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Evaluating the Reproductive Success and Long-Term Survival Potential of Common Terns (*Sterna hirundo*) in the St. Mary's River, MIchigan

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Nicole Elizabeth Lamp

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Kelly Millenbah
Major professor

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EVALUATING THE REPRODUCTIVE SUCCESS AND LONG-TERM SURVIVAL POTENTIAL OF COMMON TERNS (*STERNA HIRUNDO*) IN THE ST. MARY'S RIVER, MICHIGAN

By

Nicole E. Lamp

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ABSTRACT

EVALUATING THE REPRODUCTIVE SUCCESS AND LONG-TERM SURVIVAL POTENTIAL OF COMMON TERNS (*STERNA HIRUNDO*) IN THE ST. MARY'S RIVER, MICHIGAN

By

Nicole E. Lamp

The common tern (*Sterna hirundo*) is listed as a Threatened species in Michigan and is declining due to predation, vegetation encroachment, and loss of suitable breeding habitat due to high water levels. I investigated the relationship between reproductive success and vegetation cover on three nesting sites in the St. Mary's River: Lime Island, Andrews Reef, and Harbor Island Reef. On natural islands (e.g., Andrews and Harbor Island Reefs), common terns have better nesting success in low to moderate amounts (20-40%) of vegetation cover but on human-made sites (i.e., Lime Island), they have better nesting success in moderate amounts (40-50%) of total vegetation cover. Nesting sites used by common terns during years of low water levels (< 174.8 m) supported less vegetation cover (28.8%) and had greater egg survival (67.9%) than nesting sites used during years of high water levels (> 175.8 m; 66.1% total vegetation cover, 35.9% egg survival). A population viability analysis (PVA) conducted using VORTEX indicates that the St. Mary's River population is declining at a rate ranging from 6.3% - 10% per year (100-year probability of extinction = 70.4% - 99.9%). The most significant factors affecting the population's long-term persistence are juvenile and sub-adult survival. Management strategies should be directed at increasing juvenile and sub-adult survivals and manipulating vegetation cover to levels in which reproductive success is the greatest.

To my mom and dad.
I wouldn't have gotten this far without your love, support, and sacrifices.

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THESIS STRUCTURE

This thesis is divided into three chapters:

Chapter 1: Impacts of Vegetation Cover on Common Tern Reproductive Success in the St. Mary's River, Michigan.

Chapter 2: Impacts of Vegetation Cover on Common Tern Egg Survival on High and Low Water Nesting Sites in the St. Mary's River and Saginaw Bay, Michigan.

Chapter 3: Analyzing Population Viability of Common Terns in the St. Mary's River, Michigan using VORTEX.

In Chapter 1, I investigated the relationship between vegetation cover and common tern reproductive success among three nesting sites used in the St. Mary's River, Michigan (1997-2001). The focus of Chapter 2 is a comparison of vegetation cover and egg survival between nesting sites used during high water years (1996-1998) and low water years (2000-2001) in the St. Mary's River (1997-2001) and in Saginaw Bay (1996-1997), Michigan. In Chapter 3, I have developed a population viability analysis (PVA) for common terns in the St. Mary's River using VORTEX. Using VORTEX, I have predicted the long-term survival potential of common terns in the St. Mary's River.

Each chapter contains Abstract, Introduction, Objectives, Methods, Results, Discussion and Management Implications, and Literature Cited sections as well as Appendices. A study area description precedes Chapter 1.

STUDY AREA

In the St. Mary's River, common terns (*Sterna hirundo*) nested on Lime Island from 1997-1998 and on Andrews Reef and Harbor Island Reef from 2000-2001.

Andrews Reef is located approximately 6 km from the eastern shore of Michigan's Upper Peninsula in Chippewa County (46°4'N 83°53'W; Figure 1). In 2000 and 2001, the entire area of Andrews Reef was used as a nesting site by common terns (Figure 2). One pair and 25 pairs of ring-billed gulls (*Larus delawarensis*) nested on the southwestern end of Andrews Reef in 2000 and 2001, respectively. During both years, double-crested cormorants (*Phalacrocorax auritus*) were seen roosting along the western shore of the reef. There are no mammalian residents on Andrews Reef. Andrews Reef is approximately 0.13 ha in size. The highest point on Andrews Reef is approximately 1 m above the water level, and the substrate ranges from cobble to boulders. Distinct areas of vegetation occurring on Andrews Reef include spotted knapweed (*Centaurea maculosa*) and lady's thumb (*Polygonum persicaria*; Figure 2).

Harbor Island Reef is located approximately 10.4 km from the eastern shore of Michigan's Upper Peninsula in Chippewa County (46°3'N 83°47'W; Figure 1). In 2000, common terns nested on the north and south ends of Harbor Island Reef, with the center of the island used as a nesting site by a colony of ring-billed gulls (approximately 400 breeding pairs; Figure 3). In 2001, common terns nested within the first 11.5 m on the north end of Harbor Island Reef and 700 – 800 ring-billed gull pairs nested on the remainder of the reef south of the tern nesting area. Common terns also nested on a small rocky area 5 m north of Harbor Island Reef. This area was 36 m long, 1 m wide at the narrowest point, and 9.3 m at the widest point. During both years, double-crested

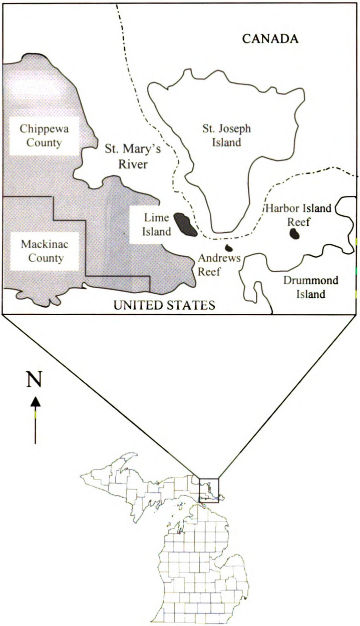

Fig. 1. Location of Andrews Reef, Harbor Island Reef, and Lime Island in the St. Mary's River, Michigan.

Fig. 2. Aerial view of Andrews Reef, Michigan. In 2000 and 2001, common terns nested on the entire area of Andrews Reef, except within the dotted line. Ring-billed gulls nested within the dotted line. The shaded regions represent distinct areas of vegetation cover.

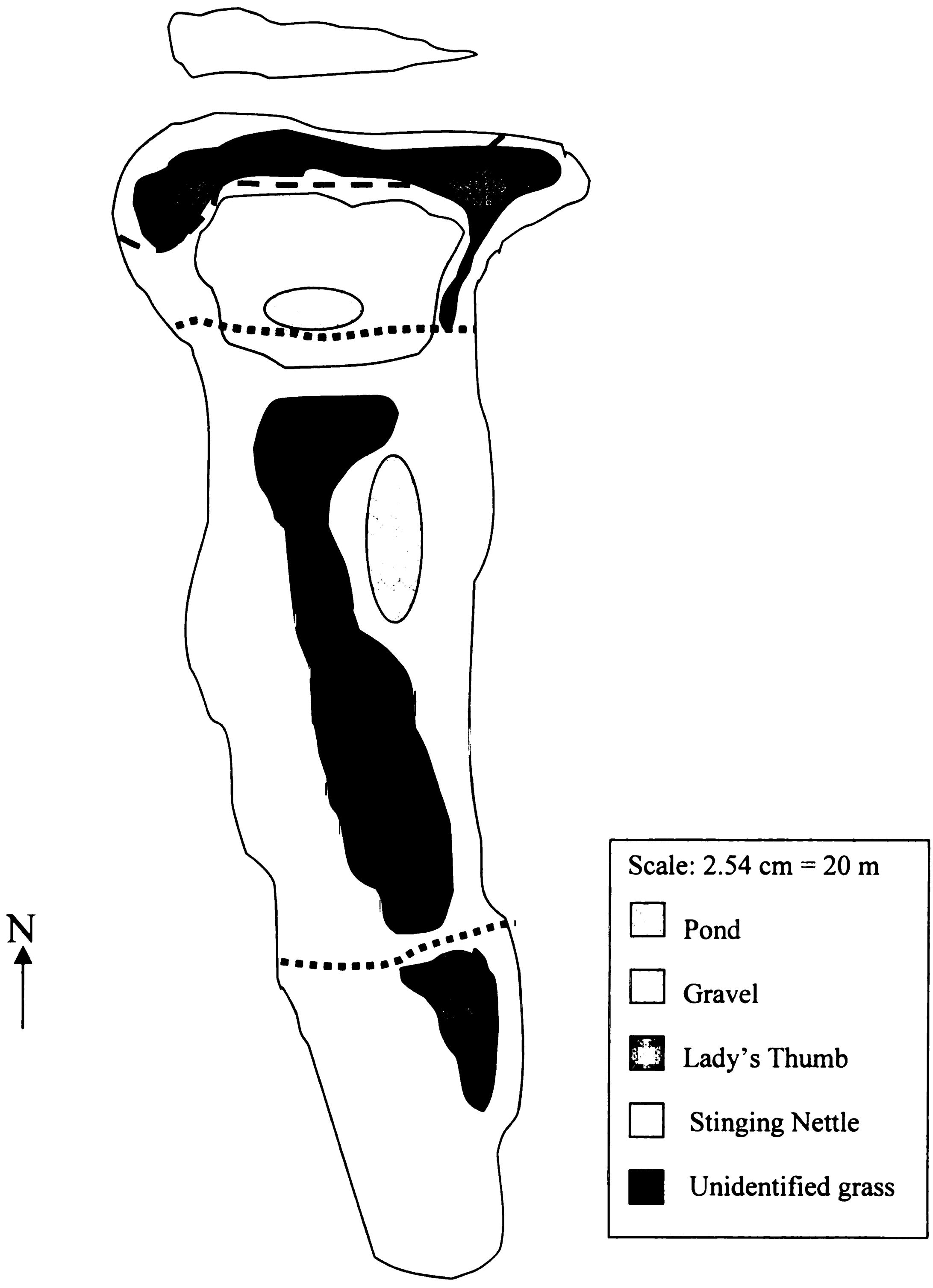

Fig. 3. Aerial view of Harbor Island Reef, Michigan. In 2000, common terns nested north of the upper dotted line and south of the lower dotted line. Ring-billed gulls were located between the dotted lines. In 2001, common terns nested north of the dashed line and on the rocky area north of Harbor Island Reef. Ring-billed gulls nested south of the dashed line.

cormorants were seen roosting along the southwestern end of Harbor Island Reef. No mammalian residents are found on Harbor Island Reef, but garter snakes (*Thamnophis* spp.) are common. Harbor Island Reef is approximately 0.43 ha is size. The highest point on Harbor Island Reef is approximately 1.5 m above the water level, and the substrate includes sand, gravel, cobble and boulders. There is a pond approximately 20 m long by 5 m wide located near the center of the island (Figure 3). Distinct areas of vegetation occurring on Harbor Island include lady's thumb, stinging nettle (*Urtica dioica*), and an unidentified grass species (Figure 3).

Lime Island is located approximately 4.0 km from the eastern shore of Michigan's Upper Peninsula in Chippewa County (46°05'N 84°01'W; Figure 1). Historically, two areas on Lime Island were used as nesting sites by common terns: 1) an old coal dock (along the west side of Lime Island; Figure 4) and 2) a rock pile adjacent to the coal dock (Figure 4). The coal dock, connected to the north end of Lime Island via a bridge (5.5 m long by 1.8 m wide), is 0.8 ha in size and is covered with mowed grass. In 1997 and 1998, common terns nested on the southern end of the coal dock and shared the area with a small colony of ring-billed gulls (Cook 1999; Figure 4). The vegetation in the colony area of the coal dock is mowed twice a year: once in early May and once in late August. The adjacent rock pile rises 1.9 m out of the water, is approximately 0.01 ha in size, and the substrate ranges from cobble to boulders. The vegetation on the rock pile consists primarily of forb species (e.g., catnip [*Nepeta cataria*], pale touch-me-not [*Impatiens pallida*], and goldenrod [*Solidago* spp.]).

