed.

General Observations

Duck Island

The primary threat to common tern reproductive success on Duck Island was high water levels. As Duck Island sits relatively low in the water (Figure 3), it is highly susceptible to wave inundation and complete submersion. High water years will continue to pose a threat to the reproductive success of the Duck Island colony. Waters of the Great Lakes are known to fluctuate, with high water levels reported every 8 - 15 years (Project Management Group 1989). Changes in water levels occur as a result of long-term shifts in precipitation, inflow and outflow, and evaporation patterns, and short-term changes in wind intensity and direction and atmospheric pressure (Project Management Group 1989). However, although cycles in Great Lakes water levels are known, the

recent impacts of El Nino may make these cycles less predictable. Although El Ninos generally appear every 2 - 7 years, since the early 1990's they have appeared almost yearly (Nash 1997). El Ninos are responsible for major month-to-month variations in climate and depending on the impacts to the jet stream can result in higher snow- and rainfall in the northern sections of the United States, including the Great Lakes region (Nash 1997), thus elevating lake levels. If the current trends in El Nino continue, this site may be lost for breeding for several years to come. Because patterns in high water levels can be tracked, it may be possible to circumvent the problem of no nesting at this site during these years by taking steps that may prevent loss of the entire colony's reproductive effort in these years. Suggestions for increasing reproductive success during high water years include the use of nesting platforms that are discussed in detail in Chapter II of this document.

Confined Disposal Facility

The phenology of egg laying, hatching, and fledging was relatively consistent from 1995 - 1997 with chicks hatching approximately 2 weeks later on the CDF in 1995 than in other years. While the amount of precipitation and temperature have been linked to the timing of initial nesting (Becker et al. 1985, Burger and Gochfeld 1991), it is not known whether weather is linked to chick hatching. In 1995, when chicks hatched approximately 2 weeks later than in 1996 or 1997, temperatures were actually warmer than normal and warmer than in 1996 and 1997, and precipitation at this site was normal (NOAA 1995, 1996, 1997), therefore, these factors may not have influenced chick hatching.

Researchers were able to band considerably more chicks on the CDF in 1997 than in other years for several reasons. First, researchers improved their handling of birds and captured birds earlier (0 - 5 days old) when they were less mobile which increased the number of birds banded. Second, more chicks were likely banded in 1997 due to the increased survival of eggs which in turn increased the number of eggs that hatched (Table 14). The increased survival of eggs in 1997 may be attributed to a lower predation rate, which is discussed below. Finally, because enclosures were used in 1997, chicks were contained in an area which permitted researchers to more easily capture chicks throughout the hatchling stage.

Predation

The literature indicates that chicks are most susceptible to death within 5 days of hatching (Langham 1972, LeCroy and Collins 1972, Matteson 1988). Data collected in this study support this finding with approximately 50% of chick deaths or last age when known alive occurring at ≤ 5 days old (Table 7) in 1996 and 1997. Although chicks are semi-precocial, most stay in or near the nest for 1 - 3 days after hatching. Thus, the loss of these chicks is likely due to predation rather than an inability of researchers to relocate chicks.

Although not captured on film, it is suggested that predation of eggs and chicks (Table 7) may be the primary threat to the CDF common tern colony. A predation event by a garter snake of a common tern chick was witnessed in the colony. Although only one removal of a chick by a garter snake was observed, it is highly probable that this was

not an isolated incident. Additionally, many eggs that were lost from the colony were completely removed, that is, no egg shell fragments were left behind. The removal of complete eggs is consistent with removal by snakes. Garter snakes have been documented removing eggs from other common tern colonies in northern Michigan (F. Cuthbert, unpubl. data). However, it is recognized that snakes are not the only predator that remove entire eggs from a nest. Other potential predators that remove entire eggs include black-crowned night herons (Collins 1970, Hunter and Morris 1976) and skunks (Austin 1945).

Analysis of scat found within the colony also suggests predation by a fox and/or coyote. Although coyotes have not been reported in the literature as potential predators of common tern eggs or chicks, foxes have been previously suspected in the removal of eggs and chicks at colonies in locations along Lake Michigan (Scharf and Shugart 1991), Minnesota (McKearnan and Cuthbert 1989), Lake Ontario (Courtney and Blokpoel 1983), and the Atlantic coast (Palmer 1941). Additionally, on four separate occasions cached piles of dead chicks were found within the colony, a behavior attributed to foxes (Hazard 1982). Other potential predators of common terns that may cache prey items include mink (Courtney and Blokpoel 1983), although this species was not identified on the CDF.

Although herring gulls and ring-billed gulls also have been suspected predators of common tern eggs and chicks, observation of interactions with these species often did not illicit defense responses from common terns at the CDF. Herring gull chicks and adults were observed on several occasions walking through the common tern colony and rarely,

if ever, caused a defense response from nesting adults. On more than one occasion common tern adults remained on their nests as herring gulls passed through the colony without apparently acknowledging the presence of these intruders. Thus, it may be that herring gulls and ring-billed gulls on the CDF pose more of a threat in the form of competition for nesting space (Figure 5), as suggested by Courtney and Blokpoel (1980) and Morris and Hunter (1976), than they do as predators of common tern eggs and chicks.

Of the other common avian predators of common tern eggs and chicks, including ruddy turnstones (Faraway et al. 1986), black-crowned night herons (Collins 1970, Morris and Hunter 1976), and great horned owls (Courtney and Blokpoel 1983), only black-crowned night herons were observed in the colony vicinity. Anecdotal evidence suggests that black-crowned night herons may have impacted the survival of common tern eggs and young. As the occurrence of black-crowned night heron declined on the CDF, overall common tern egg and chick survival increased from 1995 - 1997 (Tables 14 and 16, respectively). However, this is purely anecdotal and more research on potential impacts to common tern survival from black-crowned night herons needs to be conducted.

One advantage of coloniality is that it allows for synchronized nesting (i.e., all eggs hatch at approximately the same time). Synchronized nesting produces a sudden abundance of eggs and chicks that exceeds the daily needs of the local predators, thus each individual's chances of being preyed upon are decreased (Lack 1968). While synchronized nesting was evident on the CDF colony (Figures 7 - 9) it is questionable whether or not this advantage was fully realized at this site. It may be possible that given

the small size of the colony in relation to the overall size of the CDF, and the number of potential predators that it can support, that it is unlikely that common terns could produce enough eggs and chicks to sufficiently swamp the needs of the predators for an extended period of time. Thus, impacts due to predation at this site may remain high.

While it is possible that eggs and chicks may have been lost due to factors other than predation, their impacts were not readily obvious. For example, contaminants may have impacted survival of eggs and chicks, however, evidence consistent with contaminant effects (e.g., cross bills, thin egg shells; Gilbertson et al. 1991, Lundholm 1987) was only evident when one chick was found with a crossbill, suggesting this is an unlikely impact to survival. However, to completely rule out impacts due to contaminants, further research needs to be completed.

Although avian cholera was reported for one bird in the colony, it is not known what impact it had on other common terns. Due to the acute nature of the disease, few sick birds can be seen during an outbreak (Friend 1987). However, once cholera is present, death follows relatively immediately with birds generally dying off in large numbers in a short time period. Although other young birds were lost at this site a large die-off did not take place. Rather, deaths of many of these birds could likely be attributed to predation (Table 7). However, to completely rule out the presence of avian cholera, necropsies and virology investigations would need to be performed. Although avian cholera was isolated in the dead bird, cholera is known to occur in many forms (K. Miller, Nat. Wildl. Health Center, Madison, Wisconsin, pers. commun.), and this strain may have been less aggressive than strains that can be linked to large die-offs of other

avian species.

While infra-red cameras produced high quality pictures of nest sites, no predation attempts were captured on film. Although this may be interpreted as failure of this technique in assessing predation at this site, there were many factors that may have affected the overall success of this technique. First, given the structure and location of the CDF, it was often difficult to run cameras on consecutive days. Often times, wave and weather conditions did not permit transport of batteries, which powered the system, out to the site under safe conditions. This left cameras unattended for extended periods of time which resulted in either draining of the battery or running out of VHS tape. If procedures could be developed to safely transport batteries and tapes to the CDF on a daily basis, it is possible that cameras could run more regularly, thus potentially capturing predation events on tape.

One drawback of this technique, however, is the small field of view of the camera. During daylight hours the nest of interest and adjacent nests could be seen easily. However, during the evening hours, only the nest of interest was fully illuminated. The use of a camera which supports a stronger infra-red beam of light may address this problem. It may be possible that predation events at nearby nests were missed during the evening hours as camera optics were not powerful enough to illuminate the surrounding area.

While trail monitors proved useful in identifying species that entered either end of the colony, they were only useful in identifying potential predators to the site. A technique such as described by Danielson et al. (1996) may prove beneficial in recording

predators at the nest site. They developed an inexpensive camera system that works similar to the trail monitors but is triggered to take a picture on 35 mm film when there is motion within a nest (i.e., an egg is removed). However, this system works only on a single nest at one time and may not prove adequate in assessing predation of colonial nesters (i.e., would require several camera systems to obtain a sample of nests within the colony).

Site Characteristics

While vegetation variables fluctuated between years and within a year between successful and unsuccessful nests, no apparent significant changes in vegetation variables in relation to success or failure of nests are evident on the CDF. Comparisons of all nests between 1997 and 1996 yielded a significant difference with common terns nesting closer to a neighboring nest in 1997. It is unclear why nests were closer together in 1997 than 1996 as the greatest number of nests in 1997 was less than in 1996 (Table 2), and the overall size (length and width) of the colony did not change between years. This may be an artifact of a small sample size in 1996.

Significantly higher percentage of grass canopy and lower percentage of forb canopy in 1997 (Table 8) was likely due to the annual succession of vegetation at this site. Basu et al. (1978) stated that vegetation on a legume-dominated site undergoes successional changes, eventually becoming grass dominated which may account for the apparent shift from forb to grass canopy cover. It is unclear why percent bare ground increased from 1996 to 1997. In general, the amount of bare ground decreases over time,

on an undisturbed site, due to an increase in the accumulation of dead and dying matter. However, the apparent increase in bare ground may be an artifact of a small sample size in 1996 or may be linked to the acidic nature of fecal matter produced by the birds that can kill vegetation at the nest site (McBrayer et al. 1995).

No apparent changes in vegetation variables in relation to success or failure of nests are evident on the CDF. However, it should be noted that the percent of vegetation cover at this site in both years at nests that successful and unsuccessful hatched and fledged young was higher (approximately 60%; Tables 8 - 13) than the 10 - 30% vegetation cover reported in the literature (Blokpoel et al. 1978, Burger and Gochfeld 1991, Soots and Parnell 1975) as the preferred amount of cover at common tern nest sites. It is possible that if the vegetation cover at this site were less, survival of eggs and chicks would be greater than that calculated for 1995 - 1997. Matteson (1988) reported that higher percentages of vegetation cover caused lower reproductive success and/or greater nest abandonment of common terns in Green Bay, Wisconsin. Additionally, Palmer (1941) indicated that while some amount of vegetation is necessary to provide refuge from predators and thermal exposure, too much may be detrimental to survival. Researchers on Lime Island, Michigan, were able to follow common tern chicks for longer periods of time due to chicks becoming entangled in the vegetation as they tried to escape, thus making them more vulnerable to predation (Millenbah and Cook 1997). Vegetation cover at this site averaged 69.3%. Therefore, researchers are planning to investigate whether manipulation of substrate at this site to decrease vegetation cover will increase the overall survival of common tern eggs and chicks. A similar investigation

may be warranted at the CDF colony.