Permanent mammalian residents found on Lime Island include weasels (*Mustela* spp.), mink (*Mustela vision*), raccoon (*Procyon lotor*), black bear (*Ursus americanus*),

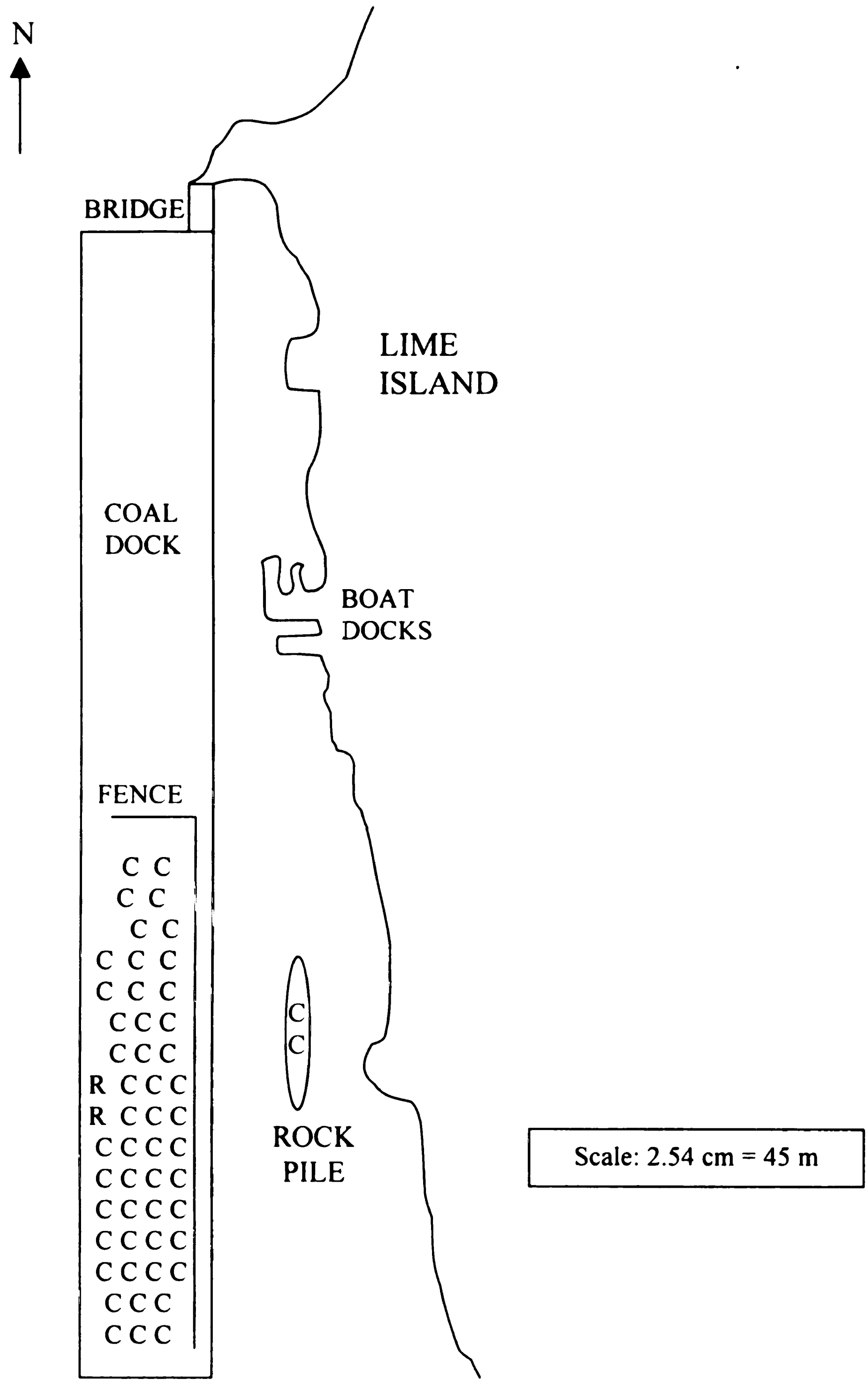

Fig. 4. Aerial view of the west side of Lime Island, Michigan. Common terns (C) were located within the fence line on the coal dock and on the rock pile in 1997 and 1998. Ring-billed gulls (R) were also located on the west side of the fence line in 1997 and 1998.

coyote (*Canis latrans*), red fox (*Vulpes vulpes*), white-tailed deer (*Odocoileus virginianus*), beavers (*Castor canadensis*), and river otter (*Lutra canadensis*). Avian residents include Canada geese (*Branta canadensis*), ring-billed gulls, herring gulls (*Larus argentatus*), bald eagles (*Halia leucocephalus*), osprey (*Pandion haliaetus*), killdeer (*Charadrius vociferus*), spotted sandpipers (*Actitis macularia*), common mergansers (*Mergus merganser*) and many songbirds.

LITERATURE CITED

Cook, B. S. 1999. Impacts of vegetation manipulations on the reproductive success of common terns (*Sterna hirundo*) on Lime Island in the St. Mary's River, Michigan. M.S. Thesis, Mich. State Univ. 101 pp.

CHAPTER 1
IMPACTS OF VEGETATION COVER ON COMMON TERN REPRODUCTIVE SUCCESS IN THE ST. MARY'S RIVER, MICHIGAN

ABSTRACT

Common terns are believed to prefer 10-30% total vegetation cover around their nests. However, research on Lime Island (1997-1998) in the St. Mary's River, Michigan has shown that common tern nest success is better in areas with moderate amounts (40-50%) of total vegetation cover. To determine in which amount of vegetation cover reproductive success is the greatest, I investigated the relationship between reproductive success and vegetation cover on three nesting sites in the St. Mary's River: Lime Island (1997-1998), Andrews Reef (2000-2001) and Harbor Island Reef (2000-2001). Percent total vegetation cover was 21.2% on Andrews Reef, 36.3% on Harbor Island Reef, and 70.3% on Lime Island. Percent bare ground was 61.9% on Andrews Reef, 45.5% on Harbor Island Reef, and 5.9% on Lime Island. Egg and chick survival rates were the highest on Andrews Reef (69.5% and 88.7%, respectively), followed by Harbor Island Reef (66.3% and 86%, respectively) and Lime Island (25.3% and 43.6%, respectively). Percent total cover was negatively correlated with egg survival ($r_s = -0.94$, $P = 0.005$) and percent bare ground was positively correlated with egg ($r_s = 0.89$, $P = 0.02$) and chick ($r_s = 0.83$, $P = 0.04$) survivals. Analyses suggest that common terns in the St. Mary's River have the highest survival in areas supporting 20-40% vegetation cover and > 40% bare ground. On naturally occurring islands (e.g., Andrews and Harbor Island Reefs), common terns in the St. Mary's River have better nesting success in low to moderate amounts (20-40%) of vegetation cover but on human-made sites (i.e., Lime Island), they have better nesting success in moderate amounts (40-50%) of total vegetation cover.

More research is needed to support or refute these conclusions. Management should include vegetation manipulations to provide the amount of vegetation cover under which reproductive success is the greatest.

INTRODUCTION

Common terns prefer nest sites in early stages of plant succession with 10-30% cover (Soots and Parnell 1975). Although this amount of cover is minimal, it offers a number of advantages. First, this sparse amount of cover offers open spaces that adult common terns use in courtship displays prior to copulation (Burger and Gochfeld 1991). Second, these open spaces allow for movement within vegetation without the risk of entanglement, thus making common terns less susceptible to predation (Burger and Shisler 1978). Third, this amount of cover provides protection of chicks against avian and mammalian predators (by providing hiding cover) and protection of adults and chicks from harsh weather conditions (e.g., sun, wind, rain; Blokpoel et al. 1978). Finally, the vegetation creates a barrier that decreases the amount of visual contact between nests, thereby reducing territorial conflict between neighboring terns (Burger and Shisler 1978).

As vegetation grows tall (> 0.60 m) and dense (> 30% total cover) with succeeding years, common terns may abandon nest sites (Courtney and Blokpoel 1983, Shields and Townsend 1985, Burger and Gochfeld 1991). Dense vegetation creates a number of disadvantages for nesting common terns: disappearance of required landing sites (Palmer 1941), reduced visibility resulting in a reduction of social stimulation among colony members (Palmer 1941), increased risk of entanglement in thick vegetation making adults and chicks more susceptible to predation (Burger and Shisler 1978), and an inability to detect predators through loss of visual contact. These factors can decrease common tern reproductive success by either reducing mating (Palmer 1941) or causing adult, chick, and egg mortality (Burger and Shisler 1978).

Previous research has investigated the impacts of vegetation on common tern reproductive success and nest site selection on natural and human-made sites. In a newly established colony at the Eastern Headland, Toronto, Ontario, the relationship between nest sites and vegetation was investigated (Blokpoel et al. 1978). In a 130 x 215 m study plot on the headland (an elevated breakwater), vegetation cover within the plot was compared to vegetation cover around nests within the plot. Mean vegetation cover within the study plot (n = 495) was 16%. Greater (> 31%, $\bar{x}$ = 44%) vegetation cover occurred more frequently (χ^2 = 89.58, P < 0.001) around nests (n = 49) within the plot than areas where no nests where located. In the study plot, the majority of terns nested on or near broad bands of low and clumped vegetation parallel to bare beaches, indicating terns avoided nesting in areas with little or no vegetation (Blokpoel et al. 1978).

To determine how vegetation encroachment affected common tern nesting habits, researchers cleared vegetation from two islands in the Eastern Headland of Lake Ontario in April and May of 1982 (Morris et al. 1992). Common tern numbers rose from 13 breeding pairs on each island in 1981 to 218 and 562 breeding pairs in 1982. In succeeding years, no vegetation control was undertaken, and common terns abandoned the islands as vegetation height and density increased (Morris et al. 1992).

Other studies have examined the use of different substrate types and vegetation in determining preferred nesting sites of common terns. In one of these studies, researchers provided a choice of three substrate types on a breakwall in Lake Erie to test nesting substrate preferences of late-nesting common terns (Richards and Morris 1984). Terns preferred "super-enhanced" areas (103 nests) covered with small rocks and clumps (15-40 cm diameter) of mossy stonecrop (*Sedum acre*) and driftwood randomly distributed over the area to the enhanced (small rocks; 48 nests) and control (bare concrete; 15 nests) areas (Richards and Morris 1984). In addition, mean clutch size and fledging success were all higher on the super-enhanced substrate, suggesting that enhancement procedures are valuable management tools for improving reproductive success of late-nesting common terns (Richards and Morris 1984).

In a similar study of habitat enhancement in Lake Erie near Port Colbourne, Ontario, large and small rocks were spread over a breakwater area, and then small logs, driftwood, and debris were placed on the rocky substrate (Morris et al. 1992). Additionally, mossy stonecrop was planted in the substrate. Following these manipulations, common tern numbers rose from 906 breeding pairs in 1988 to 1,052 breeding pairs in 1989 (Morris et al. 1992).

In another experimental study on Long Island, Oneida Lake, New York, 5 nesting substrate types with 2 replicates each were set up in parallel strips to investigate nest site selection by common terns (Severinghaus 1982). The typical nesting substrate at this site was dried grass interspersed with stones of different sizes (control). The experimental substrates added were: dried grass, large stones ($\geq$ 2 times the size of a tern egg), medium stones (1-2 times egg size), and small stones ($\leq$ 1 egg size). Terns preferred (χ^2 = 25.1251, df = 4, $P < 0.05$) dried grass (21 nests) as a nesting substrate followed by the control (14 nests; Severinghaus 1982). Relatively fewer nests were found on the stone substrates (13 nests in 3 substrates; Severinghaus 1982). Nest site selection was not linked to nesting success in this study.