Successful hatchers nested significantly closer to the water's edge than unsuccessful hatchers in 1996 (Table 10). Austin (1948) noted that land predators, such as the common rat, start predation attempts at one edge of the colony, working their way to the other side, with predation occurring more frequently on the outer edges of the colonies than in the middle or edges closest to the water, which may support why successful hatchers nested closer to the water's edge.

Assessing Reproductive Success and Determining Survival Estimates

Estimates of common tern egg survival from initiation of incubation to hatching fluctuated from 1995 - 1997. Higher survival rates in 1997 (Table 14) may be attributed to less frequent loss of eggs to predators. Throughout 1997 researchers noted an apparent lack of predation of common tern eggs. Although eggs were lost due to nest abandonment and human error, the majority of losses could be assigned to some type of predation activity, with most nests experiencing complete loss of eggs or obvious destruction of eggs (i.e., holes poked in eggs). In 1995 and 1996, several predation events were evident with a loss of up to a quarter of the nests in one night. In 1997, this type of event was not seen. Although only anecdotal, it may be possible that the increase in survival of common tern eggs in 1997 may be related to the decrease in black-crowned night herons on the CDF. However, further research is needed to determine the link between black-crowned night heron occurrence and egg loss, if one truly exists.

Use of enclosures in 1997 likely did not contribute to reducing survival of

common tern eggs because although nests are contained within an area, eggs are not mobile, thus having them enclosed does not permit them to be captured more frequently or more easily. It is difficult to compare these estimates with survival estimates in the literature as most survival estimates are in relation to adult annual survival and sub-adult survival (Austin 1948, Austin and Austin 1956, DiConstanzo 1980, Nisbet 1978, Penning 1993).

Chick survival on the CDF was higher in 1997 than 1996 (Table 16) and may be attributed to the use of enclosures, however, this is difficult to verify. While enclosures may have artificially inflated survival estimates for chicks by protecting them from predators, it is difficult to assign an increase in survivorship specifically to the use of enclosures. Because censoring of chicks in 1996 and outside of the enclosures in 1997 was high ($> 10\%$) estimates of chick survival at these time periods and for these locations may be unreliable. Thus, comparisons with enclosure data may be inappropriate.

Survival of chicks was higher than survival of eggs for common terns on the CDF from 1995 - 1997 (Tables 14 and 16). One reason for the increased survival of chicks may be attributed to chick mobility. Eggs are not mobile so chicks may be less susceptible to predation. Additionally, parental aggression at nests was markedly more noticeable after hatching, which is consistent with the parental investment theory (Trivers 1974), thus parental defense of chicks may have helped reduce impacts due to predation.

Population Projections

Information synthesized in population projection models of the common tern colony on the CDF suggest that the population is declining. This is consistent with reports of other common tern populations in the Great Lakes (Courtney and Blokpoel 1983, Morris et al. 1980, Shugart and Scharf 1983). As values for sub-adult survival and adult survival were taken from the literature, it may be possible that these projections overestimated or underestimated the actual trends in overall population numbers. To obtain the most accurate reflection of population trends on the CDF, values for adult and sub-adult survival for birds at this site would be needed. Obtaining these values would require, at a minimum, several years of intensive mark-recapture. However, the values generated from the population projection models presented here provide a general view of the dynamics of this population and, along with observations, offer a starting point for understanding the threats and impacts to the continued existence of this species. One drawback of the population projections presented here is that they were developed assuming constant conditions (e.g., weather, predation, competition) across many years which does not accurately reflect the changing nature of the environment. A more intensive modeling project would need to be initiated to account for all possible variations in population projection variables.

Manipulations of variables (mean clutch size, egg survival, and chick survival) assist in determining where the primary impact to survival lies. These manipulations suggest that both egg and chick survival need to be improved to increase population numbers at this site (Table 22). Manipulating only egg or chick survival requires the

survivorship of these variables to be unrealistically high. Chick survival would have to be greater than 100%, if egg survival were kept constant, to achieve a $\lambda \geq 1$. This is not biologically possible. Egg survival would need to equal or exceed 90% and this rate of survival would be uncharacteristic of a ground-nesting shorebird. Additionally, egg survival appears to be the more limiting factor (Tables 5 and 22) in determining whether the population will increase or not, thus both variables need to be manipulated. While clutch size can also be manipulated, mean clutch size would need to be 4.5 eggs per clutch (Table 22), if egg and chick survival were kept constant, for $\lambda \geq 1$. As common terns rarely have clutches larger than 3 eggs, this option is unrealistic. Other options for manipulating clutch size are presented below.

Egg and chick survival are the most logical variables that can be manipulated in Michigan because little impact can be made on birds in the 1 - 2 year old age class as they are generally not present in Michigan until they reach breeding age of 3 - 4 years old. Additionally, little evidence of threats to adult survival were observed in Saginaw Bay suggesting that adult survival is not limiting the population size. Although it may be possible to have some impact on clutch size, common terns in Saginaw Bay have been fairly consistent in being able to produce average sized clutches, as reported in the literature for this species (Ehrlich et al. 1988), and thus this variable does not appear to be abnormal. However, data suggest that those clutches that support more eggs (2 - 3 eggs) have a better chance of fledging more young than those nests that only support one egg (Table 5). This is somewhat intuitive based solely on probabilities. One option for increasing fledging success may be to transfer eggs from larger clutches to smaller

clutches. That is, remove one egg from a 3 egg clutch and place it with a one egg clutch. Data from this study suggest that clutches that support 2 eggs have the greatest success in fledging young from a nest (Table 5). However, this suggestion may be a moot point given that in 3 egg clutches the third egg is generally smaller and has a reduced likelihood of survival (Nisbet 1973). A more feasible option may be the complete removal of a completed clutch from a successful nesting pair to a pair that produces only a one egg clutch. As common terns are known to renest when initial nesting is unsuccessful, this option may be more appropriate. However, further investigations into the feasibility of this option are warranted.

The population projections generated in this study do not provide a positive outlook for common terns nesting on the CDF. Additionally, previous data suggest that the population on the CDF has decreased considerably from the 1980's when the number of breeding pairs exceeded 600 (Michigan Natural Features Inventory (MNFI) 1996). Although the common tern population has persisted on the CDF for almost 20 years, it is apparent that the population is decreasing and it appears that it will continue to follow this trend. One obvious concern, therefore, for this population relates to the concept of minimum viable population (MVP). Defined, MVP is the minimum conditions necessary for the long-term persistence and adaptation of a population in a given area. Has the CDF common tern colony reached its MVP or is it actually below its MVP threshold level? If the population is below its MVP, measures need to be implemented immediately to increase the population as management under the current regime will not be sufficient to support the population at a $\lambda \geq 1$. Thus, under the current regime, if the population is

below its MVP it would be impossible to increase egg and chick survival to a level that would permit the population to increase on its own without intervention through some additional form of intensive management. Data from this study intimate that it may be possible that the CDF colony has reached or dropped below its MVP (Table 22), however, further investigations and data collection would be needed to determine the accuracy of this statement.

CHAPTER II

USE OF NESTING PLATFORMS TO INCREASE COMMON TERN REPRODUCTIVE SUCCESS

INTRODUCTION

As common tern numbers have declined in recent years due to loss of habitat, competition with gulls, and predation, a variety of steps have been taken to promote the continued existence of the species. In some locations throughout Canada, management efforts aimed at increasing the reproductive success of common terns include reducing vegetation cover and halting succession (Dunlop et al. 1991, Morris et al. 1992), excluding ring-billed gulls from common tern nesting areas using monofilament line (Blokpoel and Tessier 1983, Blokpoel et al. 1997), and posting areas to deter visitation by human intruders (Dunlop et al. 1991, Morris et al. 1992). However, in some instances these efforts have proved less than successful. Thus, researchers continue to investigate alternatives for increasing the reproductive success of common terns.

One alternative that has proved to be somewhat successful at increasing common tern reproductive success is the use of nesting platforms. Nesting platforms or rafts have been used in a variety of locations in the United States (Stricker 1995), Canada (Dunlop et al. 1991), and Europe (Norman 1987, Hoeger 1988) and have been described for

common terns (Eades 1970, Turrian 1980, Norman 1987, Hoeger 1988, Dunlop et al. 1991, Stricker 1995), Forster's terns (*Sterna fosteri*; Techlow 1983, D. Best, USFWS, pers. commun.), and caspian terns (Lampman et al. 1996). Dunlop et al. (1991) found that common tern nesting platforms provided suitable nesting sites that were not susceptible to erosion, not occupied by ring-billed gulls, and were isolated from ground predators and human disturbance. The platforms were built to rise with increasing water levels, thus protecting the nests from flooding. Platforms have been deemed successful in providing quality nest sites for common terns where otherwise quality habitat is lacking (Norman 1987).

Michigan common terns have historically nested on islands in Wildfowl State Game Area in Saginaw Bay that are highly susceptible to flooding by rising water levels and wave inundation. Islands in this area that are known to support or have supported nesting common terns include Defoe, Lone Tree, and Duck Islands (MNFI 1996; Figure 10). Lone Tree Island once supported up to 2,000 breeding pairs but the last record of nests at this site occurred in 1977 when 25 nests were observed (MNFI 1996). Defoe Island has supported only a small number of nests at any given time with the last occupancy of common terns also recorded in 1977. Duck Island, however, had been observed to support approximately 75 - 100 breeding pairs as recently as 1995 (D. Best pers. commun., K. Millenbah pers. observ.). The threat of flooding due to high water levels and wave inundation coupled with the recent presence of common terns make Duck Island an ideal site for testing the effectiveness of nesting platforms in increasing the reproductive success of the common tern. Placement of platforms at this site may