Vegetation manipulations were performed on Lime Island, located in the St. Mary's River, Michigan, to determine if reduced vegetation cover increased reproductive success (Cook 1999, Cook-Haley and Millenbah 2002). Common terns used an old coal dock connected to Lime Island as a nesting site in 1997 and 1998. The vegetation cover on Lime Island (81.5% in 1997) exceeded the 10 - 30% cover normally preferred by this species (Soots and Parnell 1975) and was believed to be negatively impacting common tern reproductive success by causing possible entanglement or becoming a barrier to predator detection (Cook 1999, Cook-Haley and Millenbah 2002).

In cooperation with the MDNR, vegetation manipulations were performed in 1998 to determine if vegetation cover was affecting common tern reproductive success. Two treatment types, complete herbiciding (spraying of all vegetation within the plot) and partial herbiciding (spraying of dense spots of vegetation within the plot), and a control were randomly applied to 5 x 5 m plots (n = 16 or 17 for each treatment). Common tern nest success on Lime Island in 1998 was affected by treatment type (χ^2 = 24.5, df = 9, P < 0.005; Cook-Haley and Millenbah 2002). Partial herbicide areas (41.3% total cover) had a lower than expected number of nests that failed to hatch any young (partial χ^2 = 4.5; P $\leq$ 0.10) and greater than expected number of nests that successfully hatched 2 young (partial χ^2 = 42.7; P $\leq$ 0.10; Cook-Haley and Millenbah 2002*)*. However, in the complete herbicide areas (24.4% total cover) a greater than expected number of nests failed to hatch young (partial χ^2 = 4.5; P $\leq$ 0.10) and a lower than expected number of nests hatched 3 young (partial χ^2 = 3.2; P $\leq$ 0.10; Cook-Haley and Millenbah 2002*)*. This study suggested that common terns have better nest success in areas that supported moderate amounts (40-50%) of total standing vegetation cover (partial herbicide), indicated by the tendency to hatch more young per nest (Cook-Haley and Millenbah 2002). All of these studies suggest that common terns prefer nesting in sparsely vegetated areas to areas with no vegetation or heavily vegetated areas.

The findings on Lime Island suggest that nesting common terns may tolerate greater amounts of cover in the northern Great Lakes than predicted by the literature (10-30%; Soots and Parnell 1975; Burger and Gochfeld 1991). Soots and Parnell (1975) and Burger and Gochfeld (1991) researched common terns inhabiting the east coast of the U. S. that may be susceptible to different weather conditions (i.e., hurricanes) and have different available nesting substrate than in the Great Lakes. The difference in these factors may explain why common terns seem to tolerate greater than predicted vegetation cover in the northern Great Lakes region.

Originally, one of the purposes of this study was to continue investigating the impacts of vegetation manipulations on common tern reproductive success on Lime Island by repeating the 1998 study and determining if the conclusions of the 1998 study could be either supported or refuted. However, in 1999, following flooding and predation by a long-tailed weasel (*Mustela frenata*) and ring-billed gulls, common terns abandoned Lime Island as a nesting site in early June (Millenbah and Lamp 1999). In 1999, researchers were unable to follow common terns after they abandoned Lime Island; therefore reproductive success in 1999 is unknown. In 2000 and 2001, common terns did not return to Lime Island to nest but were found nesting on two natural sites in the St. Mary's River: Andrews Reef and Harbor Island Reef.

The purpose of this research was to assess common tern reproductive success in the St. Mary's River (1997-1998 and 2000-2001) and determine how vegetation cover affects reproductive success. The common tern is listed as a threatened species in

Michigan (Scharf 1991), with the St. Mary's River currently supporting the largest number of common terns in the state of Michigan (> 50% of breeding pairs; Cuthbert et al. 1997). Therefore, efforts to assess common tern reproductive success and factors affecting success in the St. Mary's River are necessary. By assessing vegetation cover and its effects on common tern reproductive success, management recommendations can be made to continue the existence of this species in Michigan. These management recommendations may also be applicable to other common terns colonies in the northern Great Lakes region.

OBJECTIVES

Specific objectives of this study were to:

1) determine the reproductive success of common terns in the St. Mary's River;
2) quantify the vegetation cover of different common tern nesting sites in the St. Mary's River;
3) determine the effects of vegetation cover on common tern reproductive success among different nesting sites in the St. Mary's River; and
4) make management recommendations for common terns in the St. Mary's River.

METHODS

The Lime Island common tern colony was monitored and observed from 5 June to 8 August 1997 and 21 May to 1 August 1998 (Cook 1999). Andrews Reef and Harbor Island Reef common tern colonies were monitored and observed from 12 June to 3 August 2000 and 8 May to 21 July 2001 to obtain data on reproductive success and vegetation cover.

Nest Checks and Survival Estimates

Nest checks, completed every 3-6 days, were used to estimate reproductive success. Nesting variables recorded at nests included date of egg laying, number of eggs, 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 unique number using a permanent marker on a rock or wooden dowel to allow nests to be followed until hatching, fledging, or until the nest was destroyed or abandoned. Attempts were made to follow all chicks until fledging. To facilitate following chicks to fledging, chicks were hand captured and banded using a USFWS #2 steel band and one stripe celluloid color band. Chicks were banded only after they were completely dry. Appropriate state and federal banding, capturing, and handling permits were obtained from the MDNR and USFWS. Chicks were aged according to criteria presented by Nisbet and Drury (1972). Re-nesting attempts were also followed. All methods for capturing and banding adults and chicks were approved by Michigan State University's All-University Committee on Animal Use and Care (AUF # 02/99-017-00).

Daily and period survival estimates for eggs and chicks were calculated using the Mayfield method (Mayfield 1961). Daily survival is the survival from the beginning of one day to the next, and period survival is the survival from initiation of incubation to hatching (eggs) and hatching to fledging (chicks). The Mayfield method calculates survival based on deaths and exposure days. Survival estimates were made for two time periods: 1) from initiation of incubation to hatching and 2) from hatching to fledging. Eggs were used as the experimental unit from initiation of incubation to hatching and 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 mean of 12 exposure days. Egg and chick period survivals 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 (Burger and Gochfeld 1991). Chicks were considered fledged if they were last recorded at ≥ 18 days of age. Chicks younger than 18 days of age on last capture and not found dead were considered censored (fate unknown).

Exposure days for censored eggs and chicks were incorporated into the Mayfield estimates using the midpoint method that terminates exposure days at the midpoint between the last day eggs or chicks were known to be active and the first day eggs or chicks were known to be inactive (Manolis et al. 2000). Censored individuals were included in Mayfield estimation because their exclusion results in an underestimate (Manolis et al. 2000)

Vegetation Cover

A 50 X 50 cm modified Daubenmire frame (Daubenmire 1959) was centered at each nest and vegetation measurements were taken to determine vegetation cover around nests and to compare differences in vegetation cover 1) between successful and unsuccessful nests within a nesting site, 2) between nests and random points within a nesting site, and 3) at nests among nesting sites. Vegetation variables included percent live, dead, forb, grass, and woody cover as well as estimates of percent bare ground, percent litter cover, and vegetation height. Vegetation variables were measured after a completed clutch of eggs was present in the nest cup. Vegetation variables were measured at 79 nests and paired random points and 69 nests and paired random points on Lime Island in 1997 and 1998, respectively (Cook 1999). In 2000 and 2001, vegetation variables were measured at 50 nests and paired random points on Andrews Reef and 52 and 50, respectively, nests and paired random points on Harbor Island Reef. Vegetation measurements were taken at paired random points to determine if particular vegetation characteristics are associated with nest placement. Paired points were chosen randomly in places where no nests were located by walking three paces in a random direction from each nest location.

Data Analysis

Vegetation Comparisons within Nesting Sites

Vegetation variables between successful and unsuccessful nests at each nesting site were compared ($P \leq 0.05$; Mann-Whitney U (MWU); Mann and Whitney 1947) to determine if specific vegetation variables were associated with successful nesters. A nest was considered successful if at least one young hatched and unsuccessful if no young hatched. Vegetation variables were also compared ($P \leq 0.05$; MWU) between nests and random points on each nesting site. This comparison was used to determine if nest placement was associated with specific vegetation variables. Multi-year data were pooled within nesting sites. Although there were significant differences ($P \leq 0.05$) between years for some vegetation characteristics at each nesting site, the vegetation variables identified as significantly different between successful and unsuccessful nests and nests and random points were similar when multi-year data were pooled for each nesting site. Therefore, multi-year data were pooled to evaluate each nesting site as a whole.

Vegetation Comparisons among Nesting Sites

A Kruskal-Wallis (KW) one-way analysis of variance ($P \leq 0.05$; Siegel 1956) was used to determine if there was a significant difference in vegetation cover among nesting sites used by common terns in the St. Mary's River from 1997-2001 (Lime Island, Andrews Island Reef, and Harbor Island Reef). Multi-year data were pooled within each nesting site for reasons similar to those outlined in the previous section. If significant differences were found using a KW, a KW mutiple-comparison z-test ($z > 1.96$) was used to identify specific differences. Since no vegetation manipulations were performed on Andrews Island Reef and Harbor Island Reef in 2000 or 2001, only vegetation data collected in the unmanipulated (Cook 1999) area on the Lime Island coal dock in 1997 and 1998 were used in the statistical comparisons mentioned above.

Vegetation Cover and Nest Success

Logistic regressions were performed to determine if vegetation cover could be used to predict nest success. Logistic regression was chosen because nest success is a binary response variable (i.e., successful or unsuccessful). One and 2-variable models were run for common tern nests at each nesting site (multi-year data pooled for reasons mentioned previously). Covariates in the 1-variable models were either percent total cover, bare ground, litter cover, or vegetation height. Percent total cover and vegetation height, percent bare ground and vegetation height, and percent litter cover and vegetation height were the covariates in the 2-variable models. Since percent total cover, bare ground, and litter cover are not independent variables (i.e., % total cover + % bare ground + % litter cover = 100%), these were not incorporated in the same logistic regressions. Percent live, dead, grass, forb, and woody cover were not included in the regression analysis because they are not independent of percent total cover. Height was included in the 2-variable models because vegetation height is independent of the other vegetation variables measured. All logistic regressions were conducted with a 0.20 model selection cutoff criteria (Hosmer and Lemeshow 2000) using a forward variable selection. Variables were considered significant at $P \leq 0.10$.

Vegetation Cover and Survival

A Spearman rank correlation ($P \leq 0.05$) was used to determine correlations between vegetation characteristics and common tern egg and chick survivals. Using the same rationale outlined in the logistic regression section, percent total and litter cover, percent bare ground, and vegetation height were the only vegetation characteristics used in the correlation analysis.

RESULTS

Nest Checks and Banding

Common tern nests and chicks were first observed between 17 May and 17 June and 5 June and 24 June, respectively, from 1997-2001 (Cook 1999). Common terns departed the St. Mary's River area between mid-July and mid-September from 1997-2001 (Cook 1999).

The total number of chicks banded and the average number of chicks hatched per pair were the greatest on Lime Island in 1997 (1,475 and 2.27, respectively; Cook 1999; Table 1). When common terns were not nesting on Lime Island, the greatest number of chicks was banded on Andrews Reef in 2001 (n = 254; Table 1) and the greatest number of chicks hatched per pair occurred on Andrews Reef in 2000 (1.92; Table 1). More chicks fledged per pair on Andrews Reef in 2000 (0.70) than any other year. The poorest fledging success occurred on Lime Island in 1998 (0.21 chicks fledged/pair; Table 1).