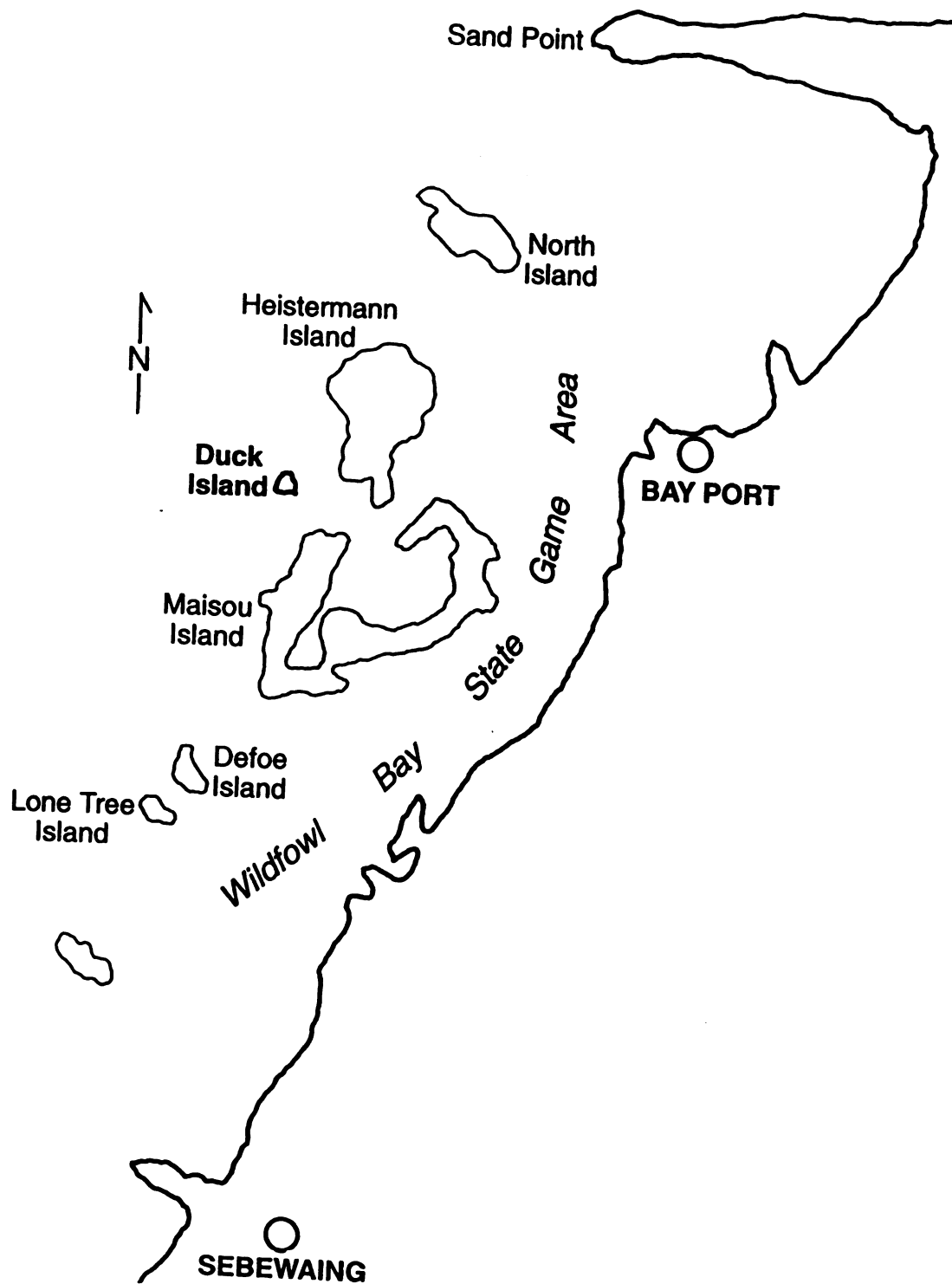


Fig. 10. Location of Duck Island and other islands of Wildfowl Bay State Game Area in Saginaw Bay, Michigan.

prove especially beneficial during high water years and/or during storm events. As Duck Island represents one of the last natural nesting sites for common terns in Saginaw Bay, evaluating the effectiveness of these platforms may prove beneficial in promoting the long-term existence of the species.

OBJECTIVES

Specific objectives of this part of the study were to:

- 1) determine the effectiveness of nesting platforms in increasing common tern reproductive success; and
- 2) make recommendations for managing common terns for increased reproductive success on nesting platforms.

METHODS

Two nesting platforms were erected near Duck Island (Figure 11) in summer 1995 and 1997 with 3 platforms erected in 1996. No platforms were installed near the CDF as water depths were not suitable for anchoring platforms. Platforms were anchored approximately 5 - 10 m from Duck Island on the northeast side of the island to provide additional shelter to the platforms from prevailing winds and wave action.

Platforms resembled those used by Dunlop et al. (1991) and Stricker (1995). Each platform consisted of 3 sections (each section = 1.2 m X 2.4 m) held together by 2 side connector panels (each panel = 3.7 m long; Figure 12). Sections were made of one sheet of 1.2 m X 2.4 m X 2 cm treated plywood and 5 - 8 sheets of 1.2 m X 2.4 m X 2.5 cm polystyrene insulating styrofoam. Connector panels consisted of a 5.1 cm X 10.2 cm X 3.7 m piece of lumber with 8 - 10 evenly spaced 15 cm X 25 - 33 cm cleats (Figure 12). Because of the size and weight of each platform component, an entire platform could be transported in the back of a pick-up truck or on a small boat (approximately 5.2 m long) with relative ease. Additionally, one platform can be easily installed by 2 individuals.

Platforms were constructed in a systematic manner to ensure that adjacent components matched during actual assembly at a common tern nest site. Initially, one 5.1

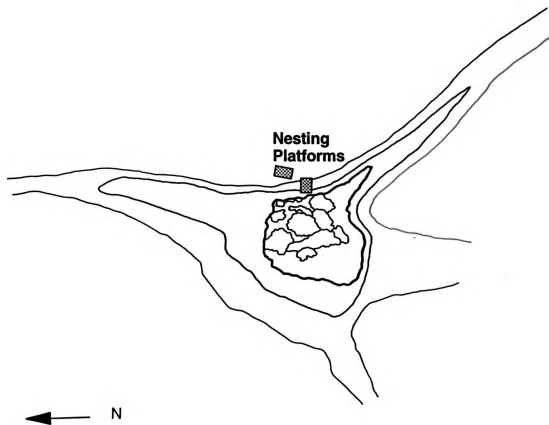


Fig. 11. Duck Island in Saginaw Bay, Michigan and placement of common tern nesting platforms in summer 1995 - 1997.

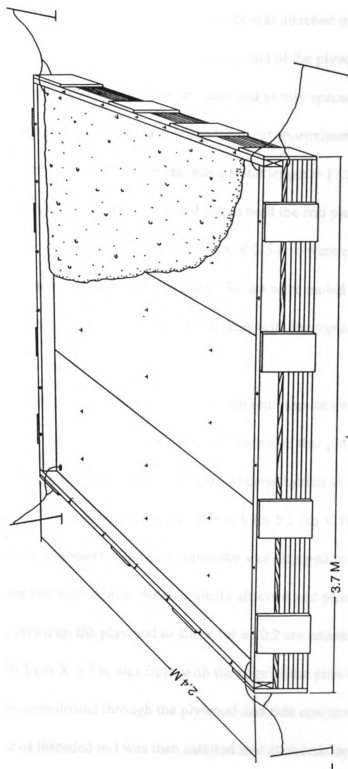


Fig. 12. Diagrammatic representation of one common tern nesting platform used near Duck Island in Saginaw Bay, Michigan summer 1995 - 1997. Illustration depicts platform completely assembled and installed.

cm X 10.2 cm X 2.4 m (end piece) piece of lumber was permanently attached to one end of each of 2 of the 3 pieces of plywood. The end piece was attached to the plywood with the 5.1 cm side down to provide a 10.2 cm wall on the end of the plywood. The end piece was attached using 8 pieces of 1.0 cm threaded rod evenly spaced along the 2.4 m side of the plywood (Figure 12). The threaded rod was cut approximately 5.1 cm longer than the thickness of the plywood and the end piece (total length = 17.2 cm). A nut and washer were added to either end of the threaded rod to hold the end piece and plywood together. Next, 5 wooden cleats (15.2 cm X 24.8 cm X 2.5 cm) were evenly spaced along the 2.4 m side of the end piece and nailed in place. Cleats were nailed in place with galvanized nails with the 15.2 cm edge of the cleat flush with the top edge of the end piece (Figure 12).

Next, one section with the end piece attachment (end section) was turned upside down with the end piece end to the outside. It should be noted that platforms were completely constructed upside down due to the ease of construction in this position. Before proceeding, 12.7 cm were cut from the ends of both 5.1 cm X 10.2 cm X 3.7 m pieces of lumber (side connector). One side connector was clamped to the underside of the platform with one end butted up to the previously attached end piece. Again the 5.1 cm side was placed down on the plywood to allow for a 10.2 cm retaining wall. Ensuring that the 5.1 cm X 10.2 cm X 3.7 m was flush with the edge of the plywood, 3 - 4 evenly spaced 1.0 cm holes were drilled through the plywood and side connector piece. A 1.0 cm X 17.8 cm piece of threaded rod was then inserted into each hole and held in place by a nut and washer on either side end. The same process was repeated for the second side

connector piece. It should be noted that the side connector pieces described above should not be permanently attached to the plywood as they serve as the final step in securing all 3 platform sections together. This allows the platform sections to be secured once installed but also allows for disassembly and easy transport of platforms when not in use.

The middle section of plywood was then laid across both side connector pieces adjacent to the first section with the 2.4 m sides together. Again, the side connectors were clamped to the plywood, holes drilled, and threaded rod added as previously described. Finally, the second end section (plywood with the attached end piece) was added similar to the first 2 sections. When complete, the side facing the floor supported a 10.2 cm barrier completely surrounding the outer edge of the plywood.

Next, 5 - 8 sheets of 1.2 m X 2.4 m X 2.5 cm polystyrene were added to each section and served as the floatation device. Eight sheets of polystyrene were used in 1995, however, 5 sheets were deemed to provide adequate floatation for platforms in 1996 and 1997. Polystyrene was held in place on each plywood piece by 0.6 cm threaded rod. The threaded rod was cut approximately 5.1 cm longer than the thickness of the polystyrene and plywood to allow for a washer and nut on either end of the rod. To prevent nuts and washers from wearing through the polystyrene, a 5.1 cm X 5.1 cm wooden washer also was used. A hole was counter sunk in the wooden washer to allow the nut and washer to be protected from getting pushed or stripped off during transport or once the platform was installed. It is advised to add and secure polystyrene to one section before continuing as side edges of polystyrene may need to be shaved slightly with a hacksaw to allow a proper fit between platform sections.

After the polystyrene was added and secured, 10 wooden cleats were added to each side connector as described previously. Next, the platform was disassembled and reassembled right side up on the ground. Prior to disassembling the platform, each section and connector panel was marked to ensure pieces matched properly when reassembling. Before attaching side connector panels, one additional modification was made to each side connector panel and the threaded rod securing it to the plywood. Each piece of threaded rod received an additional nut and washer on the plywood side opposite the side with the polystyrene. This ensured stability of the threaded rod and held the threaded rod in place during transport and storage of the platforms. To accommodate the additional nut and washer, holes were counter sunk on the side of the connector panel that meets the plywood to allow for clearance of the nut and washer. The connector panels were then placed over the threaded rod on both sides of the platform and secured with a nut and washer (Figure 13).

To secure anchors, 2.5 cm holes were drilled through the plywood at each corner of the platform inside of the side connector panels. In 1995, platforms were anchored using 3.7 m of polypropylene rope connected at each corner to 4 - 15 cm X 30 cm concrete blocks (16 per platform). In 1996 and 1997, anchors consisted of 3.7 m of wire rope connected to a 2 m piece of rebar (4 per platform). Wire rope was attached to the platform using u-clamps. To attach the wire rope to the rebar, a hole was drilled near the top of the rebar, an eyebolt secured through the hole, and the wire rope threaded through the eyebolt. The rope was held in place using u-clamps. Each piece of rebar was subsequently driven approximately 1.0 m into the bay floor.