The mean number of chicks hatched per pair ranged from 1.78 on Harbor Island Reef to 1.88 on Andrews Reef (Table 1). The mean number of chicks fledged per pair was the greatest on Harbor Island Reef (0.69) and the lowest on Lime Island (0.42; Table 1).

Vegetation Comparisons within Nesting Sites

Nests vs. Random Points

On Lime Island, percent bare ground was greater ($P = 0.005$) around nests than random points (Table 2). Conversely, percent litter cover was greater ($P < 0.001$) around

Table 1. Number of breeding pairs (greatest number of active nests on a given day), total number of chicks banded, number of chicks hatched per pair, mean number of chicks hatched per pair, number of chicks fledged per pair, and mean number of chicks fledged per pair for common terns nesting in the St. Mary's River, Michigan, summers 1997-1998 and 2000-2001.

Year and Site	Number of Breeding Pairs	Total Number of Chicks Banded	Number of Chicks Hatched per Pair	Mean Number of Chicks Hatched per Pair	Number of Chicks Fledged per Pair	Mean Number of Chicks Fledged per Pair
1997 Lime Isl.*	649	1,475	2.27	1.87	0.65	0.42
1998 Lime Isl.*	727	1,130	1.51		0.21	
2000 Andrews Reef	186	196	1.83	1.88	0.70	0.52
2001 Andrews Reef	288	254	1.92		0.41	
2000 Harbor Isl. Reef	63	191	1.77	1.78	0.68	0.69
2001 Harbor Isl. Reef	137	227	1.78		0.69	

*numbers reported are from data gathered on the entire area of the Lime Island coal dock, which includes the manipulated and unmanipulated areas (Cook 1999).

Table 2. Mean (SE) vegetation characteristics at common tern nests and random points on Lime Island, Michigan (summers 1997 and 1998).

Characteristic	Nests (n = 148)	Random Points (n = 148)
% Total Cover	70.3 (2.2)	65.6 (2.3)
% Live Cover	59.7 (2.1)	54.6 (2.2)
% Grass Cover	57.8 (2.1)	52.0 (2.2)
% Forb Cover	2.2 (0.8)	2.6 (0.9)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	10.6 (1.0)	11.0 (1.1)
% Bare Ground*	5.9 (1.1)	4.7 (1.2)
% Litter Cover*	23.8 (1.9)	29.7 (2.1)

*significantly different (Mann-Whitney U (MWU) test, $P \leq 0.05$)

random points than around nests (Table 2). Nests and random points on Lime Island were not significantly different for any other vegetation variables. Since no measurements of vegetation height were taken in 1997, vegetation height was not compared between nests and random points on Lime Island.

There was a greater ($P = 0.03$ and $P < 0.0001$, respectively) percentage of dead and litter cover around common tern nests than random points and a greater ($P < 0.001$) amount of bare ground around random points than nests on Andrews Reef (Table 3). No other vegetation variables were significantly different between nests and random points on Andrews Reef.

On Harbor Island Reef, percent total and live cover were greater ($P = 0.04$ for both variables) around random points than around nests (Table 4). Percent litter cover was greater ($P < 0.0001$) around common tern nests than around random points (Table 4). No significant differences were found between nests and random points for any other vegetation variables (Table 4).

Common vegetation species found growing on the Lime Island coal dock in 1997 and 1998 and on Andrews Reef and Harbor Island Reef in 2000 and 2001 are listed in Appendix 1.

Successful vs. Unsuccessful Nests

There were no significant differences between successful and unsuccessful nests for any vegetation variables measured on Lime Island (Table 5) or Andrews Reef (Table 6).

On Harbor Island Reef, successful nests had a greater ($P = 0.04$, $P = 0.03$,

Table 3. Mean (SE) vegetation characteristics at common tern nests and random points on Andrews Reef, Michigan (summers 2000 and 2001).

Characteristic	Nests (n = 100)	Random Points (n = 100)
% Total Cover	21.2 (2.6)	23.2 (3.0)
% Live Cover	21.1 (2.6)	23.2 (3.0)
% Grass Cover	14.9 (2.3)	14.4 (2.6)
% Forb Cover	5.7 (1.7)	8.6 (2.2)
% Woody Cover	0.1 (0.1)	0.1 (0.1)
% Dead Cover*	0.6 (0.3)	0.2 (0.2)
% Bare Ground*	61.9 (3.0)	73.4 (3.1)
% Litter Cover*	17.0 (1.2)	3.4 (0.4)
Height (cm)	12.2 (1.4)	12.4 (1.5)

*significantly different (Mann-Whitney U (MWU) test, $P \leq 0.05$)

Table 4. Mean (SE) vegetation characteristics at common tern nests and random points on Harbor Island Reef, Michigan (summers 2000 and 2001).

Characteristic	Nests (n = 102)	Random Points (n = 102)
% Total Cover*	36.3 (2.2)	46.6 (3.4)
% Live Cover*	36.0 (2.2)	46.3 (3.4)
% Grass Cover	20.1 (2.4)	28.3 (3.5)
% Forb Cover	13.0 (1.9)	16.1 (2.8)
% Woody Cover	0.5 (0.4)	0.0 (0.0)
% Dead Cover	2.6 (0.5)	2.1 (0.7)
% Bare Ground	45.5 (2.4)	46.8 (3.5)
% Litter Cover*	18.3 (1.1)	6.6 (1.1)
Height (cm)	26.3 (1.6)	24.8 (1.8)

*significantly different (Mann-Whitney U (MWU) test, $P \leq 0.05$)

Table 5. Mean (SE) vegetation characteristics at successful (those that hatched at least one young) and unsuccessful (those that did not hatch any young) common tern nests on Lime Island, Michigan (summers 1997 and 1998).

Characteristic	Successful (n = 93)	Unsuccessful (n = 40)
% Total Cover	66.9 (2.9)	74.3 (3.4)
% Live Cover	58.4 (2.7)	62.1 (3.5)
% Grass Cover	56.5 (2.7)	61.1 (3.5)
% Forb Cover	1.9 (0.9)	1.1 (0.6)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	8.5 (1.5)	12.1 (1.9)
% Bare Ground	5.6 (1.4)	5.8 (1.5)
% Litter Cover	27.4 (2.6)	20.0 (3.2)

Table 6. Mean (SE) vegetation characteristics at successful (those that hatched at least one young) and unsuccessful (those that did not hatch any young) common tern nests on Andrews Reef, Michigan (summers 2000 and 2001).

Characteristic	Successful (n = 20)	Unsuccessful (n = 38)
% Total Cover	28.8 (6.1)	15.4 (3.7)
% Live Cover	28.8 (6.1)	15.4 (3.7)
% Grass Cover	13.8 (4.5)	10.4 (3.2)
% Forb Cover	15.0 (6.1)	4.3 (2.1)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	0.0 (0.0)	0.7 (0.5)
% Bare Ground	50.8 (6.6)	67.8 (4.6)
% Litter Cover	20.5 (3.0)	16.8 (2.0)
Height (cm)	15.3 (2.8)	8.4 (1.7)

$P < 0.0001$, and $P = 0.004$, respectively) percentage of total, live, grass, and dead cover around them than did unsuccessful nests (Table 7). Percent forb cover and bare ground were greater ($P < 0.0001$ and $P = 0.006$, respectively) around unsuccessful nests than around successful nests (Table 7).

Vegetation Comparisons among Nesting Sites

Percent total, live, grass, forb, and dead cover and percent bare ground were different ($P < 0.0001$ for all 6 variables) among all nesting sites (Table 8). Percent total cover was greater around nests on Lime Island than on either Andrews Reef or Harbor Island Reef ($z = 11.52$ and $z = 7.95$, respectively; Table 8). Percent total cover was greater ($z = 3.33$) around Harbor Island Reef nests than around Andrews Reef nests (Table 8). Percent bare ground was lower around Lime Island nests than around either Andrews Reef or Harbor Island Reef nests ($z = 13.66$ and $z = 11.17$, respectively; Table 8). Andrews Reef nests had a greater ($z = 2.35$) percent bare ground around them than did Harbor Island Reef nests (Table 8). Vegetation was taller ($P < 0.0001$) around Harbor Island Reef nests than around Andrews Reef nests (Table 8). Neither percent woody cover nor percent litter cover was different among nesting sites (Table 8).

Vegetation Cover and Nest Success

On Lime Island, the 1-variable model with percent litter cover was the only model that predicted nest success (Table 9). Percent litter cover was negatively associated ($\beta = -0.014$, $P = 0.10$) with nest success. On Andrews Reef, the 1- variable models with percent total cover, percent bare ground, and vegetation height correctly predicted nest

Table 7. Mean (SE) vegetation characteristics at successful (those that hatched at least one young) and unsuccessful (those that did not hatch any young) common tern nests on Harbor Island Reef, Michigan (summers 2000 and 2001).

Characteristic	Successful (n = 33)	Unsuccessful (n = 30)
% Total Cover*	42.0 (4.0)	28.7 (4.0)
% Live Cover*	41.8 (4.0)	28.0 (4.0)
% Grass Cover*	35.5 (3.9)	12.5 (3.9)
% Forb Cover*	1.4 (1.0)	14.9 (3.5)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover*	5.1 (1.2)	1.3 (0.8)
% Bare Ground*	37.3 (3.9)	54.8 (4.6)
% Litter Cover	21.1 (2.0)	16.5 (1.8)
Height (cm)	27.4 (2.2)	21.1 (2.5)

*significantly different (Mann-Whitney U (MWU) test, $P \leq 0.05$)

Table 8. Mean (SE) vegetation characteristics around common terns nests on all nesting sites in the St. Mary's River, Michigan, summers 1997-1998, 2000-2001.

Characteristic	Lime Island 1997-1998 (n = 148)	Andrews Reef 2000-2001 (n = 100)	Harbor Island Reef 2000-2001 (n = 102)
% Total Cover*	70.3 (2.1)^{A}	21.2 (2.5)^{B}	36.3 (2.5)^{C}
% Live Cover*	59.7 (2.0)^{A}	21.1 (2.5)^{B}	36.0 (2.4)^{C}
% Grass Cover*	57.8 (1.4)^{A}	1.0 (1.7)^{B}	2.7 (1.7)^{B}
% Forb Cover*	2.2 (1.6)^{A}	20.0 (1.9)^{B}	32.7 (1.9)^{C}
% Woody Cover	0.0 (0.2)	0.2 (0.2)	0.5 (0.2)
% Dead Cover*	10.6 (0.7)^{A}	0.1 (0.8)^{B}	0.3 (0.8)^{B}
% Bare Ground*	5.9 (1.8)^{A}	61.9 (2.2)^{B}	45.5 (2.2)^{C}
% Litter Cover	23.8 (1.5)	17.0 (1.8)	18.3 (1.8)
Height[1] (cm)**	______	12.2 (1.5)^{A}	26.3 (1.5)^{B}

[1]vegetation height was not measured in 1997.
*significantly different among nesting sites (KW, $P \leq 0.05$). Within a row, means having the same letter are not significantly different (multiple comparison z-test, $z < 1.96$).
**significantly different between nesting sites (MWU, $P \leq 0.05$).

success 63.8%, 62.1%, and 70.7% of the time, respectively (Table 9). Percent total cover and height were negatively associated (β = -2.14, P = 0.06 and β = -5.03, P = 0.04, respectively) with nest success whereas percent bare ground was positively associated (β= 2.00, P = 0.04) with nest success. On Harbor Island Reef, all of the 1-variable models were significant (Table 9). Percent total cover, bare ground, and litter cover and vegetation height correctly predicted nest success 61.9%, 60.3%, 63.55, and 60.3% of the time, respectively (Table 9). Percent total cover, litter cover, and height were negatively associated (β = -2.65, P = 0.03; β = -4.11, P = 0.10; and β = -3.67, P = 0.07, respectively) with common tern nest success. Conversely, percent bare ground was positively associated (β = 3.10, P = 0.01) with nest success. None of the 2-variable models for any nesting site were significant.