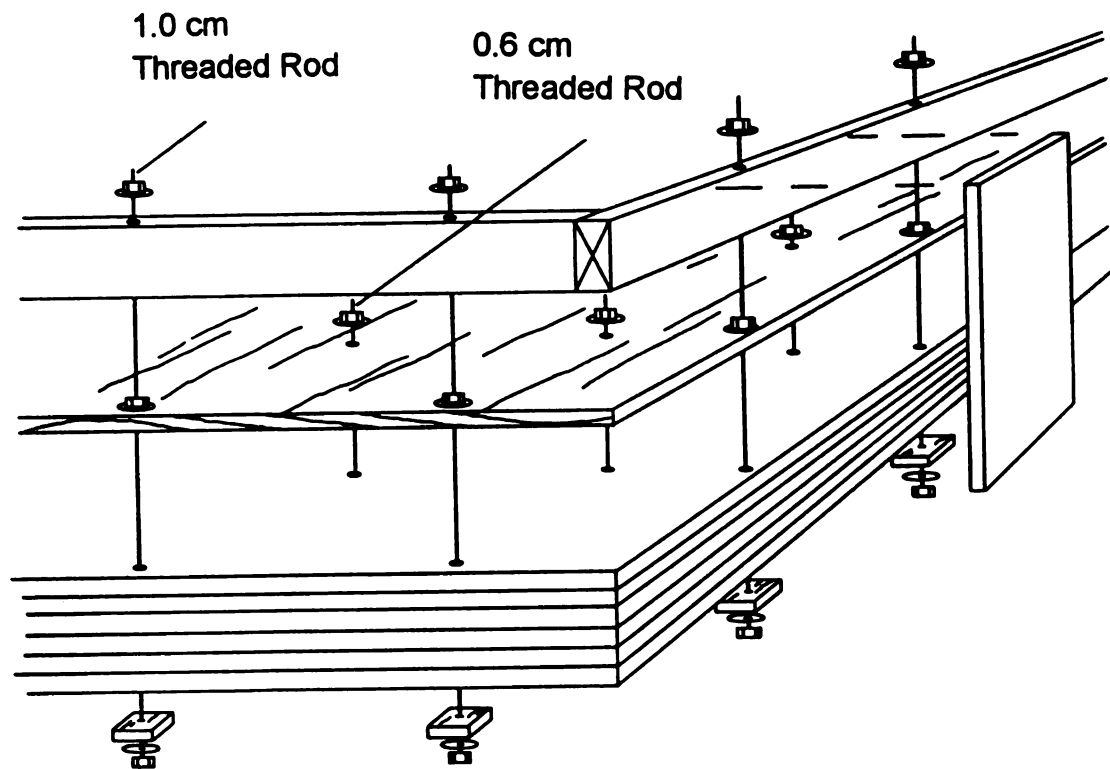


Fig. 13. Diagrammatic representation of one common tern nesting platform used near Duck Island in Saginaw Bay, Michigan summer 1995 - 1997. Illustration depicts partially disassembled platform.

Platforms were covered to a depth of 5 cm with coarse gravel in 1995 and fine sand in 1996 and 1997. Each substrate provided adequate drainage of the platform. Seams were covered with window screening to prevent chicks and substrate from falling through gaps. An attempt was made to install rafts prior to the arrival of terns to the nesting site, but after ring-billed gulls had established territories. All platforms were removed at the end of the breeding season. Observations of common terns using platforms were made as described in Chapter I.

To assist other researchers in construction of similar nesting platforms, a list of supplies, including quantities and costs, is provided in Table 23. All prices and quantities are given for one platform.

Table 23. Supplies, including prices and quantities, for building one common tern nesting platform used near Duck Island in Saginaw Bay, Michigan in summer 1995 - 1997. Prices are given in 1997 dollars.

Supply	Quantity	Unit Price (\$)	Total Price (\$)
1.2 m X 2.4 m X 1.0 cm treated plywood	3	25.90	77.70
Polystyrene insulating styrofoam	15	8.43	126.45
5.1 cm X 10.2 cm X 3.7 m	2	3.99	7.98
5.1 cm X 10.2 cm X 2.4 m	2	2.29	4.58
0.6 cm nut	36	0.04	1.44
0.6 cm washer	36	0.03	1.08
5.1 cm X 5.1 cm wooden washer	18	Scrap	---
1.0 cm nut	104	0.06	6.24
1.0 cm washer	104	0.05	5.20
2 m rerod	4	5.00	20.00
3.7 m length wire rope	4	3.00	12.00
U-Clamp	8	0.39	3.12
Eyebolt	4	0.46	1.84
0.6 cm threaded rod (length = 17.8 cm)	18	0.19	3.42
1.0 cm threaded rod (length = 17.2 cm)	40	0.36	14.40
Kleat	20	Scrap	---
Galvanized nails	100	0.07	7.00
Substrate (430,000 cm ³)	1	---	45.00
Window screening (0.5 m X 2.4 m)	2	0.20	0.40
TOTAL			337.85

RESULTS AND DISCUSSION

Two platforms were installed at Duck Island on 22 May 1995 and 12 May 1997. Three nesting platforms were placed at the Duck Island colony on 8 May 1996. Platforms were removed in 1995 on 7 August. On 15 May 1996 and 20 May 1997 all platforms were missing from the area. The shorelines of Heistermann and Maisou Islands (Figure 8) were searched for remnants of the platforms but no remains were found. Platforms were believed to be lost to theft in 1996 and 1997 despite the presence of identification tags. No additional platforms were built in 1996 or 1997.

Evidence of one common tern nest scrape was found on one platform on 31 May 1995. Throughout the summer, platforms required repeated repositioning as wave action moved platforms several meters from the original location. Common terns and ring-billed gulls used platforms primarily as loafing sites. Lack of use of platforms for nesting by common terns in 1995 may be attributed to the inadequate anchoring of platforms with concrete blocks and resulting instability. To prevent excessive movement of platforms, concrete blocks were replaced with rerod that was driven into the bay floor in 1996 and 1997.