Survival Estimates

Daily survival estimates for common tern eggs in the St. Mary's River from initiation of incubation to hatching ranged from 94.4 % to 98.5% (Table 10). Period survival rates (L = 24) from egg-laying to hatching ranged from 25.3% on Lime Island to 69.5% on Andrews Reef (Table 10). Censoring of nests was greater than 10% in 1998, 2000, and 2001, violating the assumption of allowable censoring (< 10%; Mayfield 1961). Therefore, care should be taken in interpreting these results.

Daily survival estimates for common tern chicks in the St. Mary's River from hatching to fledging ranged from 97.1% to 99.6% (Table 11). Period survival (L = 28) of chicks from hatching to fledging ranged from 43.6% on Lime Island to 88.7% on Andrews Reef (Table 11). Censoring of chicks exceeded 10% in all years; therefore care

Table 9. One-variable models for predicting nesting success from vegetation variables collected at common tern nests in the St. Mary's River, Michigan, 1997-1998, and 2000-2001.

Model	χ^2	P-value	Concordance[a]
Lime Island - 1997 and 1998 (n = 133)			
% Total Cover	2.29	0.13	69.92
% Bare Ground[b]	0.00	1.00	69.92
% Litter Cover	2.89	0.09	69.92
Height[b]	0.00	1.00	81.16
Andrews Reef - 2000 and 2001 (n = 58)			
% Total Cover	3.71	0.05	63.79
% Bare Ground	4.40	0.04	62.07
% Litter Cover[b]	0.00	1.00	65.52
Height	4.43	0.04	70.69
Harbor Island Reef - 2000 and 2001 (n = 63)			
% Total Cover	5.39	0.02	61.90
% Bare Ground	8.17	0.004	60.32
% Litter Cover	2.86	0.09	63.49
Height	3.52	0.06	60.32

[a] percent likelihood of correctly classifying nests as successful or unsuccessful based on the model.
[b] using forward variable selection, these variables were not included in the model; therefore, a χ^2 of 0.00 was obtained.

Table 10. Daily (S_d) and period (S_p) survival rates (SD; Mayfield 1961) of common tern eggs on three nesting sites in the St. Mary's River, Michigan, summers 1997-1998 (Lime Island) and 2000-2001 (Andrews Reef and Harbor Island Reef).

Nesting Site	S_d	S_p
Lime Island*	0.9444	0.2530
Andrews Reef	0.9849 (0.0010)	0.6949 (0.0167)
Harbor Island Reef	0.9830 (0.0017)	0.6627 (0.0281)

* Cook 1999; data needed to calculate SD not available for Lime Island

Table 11. Daily (S_d) and period (S_p) survival rates (SD; Mayfield 1961) of common tern chicks on three nesting sites in the St. Mary's River, Michigan, summers 1997-1998 (Lime Island) and 2000-2001 (Andrews Reef and Harbor Island Reef).

Nesting Site	S_d	S_p
Lime Island*	0.9708	0.4361
Andrews Reef	0.9957 (0.0012)	0.8866 (0.0285)
Harbor Island Reef	0.9946 (0.0015)	0.8597 (0.0332)

* Cook 1999; data needed to calculate SD not available for Lime Island

should be taken when interpreting these results.

Although adults were trapped for band returns, no survival estimates could be calculated for sub-adult or adult breeders (due to lack of adequate return data). A summary of adult trapping results and band returns is shown in Appendix 2.

Vegetation Cover and Survival

Percent total cover was negatively correlated with egg survival ($r_s = -0.94$, $P = 0.005$). Percent bare ground was positively correlated with egg ($r_s = 0.89$, $P = 0.02$) and chick survivals ($r_s = 0.83$, $P = 0.04$). Percent total ($r_s = -0.66$, $P = 0.16$) and litter cover ($r_s = -0.77$, $P = 0.07$) were negatively correlated with chick survival, but these differences were not significant. There were no significant correlations between percent litter cover and egg survival or between vegetation height and either egg or chick survival. Figure 1 shows a comparison between egg and chick survival rates and vegetation cover on Lime Island and Andrews and Harbor Island Reefs.

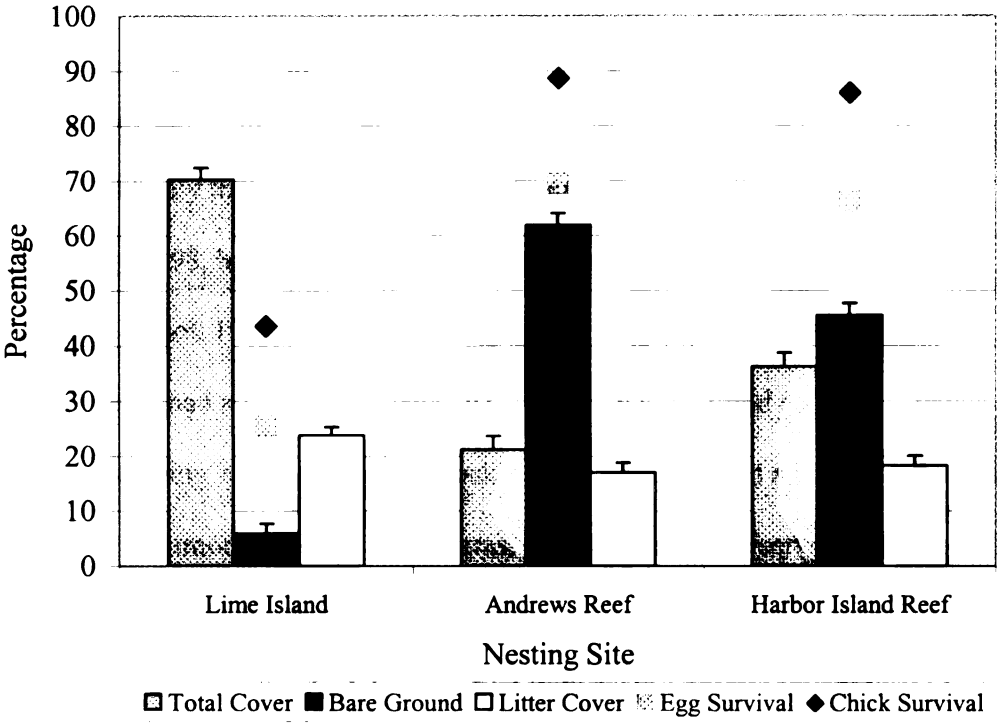

Fig. 1. Egg and chick survival rates and mean percent total cover, bare ground, and litter cover on the three nesting sites used by common terns in the St. Mary's River, Michigan, 1997-1998 and 2000-2001.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Nest Checks and Banding

It is likely that common terns began nesting on Lime Island before 5 June 1997 and 21 May 1998, but due to weather, researchers were unable to reach the island before those dates (Cook 1999). In 1999, researchers arrived on Lime Island on 26 May, and common terns had already established nests. Following a flood on 3 June, which left 2 inches of standing water on the coal dock, ring-billed gulls and a long-tailed weasel were seen eating common tern eggs (W. Mieras, pers. comm.). I observed the long-tailed weasel entering and leaving the colony on two occasions and captured the weasel crossing the bridge to the coal dock on film with a Trail-Master trail monitor (Goodson and Associates, Inc., Lenexa, Kansas) connected to a 35-mm camera. Cached and crushed eggs were further evidence of weasel predation within the colony (pers. observ.). Weasels have been reported to destroy colonies in Massachusetts (Austin 1929), and ring-billed gulls can be significant egg predators of common terns (Cuthbert et al. 1984).

Following the flooding and predation events in 1999, common terns abandoned Lime Island as a nesting site in early June (pers. observ.) Because I was unable to follow common terns to other nesting sites in 1999, survival rates are unknown in the St. Mary's River for 1999. Some of the terns from Lime Island re-nested on Little Cass Island in the St. Mary's River (T. Ludwig, pers. comm.). In 2000, common terns did not return to Lime Island to nest, and I was unable to locate the new common tern nesting sites until mid-June of that year. In 2001, common terns began nesting sometime between 8 or 9 May and May 17. When I visited Andrews Reef and Harbor Island Reef on 8 May and 9 May, respectively, common terns were observed displaying courtship rituals and copulating, but no nests had been laid. When I returned on 17 May, common tern nests were observed on both islands.

The number of common tern breeding pairs in the St. Mary's River fluctuated from 649 in 1997 to 727 in 1998, 249 in 2000, and 425 in 2001. Since I was unable to reach common tern nesting sites until mid-June in 2000, the estimate of number of breeding pairs in that year is an underestimate. By mid-June, many chicks had already hatched and were moving out of their nests, making it difficult to associate chicks with nests and estimate the total number of nests. The number of breeding pairs in 2000 is also an underestimate for the St. Mary's River as a whole. There were 4 small colonies (< 50 breeding pairs on each) in the northern part of the St. Mary's River (T. Ludwig pers. comm.) that were too far away for researchers to monitor intensively. The total number of breeding pairs in the St. Mary's River during 2000 was therefore at least 400 – 500 pairs. The only islands used by common terns in the St. Mary's River in 2001 were Andrews Reef and Harbor Island Reef (T. Ludwig, pers. comm.), therefore 425 breeding pairs is an accurate estimate of the population size in 2001. Overall, the number of breeding pairs, and thus the population size, of common terns using the St. Mary's River area appears to have decreased since 1997. It is possible that some individuals that nested on Lime Island in 1997 and 1998 may have nested on the Canadian side of the St. Mary's River or other areas in Michigan in 2000 and 2001, resulting in the apparent decrease in breeding pairs over time.

It is believed that common tern colonies require 1.1 young fledged/pair to maintain a stable breeding population (DiConstanzo 1980). The weighted mean number of chicks fledged/pair on Lime Island, Andrews Reef, and Harbor Island Reef were

61.8%, 52.7%, and 37.3% less than the required chicks/pair, respectively (Table 1). The weighted mean number of chicks fledged per pair on all nesting sites was less than the required 1.1 chicks fledged pair, indicating a declining population in the St. Mary's River. Long-term population persistence is discussed thoroughly in Chapter 3 of this document.

As mentioned previously, the number of breeding pairs on both Andrews and Harbor Island Reefs in 2000 was an underestimate. Since the numbers of chicks hatched per pair and fledged per pair is based on the number of breeding pairs, these values for Andrews and Harbor Island Reefs in 2000 (Table 1) are overestimates. It is thus likely that the number of chicks hatched and fledged per pair were less than 1.83 and 0.70, respectively, on Andrews Reef and 1.77 and 0.68, respectively, on Harbor Island Reef.

Vegetation Comparisons within Nesting Sites

Nest vs. Random Points

Across all nesting sites the only consistently significant difference in vegetation cover between areas where common terns nested and areas they did not nest (i.e., random points) was mean percent litter cover. On Lime Island, there was significantly less litter cover around nests (23.8%) than around random points (29.7%; Table 2). On Andrews Reef and Harbor Island Reef 2000, there was significantly more litter cover around nests (17.0% and 18.3%, respectively) than around random points (3.4% and 6.6%, respectively; Table 3 and Table 4). These results indicate that common terns nesting in the St. Mary's River are preferentially building their nests in areas where there is approximately 15-25% litter cover. Excess litter cover can increase the chance of chick entanglement and susceptibility to predation (Burger and Shisler 1978); therefore, common terns may be avoiding litter cover greater than 25% on these nesting sites.

Successful vs. Unsuccessful Nests

There were no consistent differences in vegetation characteristics between successful and unsuccessful nests among nesting sites. On Harbor Island Reef, successful nests had greater percent total, live, and grass cover and less percent bare ground than did unsuccessful nests (Table 7). However, there were no significant differences between successful and unsuccessful nests on either Lime Island (Table 5) or Andrews Reef (Table 6). Therefore, no vegetation characteristics seemed to have a consistently strong impact on the success of common tern nests.