Although little data were collected on the effectiveness of using nesting platforms to increase reproductive success of common terns in Saginaw Bay, other researchers have

had varying degrees of success (Eades 1970, Turrian 1980, Norman 1987, Hoeger 1988, Dunlop et al. 1991, Sticker 1995) with similar nesting platforms. The most limiting factor when using platforms at this site is the semi-remote location which makes it difficult to monitor platforms on a regular basis thus ensuring that they are not removed or taken without prior authorization of the researcher. Prior to further attempts at using nesting platforms in this area, procedures need to be developed that ensure platforms are not removed without consent of the researcher. It is recommended, however, that once this problem is dealt with that future attempts to assess the effectiveness of nesting platforms be initiated.

SUMMARY AND RECOMMENDATIONS

Results from this study indicate that the common tern population in Saginaw Bay of eastern Michigan is declining. Threats to survival include wave inundation (Duck Island) and predation (CDF). To reverse this declining trend it will be necessary to increase the survival of common tern eggs and chicks, the primary variables that can be impacted in Michigan. While other factors such as contaminants and site characteristics (e.g., distance to neighboring nest, vegetation cover at nests) may impact survival of common tern eggs and chicks, threats to survival due to these factors were not readily obvious and further investigations of these impacts are needed to fully understand all the potential impacts to the survival of these colonies. Although little data were collected on the effectiveness of using nesting platforms to increase reproductive success of common terns in Saginaw Bay they may prove useful if logistical details can be corrected.

As the common tern population in Saginaw Bay continues to decline immediate steps need to be taken to halt this trend and to increase survival of eggs and chicks. Predator control activities may be warranted on the CDF as a threat to survival at this site appears to be predation by a number of different species (i.e., snakes, foxes, birds). One option to explore may be the use of predator exclosures similar to those used by piping plover (*Charadrius melodus*; F. Cuthbert, pers. commun.) researchers with the exception

plover (*Charadrius melodus*; F. Cuthbert, pers. commun.) researchers with the exception of an open top. These exclosures would be identical to the enclosures used in this study, however, their primary purpose would be to exclude predators not enclose common tern eggs and chicks. One drawback of using this technique is that it would not exclude avian predators, as the top of the exclosures would be open. It may be possible to fence in the entire colony, with the subsequent removal of all terrestrial predators (i.e., snakes, foxes), however, this does not address the potential impacts due to avian predators. Impacts due to predation also may be addressed through an intensive predator control and removal program on the CDF, however, a great deal of time, money, and energy would be needed to make this a viable solution. At best it appears that efforts such as using predator exclosures would be the most feasible solution for providing some temporary relief to the colony from predation activities.

Options also need to be explored to increase reproductive success at sites impacted during high water years and may include using nesting platforms. Nesting platforms have been used for common terns in Canada and Ohio with varying degrees of success (Dunlop et al. 1991, Stricker 1995). Nesting platforms may be advantageous because they are insusceptible to erosion, not occupied by ring-billed gulls, and isolated from ground predators and human disturbance. Further investigations need to be conducted to assess the feasibility of using these structures in Saginaw Bay including research on site locations for placements of these structures. Another option to investigate for low-lying nest sites may be the addition of substrate to the site to elevate the area further above the water line. This technique has been used in Wisconsin with

some success (F. Strand, Wisc. Dept. Nat. Resour., pers. commun). In addition to the placement of substrate, a wooden frame was added around the site to hold the substrate in place. One drawback of this technique, however, was the damage incurred to the structure during the winter months due to freezing conditions.

Although site characteristics generally did not vary significantly between years, and thus did not appear to alter survival from year to year, the values recorded for some variables (i.e., cover) were greater than those reported in the literature as preferred habitat conditions for the species. This suggests that the quality of habitat at this site may be poor. Although no year to year differences were detected, negative impacts to survival may have been greater than if the habitat quality more accurately reflected the values reported in the literature as quality habitat. Thus, investigations into the quality of habitat, specifically on the CDF, and its relationship to egg and chick survival are necessary to account for potential impacts to survival due to poorer quality habitat. Examples of potential impacts to survival due to poor quality habitat may include: 1) a decrease in visibility around the nest due to encroaching vegetation which may reduce an adults ability to identify predators thus increasing predation attempts, and 2) an increase in vegetation cover surrounding a nest may provide too much shade thus not keeping eggs and chicks warm resulting in death due to exposure. Manipulations to the habitat (i.e., vegetation control and removal) may be necessary if current habitat conditions are found to be of poor quality and resultantly negatively impact survival of common tern eggs and chicks.

Investigations also need to be performed on the potential impacts of contaminants

to the CDF colony. Previous research (L. Williams, pers. commun.) has documented elevated levels of some contaminants in Saginaw Bay. Although the objectives of this study were not to determine the impacts due to contaminants, more research is needed to rule this out as a factor affecting survival.

Ultimately, the best solution for ensuring the long-term survival of the Great Lakes common tern population is to restore areas that previously supported thriving populations of common terns. But how, where, and when this becomes a feasible solution are up for debate. In the interim, however, it may be beneficial to investigate alterations to existing human-made sites for increasing reproductive success and survival of common terns. For example, researchers in Wisconsin (F. Strand, pers. commun.) created habitat on the end of an old coal dock by filling an area (approximately 50 m²) with fine grained sand. This area had previously supported common terns but this modification resulted in an increase in common terns nesting on the site with a peak number of nests reported on the site 2 years after the manipulation. A similar response was evident on Lime Island, Michigan after substrate was added to the existing coal dock (Millenbah and Cook 1997). It may behoove researchers to identify potential sites throughout Michigan, particularly in Saginaw Bay, that could be manipulated to encourage common tern nesting. Additionally, investigations into manipulations on the Saginaw Bay CDF (e.g., vegetation control) at different locations may be warranted. However, care should be taken when approaching this option as threats from predators are intense at this site and may actually cause a further decline in reproductive success than if another more suitable site (e.g., less threat due to predation) was identified.

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