It is possible that nest success was influenced by more minute differences in vegetation that were not measured in this study or the study done in 1997 and 1998 (Cook 1999). Additionally, there are other factors such as predation (Hatch 1970, Morris and Hunter 1976, Scharf 1991, Ludwig 1991, Burness and Morris 1992), competition with ring-billed gulls (Morris and Hunter 1976, Scharf 1981, Scharf and Shugart 1985, Ludwig 1991), food availability (Courtney and Blokpoel 1980; Safina et al. 1988) parental incubation attentiveness (Courtney 1976), and weather conditions (e.g., wind, heavy rain, and waves; Blokpoel et al. 1978) influencing nest success.

Vegetation Comparisons among Nesting Sites

Among nesting sites, Andrews Reef supports the lowest percent total cover (21.2%) and highest percent bare ground (61.9%), followed by Harbor Island Reef nests with intermediate percentages of total cover (36.3%) and bare ground (45.5%) and Lime Island nests with the highest percent total cover (70.3%) and lowest percent bare ground (5.9%; Table 8). Percent litter cover does not differ among nesting sites. It is interesting to note that 82.2% of the total cover on Lime Island is comprised of grass cover, while on Andrews Reef and Harbor Island Reef, forb cover accounts for 94.3% and 90.1% of the total cover on each site. This difference is not surprising and is due to the nature of the three nesting sites. The Lime Island coal dock is a man-made site that was seeded with grasses by the MDNR (Cook 1999) whereas Andrews Reef and Harbor Island Reef are natural, rocky reefs in the early stages of succession with vegetation composed primarily of forb species.

During 2001, vegetation on Andrews Reef and Harbor Island Reef was denser and taller than 2000 (pers. observ.). By mid-July 2001, common terns had vacated Andrews Reef and Harbor Island Reef. Since common terns are known to abandon sites when the vegetation grows taller than 0.60 m (Morris et al. 1980, Courtney and Blokpoel 1983, Shields and Townsend 1985, Burger and Gochfeld 1991, Morris et al. 1992) and the vegetation had grown to a height of approximately 1 meter on Andrews Reef and 1.5 m on Harbor Island Reef by mid-July 2001, it is likely that common terns vacated both sites early because of tall, dense vegetation.

Vegetation Cover and Nest Success

Logistic regression analyses indicate that none of the vegetation variables measured (e.g., percent total cover, percent bare ground, percent litter cover, and vegetation height) consistently predicts nest success among the nesting sites used in the

St. Mary's River. Percent total cover, percent bare ground, and vegetation height were predictors of nest success on Andrews and Harbor Island Reefs but not on Lime Island (Table 9). Percent litter cover predicted nest success on Lime Island and Harbor Island Reef, but not on Andrews Reef (Table 9).

Predictions from logistic regressions run for Lime Island, Andrews Reef, and Harbor Island Reef vegetation variables support the pattern seen in comparisons between successful and unsuccessful nests (i.e., quantitative differences in mean vegetation characteristics between successful and unsuccessful nests) for each nesting site. However, due to the dissimilarity of logistic regressions and MWU tests, statistical differences were not always found for the same vegetation variable in both analyses. For instance, there was no significant difference between successful and unsuccessful nests in percent total cover, bare ground, or vegetation height on Andrews Reef (MWU; Table 6) but the same vegetation variables were predictors of nest success in logistic regression analyses for Andrews Reef (Table 9).

Survival Estimates

Common tern egg survival was highest on Andrews Reef (69.5%) followed by Harbor Island Reef (66.3%) and Lime Island (25.3%; Table 10). Following the same pattern, common tern chick survival was highest on Andrews Reef (88.7%) followed by Harbor Island Reef (86.0%), and Lime Island (43.6%; Table 11). On all nesting sites, chick censoring exceeded the allowable level of censoring (10%; Mayfield 1961). Therefore, chick survival rates should be interpreted with caution.

Lower egg and chick survivals on Lime Island were due in part to heavy weasel predation on the site in 1998 (Cook 1999). Because excess vegetation cover can cause chicks to become entangled and increase susceptibility to predation (Burger and Shisler 1978) and decrease open spaces used by adults to detect predators (Palmer 1941), effects of weasel predation were likely exacerbated by excess total standing vegetation cover on Lime Island.

Common terns nesting on Andrews Reef and Harbor Island Reef were not affected by mammalian predation because the reefs are not connected to a mainland area (a potential source of mammalian predators). Therefore, unlike common terns nesting on Lime Island, those nesting on Andrews and Harbor Island Reef did not experience decreased survival due to weasel or other mammalian predation.

Vegetation Cover and Survival

There were distinct differences in vegetation cover and common tern egg and chick survival rates between Lime Island and Andrews Reef and Harbor Island Reef (Fig. 1). Total vegetation cover was greater and the amount of bare ground was less on Lime Island than on Harbor Island Reef; and total vegetation cover was greater and the amount of bare ground was less on Harbor Island Reef than on Andrews Reef. The opposite trend was seen in survival rates. Overall survival was the highest on Andrews Reef followed by Harbor Island Reef and Lime Island (Fig. 1). Correlation analyses provide evidence egg and chick survival rates may be linked to vegetation cover: as percent total cover increases, egg survival decreases and as percent bare ground increases, egg and chick survivals increase.

Since survival rates were the highest on Andrews Reef and Harbor Island Reef, and vegetation cover was lowest on these two sites (2.12% on Andrews Reef and 36.3% on Harbor Island Reef), these results suggest that common terns in the St. Mary's River have the highest survival in areas with 20-40% cover and > 40% bare ground.

Results from the study conducted on Lime Island in 1997 and 1998, which investigated the impacts of vegetation manipulations on common tern reproductive success, suggest that terns have better nest success in moderate amounts (40-50%) of total standing vegetation cover and lower amounts of litter cover (< 53%; Cook-Haley and Millenbah 2002). In another study of common terns in the Great Lakes, researchers found that vegetation cover around common tern nests on a human-made peninsula in Ontario ranged from 30-50% (Blokpoel et al. 1978). However, survival was not estimated or related to vegetation cover around nests.

I speculate that common terns in the St. Mary's River and the northern Great Lakes region may experience better reproductive success in different amounts of total vegetation cover depending on whether they nest on a human-made or natural site. When nesting on naturally occurring islands like Andrews Reef or Harbor Island Reef, common terns appear to have better reproductive success in low to moderate amounts (20-40%) of total vegetation cover, whereas when nesting on human-made sites like Lime Island terns experience better reproductive success in moderate amounts (40-50%) of total vegetation cover (Cook-Haley and Millenbah 2002). The coal dock common terns utilized as a nesting site on Lime Island is connected to the main island by a bridge, providing predators with easy access to the nesting colony (Cook 1999, pers. observ.). Forty to 50 percent vegetation cover may provide the needed hiding cover for chicks yet allow for enough open space for visual detection and signaling of predators by adults. On natural sites like Andrews and Harbor Island Reefs, which have no direct source of mammalian predators, common terns may not require as much vegetation cover for hiding from predators. Future research on sources of predation and predation rates on both types of nesting sites is needed to address this hypothesis.

It is also possible that common terns have simply adapted to a greater amount of vegetation cover on human-made sites like Lime Island, which supports greater vegetation cover than natural sites. Natural sites are periodically submerged, depending on seasonal and annual water level fluctuations, and generally tend to support less vegetation cover.

Another year of research on Lime Island, in which managers replicate the vegetation manipulations performed in 1998 (Cook 1999), is needed to either support or refute the results of that study. If managers conclude common terns experience better reproductive success in 40-50% total vegetation cover, the Lime Island coal dock should be manipulated to reduce the vegetation cover on the entire nesting area to 40-50%. If common terns experience better reproductive success in amounts of vegetation cover different from 40-50%, vegetation should be manipulated to provide that particular amount of cover.

Another year of research on natural sites like Andrews Reef and Harbor Island Reef, is needed to support or refute the results of this study. If common tern reproductive success if better in areas with 20-40% vegetation cover, managers should maintain vegetation cover on natural sites within that range. Otherwise, vegetation should be manipulated to provide the amount of cover that supports the best reproductive success. Managers should reduce vegetation cover either through herbiciding, removing vegetation, or adding substrate such as sand, rocks, or gravel (Richards and Morris 1984, Morris et al. 1992, Cook 1999, Cook-Haley and Millenbah 2002).

It is important to note that vegetation cover is not the only factor affecting common tern egg and chick survival rates. Other factors such as predation, competition with ring-billed gulls, food availability, weather conditions, and loss of habitat due to human development influence nesting success. Therefore, future studies assessing the effects of these factors on survival are warranted.

To determine long-term patterns in survival and changes in vegetation cover, at least 5-10 more years of intensive monitoring is needed for the common tern population in the St. Mary's River. Through more intensive monitoring and further study of the relationship between reproductive success and vegetation cover, managers can better manage common terns in the St. Mary's River for increased reproductive success.

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Appendix 1. Table 1. Common vegetation species found growing on the Lime Island coal dock, Michigan in summers 1997 and 1998.

Common Name	Scientific Name
Black-eyed Susan	*Rudbeckia serotina*
Cinquefoil spp.	*Potentilla* spp.
Common evening primrose	*Oenothera biennis*
Common milkweed	*Asclepias syriaca*
Common mullen	*Verbascum thapsus*
Field peppergrass	*Lepidium campestra*
Fireweed (or Great willow herb)	*Epilobium angustifolium*
Oxeye daisy	*Chrysanthemum leucanthemum*
Poison ivy	*Toxicodendron radicans*
Red clover	*Trifolium pratense*
Red-osier dogwood	*Cornus stolonifera*
Shrubby St. Johnswort	*Hypericum spathulatum*
Sumac spp.	*Rhus* spp.
Tansy	*Tanacetum vulgare*
White sweet clover	*Melilotus alba*
Wild red raspberry	*Rubus idaeus*
Wild strawberry	*Fragaria virginiana*
Yellow goatsbeard	*Tragopogon pratensis*
Yellow sweet clover	*Melilotus officinalis*

Appendix 1. Table 2. Common vegetation species found growing on Andrews Reef, Michigan in summers 2000 and 2001.

Common Name	Scientific Name
Blue vervain	*Verbena halei*
Bull thistle	*Cirsium vulgare*
Canada thistle	*Cirsium arvense*
Common dandelion	*Taraxacum officinale*
Common milkweed	*Asclepias syriaca*
Common reed	*Phragmites australis*
Cress spp.	*Brassicaceae* spp.
Elm spp.	*Ulmus* spp.
Goldenrod spp.	*Solidago* spp.
Grass spp.	*Poaceae* spp.
Hairy willow herb	*Epilobium hirsutum*
Knotweed spp.	*Polygonum* spp.
Lady's thumb	*Polygonum persicaria*
Pale touch-me-not	*Impatiens pallida*
Path rush	*Funcus tenuis*
Queen Anne's lace	*Daucus carota*
Redtop grass	*Agrostis gigantea*
Sedge spp.	*Carex stipata*
Silverweed	*Potentilla anserina*
Spiny-leaved sow thistle	*Sonchus asper*
Spotted knapweed	*Centaurea maculosa*

Appendix 1. Table 2 (cont'd).

Common Name	Scientific Name
White clover	*Trifolium repens*
Wintercress or Yellow rocket	*Barbarea vulgaris*

Appendix 1. Table 3. Common vegetation species found growing on Harbor Island Reef, Michigan in summers 2000 and 2001.

Common Name	Scientific Name
American hazelnut	*Corylus americana*
Blue vervain	*Verbena halei*
Common evening primrose	*Oenothera biennis*
Flat-topped aster	*Aster umbellatus*
Goldenrod spp.	*Solidago* spp.
Hairy willow herb	*Epilobium hirsutum*
Knotweed spp.	*Polygonum* spp.
Lady's thumb	*Polygonum persicaria*
Orchard grass	*Dactylis glomerata*
Pale touch-me-not	*Impatiens pallida*
Queen Anne's lace	*Daucus carota*
Reed canarygrass	*Phalaris arundinacea*
Rough-fruited cinquefoil	*Potentilla recta*
Rush spp.	*Juncus* spp.
Rush, Path	*Funcus tenuis*
Sedge spp.	*Carex stipata*
Sedge spp.	*Carex* spp.
Stinging nettle	*Urtica droica*
White clover	*Trifolium repens*
Wintercress or Yellow rocket	*Barbarea vulgaris*

Appendix 2. Number of adults trapped, number of adults trapped with bands already present (band returns), percent band returns, and number of band returns from 1997 (birds banded as juveniles on Lime Island in 1997) in the St. Mary's River, summers 2000-2001.

Year	Number of Adults Trapped	Number of Band Returns	Percent Band Returns	Number of Returns from Lime Island, 1997
2000	39	9	23.1	5
2001	49	8	16.3	3

CHAPTER 2
IMPACTS OF VEGETATION COVER ON COMMON TERN EGG SURVIVAL ON HIGH AND LOW WATER NESTING SITES IN THE ST. MARY'S RIVER AND SAGINAW BAY, MICHIGAN

ABSTRACT

Among the causes of the population decline of common terns in Michigan and the Great Lakes region is the loss of suitable breeding habitat due to high water levels in the Great Lakes. During years of high water levels (> 175.8 m, International Great Lakes Datum (IGLD) 1985; 1996 – 1998) in the Great Lakes, common terns nested on human-made sites in the St. Mary's River (Lime Island) and Saginaw Bay (Confined Disposal Facility; CDF), Michigan. During years of low water levels (< 174.8 m, IGLD 1985; 2000 – 2001), common terns nested on naturally occurring islands in the St. Mary's River (Andrews Reef and Harbor Island Reef). The purpose of this research was to assess and compare common tern egg survival and vegetation cover on nesting sites used during high and low water years. Nesting sites used by common terns during years of low water levels supported less vegetation cover (28.8%) and had greater egg survival (67.9%) than nesting sites used during years of high water levels (66.1% total vegetation cover, 35.9% egg survival). Depending on Great Lakes water levels, managers should be prepared to employ vegetation management strategies specific to nesting sites used during high and low water years.

INTRODUCTION

Among the causes of the population decline of common terns in Michigan and the Great Lakes region is the loss of suitable breeding habitat due to high water levels that is exacerbated by loss of habitat due to human development in the Great Lakes (Scharf 1991). During years of high water levels [> 175.8 m, International Great Lakes Datum (IGLD) 1985, Lakes Michigan-Huron; A. Fox pers. comm.][1], natural island nesting habitat that typically supports more preferred vegetation cover is either partially or completely submerged under water (Morris and Hunter 1976, Scharf 1991), forcing common terns to select human-made sites that generally tend to support greater vegetation cover (Chapter 1 of this document).

Great Lakes water levels are influenced by a combination of precipitation, upstream inflows, groundwater, surface water runoff, evaporation, diversions into and out of the system and climatic conditions (Hanna 1964, Office of the Great Lakes: Michigan Department of Environmental Quality 2000). Great Lakes water levels fluctuate seasonally, with higher water levels in summer than in winter and average seasonal variation less than 0.2 - 0.6 meters (Tovell 1979, Office of the Great Lakes: Michigan Department of Environmental Quality 2000). Long-term water level fluctuations occur at intervals varying from 10 to 30 years between high and low water levels (Tovell 1979). Extremely low water levels (< 174.8 m, IGLD 1985, Lakes Michigan-Huron; A. Fox,

[1] Minimum value for high water year is based on the water level shown in a hydrograph for Lakes Michigan-Huron during 1998, which was reported as a high water year and was a year when common terns used Lime Island as a nesting site.

pers. comm.)[2] were recorded in the mid-1920s, mid-1930s and early 1960s while exceptionally high water levels occurred in 1929-1930, 1952, 1973-1974, 1985-1986, and 1997-1998 (Office of the Great Lakes: Michigan Department of Environmental Quality 2000).

From 1997-1998 (Office of the Great Lakes: Michigan Department of Environmental Quality 2000), a period coinciding with high Great Lakes water levels, the only nesting site used by common terns in the St. Mary's River was Lime Island, a human-made site (Cook 1999). In 1999, a year of falling water levels (Office of the Great Lakes: Michigan Department of Environmental Quality 2000), common terns abandoned Lime Island (following flooding caused by a storm and predation by a long-tailed weasel and ring-billed gulls; Millenbah and Lamp 1999) and nested on a number of small, rocky reefs in the St. Mary's River area which were exposed during that year (T. Ludwig, pers. comm.). In 2000 and 2001, two years of low water levels (A. Fox pers. comm.), common terns did not nest on Lime Island but did nest on Andrews Reef and Harbor Island Reef (Chapter 1 of this document), rocky reefs that were exposed due to low water levels.

During another period of high water levels (1996-1997; Office of the Great Lakes: Michigan Department of Environmental Quality 2000), common terns nested on the Saginaw Bay Confined Disposal Facility (CDF) in Saginaw Bay, Michigan (Millenbah 1997; see Appendix 1 for map). The Army Corps of Engineers built the CDF in 1978 to house contaminated dredge material from the Saginaw River and Saginaw Bay shipping

[2] Maximum value for low water year is based on the water level shown in a hydrograph for Lakes Michigan-Huron during 2000, which was reported as a low water year and was a year when common terns used Andrews Reef and Harbor Island Reef as nesting sites.

channel (Millenbah 1997). The CDF is a kidney shaped island (118.5 ha) near the mouth of the Saginaw River. The outer retaining wall of the CDF is approximately 3 – 5 m above water level with the top of the interior dike wall 0.5 m below the outer retaining wall. The interior cell, where dredge material is deposited, is 2 – 2.5 m below the interior dike wall. From 1996-1997, common terns nested on the east-central section of the CDF, in an area approximately 75 m long by 2 m wide (the width of the interior dike; Millenbah 1997).

From 1996-2001, common tern nest site selection followed a similar pattern in the St. Mary's River and Saginaw Bay, Michigan. During years of high water levels (1996-1998), common terns nested on human-made sites in both the St. Mary's River (Lime Island) and Saginaw Bay (CDF). During years of low water levels (2000-2001), common terns nested on naturally occurring islands in the St. Mary's River (Andrews Reef and Harbor Island Reef; common terns in Saginaw Bay were not studied during the same period of low water levels). Vegetation cover on nesting sites used during low water years appeared different from nesting sites used during high water years. Therefore, the purpose of this research was to assess and compare common tern egg survival and vegetation cover high water (1996-1998) and low water (2000-2001) nesting sites in the St. Mary's River and Saginaw Bay, Michigan.

OBJECTIVES

Specific objectives of this study were to:

1) compare the effects of vegetation cover on common tern egg survival between high water and low water nesting sites;
2) make recommendations for managing common terns in the St. Mary's River on high water and low water nesting sites.

METHODS

Common terns nesting on the CDF were observed and monitored from 22 May to 3 August 1996 and 28 May to 1 August 1997 (Millenbah 1997). The Lime Island common tern colony was monitored and observed from 5 June to 8 August 1997 and 21 May to 1 August 1998 (Cook 1999). Andrews Reef and Harbor Island Reef common tern colonies were monitored and observed from 12 June to 3 August 2000 and 8 May to 21 July 2001 to obtain data on egg survival and vegetation cover.

Egg Survival

Nest checks, completed every 3-6 days, were used to estimate egg survival. Nesting variables recorded at nests included date of egg laying, number of eggs, date of completed clutch, number of eggs lost, and reason(s) for loss. Chick censoring exceeded the allowable level of censoring (10%; Mayfield 1961). Therefore, no chick data was analyzed in this chapter. Each nest was given a unique number using a permanent marker on a rock or a wooden dowel to allow nests to be followed until hatching, fledging, or until the nest was destroyed or abandoned. Appropriate state and federal banding, capturing, and handling permits were obtained from the MDNR and USFWS. Re-nesting attempts were also followed. All methods for capturing and banding adults and chicks were approved by Michigan State University's All-University Committee on Animal Use and Care (AUF # 02/99-017-00).

Daily and period survival estimates for eggs were calculated using the Mayfield method (Mayfield 1961). Daily survival is the survival from the beginning of one day to the next, and period survival is the survival from initiation of incubation to hatching. Eggs were used as the experimental unit from initiation of incubation to hatching. Nests were considered active if at least one egg was present in the nest cup. Abandoned nests were incorporated into the estimate using a mean of 12 exposure days. Egg period survival was calculated using 24 days (L; Mayfield 1961) as the mean number of incubation days.

Exposure days for censored eggs were incorporated into the Mayfield estimates using the midpoint method that terminates exposure days at the midpoint between the last day eggs were known to be active and the first day eggs or chicks were known to be inactive (Manolis et al. 2000). Censored individuals were included in Mayfield estimation because their exclusion results in a downward bias (Manolis et al. 2000)

Vegetation Cover

A 50 X 50 cm modified Daubenmire frame (Daubenmire 1959) was centered at each nest and vegetation measurements were taken to compare differences in vegetation cover between nesting sites used during high water years and low water years in the St. Mary's River and Saginaw Bay. Vegetation variables included percent live, dead, forb, grass, and woody cover as well as estimates of percent bare ground, percent litter cover, and vegetation height. Vegetation variables were measured after a completed clutch of eggs was present in the nest cup. In 1996 and 1997, vegetation characteristics were measured at 50 and 95, respectively, nests on the CDF (Millenbah 1997). Vegetation variables were measured at 79 and 69 nests on Lime Island in 1997 and 1998, respectively (Cook 1999). In 2000 and 2001, vegetation variables were measured at 50 nests (each year) on Andrews Reef and 52 and 50, respectively, nests on Harbor Island Reef.

Vegetation Cover and Survival

Vegetation variables between nests at high water nesting sites (CDF, 1996-1997; Lime Island, 1997-1998) and low water nesting sites (Andrews Reef and Harbor Island Reef, 2000-2001) were compared ($P \leq 0.05$; Mann-Whitney U (MWU); Mann and Whitney 1947) to determine if different vegetation characteristics were associated with high and low water nesting sites. Successful (nests in which at least one young hatched) and unsuccessful (nests in which no young hatched) nests were pooled based on Chapter 1 findings that there were no consistently significant differences between successful and unsuccessful nests. Although there were significant differences ($P \leq 0.05$) between years at a nesting site and nesting sites for some vegetation characteristics, the trends were similar when multi-year and multi-site data were pooled to compare high water and low water nesting sites. Therefore, multi-year data were pooled to evaluate vegetation differences between high water and low water nesting sites.

RESULTS

Vegetation Comparisons

High vs. Low Water Sites

There were differences ($P \leq 0.05$) between high and low water nesting sites for all vegetation characteristics measured (Table 1). Percent total, live, grass, and dead cover were greater ($P < 0.0001$ for all 4 variables) around common tern nests on high water sites than on low water sites (Table 1). Conversely, on low water sites, percent forb, woody, and litter cover as well as percent bare ground were greater ($P = 0.001$, $P = 0.02$, $P < 0.0001$, and $P < 0.0001$, respectively) around nests than on high water sites (Table 1). Vegetation was taller ($P < 0.001$) around nests on low water sites than on high water sites (Table 1).

Vegetation Cover and Survival Estimates

Daily survival for common tern eggs was 95.3% on high water sites and 98.4% on low water sites. Period survival for common tern eggs was 35.9% and 67.9% on high and low water sites, respectively (Table 3). Figure 1 shows a comparison between egg survival and vegetation cover on high and low water nesting sites.

Table 1. Mean (SE) vegetation characteristics at common tern nests on high water sites (CDF, 1996-1997; Lime Island 1997-1998) and low water sites (Andrews Reef and Harbor Island Reef, 2000-2001) in Michigan.

Characteristic	High Water Sites (n = 293[1])	Low Water Sites (n = 202)
% Total Cover*	66.1 (1.3)	28.8 (1.8)
% Live Cover*	59.8 (1.3)	28.6 (1.8)
% Grass Cover*	40.9 (1.7)	1.9 (0.3)
% Forb Cover*	19.5 (1.4)	26.4 (1.7)
% Woody Cover*	0.0 (0.0)	0.3 (0.2)
% Dead Cover*	5.9 (0.6)	0.2 (0.1)
% Bare Ground*	18.2 (1.1)	53.6 (2.0)
% Litter Cover*	15.6 (1.2)	17.7 (0.8)
Height (cm)*	11.9 (0.5)	19.3 (1.2)

[1] height measurements were only made on Lime Island in 1998, therefore n = 69 for height on high water sites.
*significantly different (Mann-Whitney U (MWU) test, $P \leq 0.05$)

Table 2. Daily (S_d) and period (S_p) survival rates (Mayfield 1961) of common tern eggs on high water nesting sites (CDF, 1996-1997; Lime Island, 1997-1998) and low water nesting sites (Andrews and Harbor Island Reef, 2000-2001) in Michigan.

Nesting Category	S_d	S_p
High Water Sites	0.9528	0.3589
Low Water Sites	0.9840	0.6790

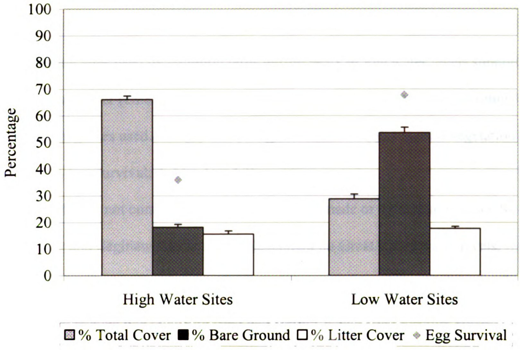

Fig. 1. Comparisons of percent total cover, bare ground, and litter cover with common tern egg survival rates on high water nesting sites and low water nesting sites used for nesting in the St. Mary's River and Saginaw Bay, Michigan.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Nesting sites used by common terns during years of low water levels supported less vegetation cover (28.8%; Table 1) and had greater egg survival (67.9%; Table 3) than did nesting sites used during years of high water levels (66.1% total vegetation cover, 35.9% egg survival; Tables 1 and 3).

Whether or not common terns nest on human-made or natural sites in the St. Mary's River and Saginaw Bay is largely dependent on Great Lakes water levels, especially when nesting locations are limited. When water levels are high in the Great Lakes, natural islands like Andrews Reef and Harbor Island Reef become either completely or mostly submerged under water, and human-made sites like Lime Island (> 1.5 m high during high water years; Cook 1999) or the CDF (3 – 5 m high during high water years; Millenbah 1997) are relatively unaffected by changes in water levels. During high water years, common terns are forced to select from fewer available nest sites. As human development in the Great Lakes has increased, loss of suitable, natural nesting habitat has also increased. Therefore, during years of high water levels, human-made sites like Lime Island may be the only available nesting sites for common terns.

When the Great Lakes water levels rise once again and submerge more suitable nesting sites like Andrews and Harbor Island Reefs, Lime Island will likely become an important (and possibly exclusive) nesting site for common terns in the St. Mary's River. Therefore, during years of high water levels, it will become imperative to provide the amount of vegetation cover in which reproductive success is the greatest on Lime Island.

Managers should be prepared to reduce vegetation cover on Lime Island by either applying herbicide to the vegetation (Cook 1999) or adding substrate such as sand, rocks, or gravel (Richards and Morris 1984, Morris et al. 1992). An additional year of study on Lime Island, in which the vegetation manipulations performed in 1998 are replicated (Cook 1999), is needed support or refute the conclusion than common terns have better nest success in areas with 40-50% vegetation cover (Cook-Haley and Millenbah 2002, Chapter 1 of this document). If it is determined that reproductive success is better in areas supporting 40-50% vegetation cover, managers should reduce the vegetation cover on Lime Island to 40-50%. Otherwise, vegetation on Lime Island should be managed for the percent cover in which reproductive success is determined to be the greatest.

When common terns return to nest on Lime Island in future years, a proactive approach to predator management should be taken (based on the predation effects seen during 1997-1999). Conibear trapping was shown to be effective for mammalian predator control of a population of California least terns (Butchko and Small 1992). Therefore, conibear traps targeted at weasels should be used on Lime Island as soon as possible after common terns arrive on the nesting site in early May. No predation was observed in the common tern colonies nesting on Andrews Reef and Harbor Island Reef in 2000 or 2001, but managers should be prepared to employ predator management (if necessary) on any islands common terns use as nesting sites in the future.

During years of low water levels, it is likely that common terns will nest on Andrews Reef and Harbor Island Reef or other similar natural sites in the St. Mary's River. If common terns nest on these sites during a number of consecutive years, it is likely the vegetation will succeed and become taller and denser. Managers should monitor the vegetation cover on these sites to determine if cover has exceeded the range within which nest success is better. Another year of research on low water sites is needed to support or refute the conclusion that common tern reproductive success is better in areas with 20-40% vegetation cover (Chapter 1 of this document). If vegetation cover exceeds the amount in which reproductive success is the greatest, managers should reduce cover either through applying herbicide, removing vegetation, or adding substrate (Richards and Morris 1984, Morris et al. 1992, Cook 1999, Cook-Haley and Millenbah 2002).

Because common terns move to different nesting sites based on Great Lakes water levels, it is essential to manage both human-made and naturally occurring islands for increased reproductive success during years in which they are used by common terns.

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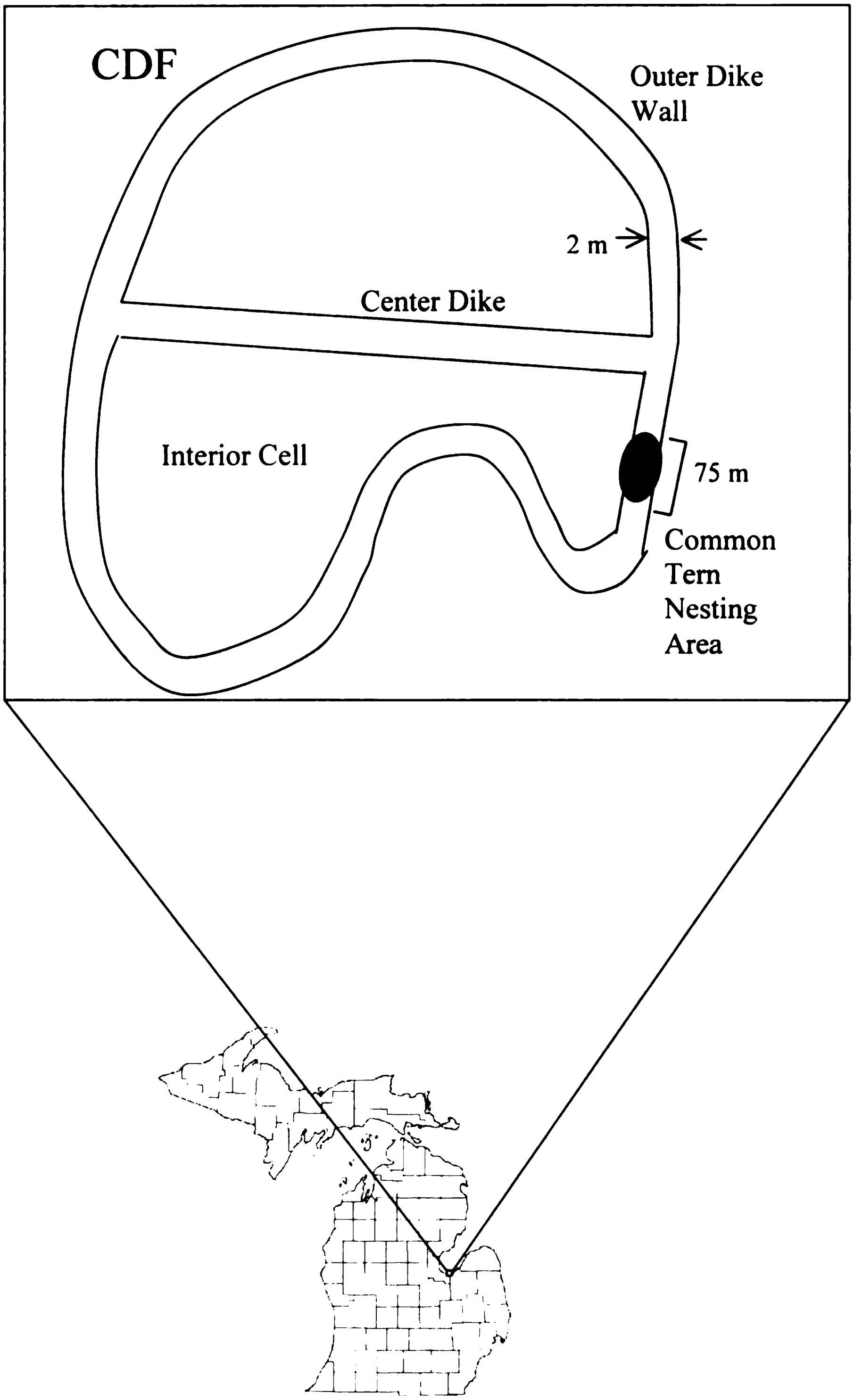

Appendix. Location of the Confined Disposal Facility (CDF) in Saginaw Bay, Michigan. The CDF was used as a common tern nesting site during summers 1996-1997.

CHAPTER 3
ANALYZING POPULATION VIABILITY OF COMMON TERNS IN THE ST. MARY'S RIVER, MICHIGAN USING VORTEX

ABSTRACT

Common terns (*Sterna hirundo*) in Michigan were listed as threatened in 1978 and have undergone an assessment in the Great Lakes for listing as federally endangered. Although researchers have evaluated the minimum population parameters necessary to maintain stable populations using deterministic models, no studies have assessed the viability of common tern populations using models that simulate stochastic events affecting population dynamics. Therefore, I developed a population viability analysis (PVA) for common terns in the St. Mary's River, Michigan using VORTEX, a stochastic simulation of the extinction process. Data for the model were assembled from survival information gathered in the St. Mary's River (1997 - 2001) and from existing literature. Analyses indicate that the population is declining at a rate ranging from 6.3% (11% flooding probability each year) to 10% (52% flooding probability each year) per year with a probability of extinction over 100 years ranging from 70.4% (11% flooding probability) to 99.9% (52% flooding probability). Sensitivity analyses suggest that the most significant factors affecting the population's long-term persistence are juvenile (egg-laying to fledging) and sub-adult (fledging to age 3) survival. Therefore, management strategies should be directed at increasing juvenile and sub-adult survivals. This PVA is limited by the lack of species-specific data regarding inbreeding depression, carrying capacity, and density dependence. Thus, PVA is an important tool for managers but has limitations and should be used as only one step in the management process.

INTRODUCTION

Declining numbers of common terns have caused concern over the future of this species in the Great Lakes region. In Michigan, estimates for common terns have declined from 6,000 breeding pairs in the 1960s (Ludwig 1962) to between 1,200 and 1,400 breeding pairs in the 1990s (Evers 1992, Cuthbert et al. 1997). As a result of this decline, in 1978 the common tern was listed as a state threatened species in Michigan and has undergone a status assessment in the Great Lakes for possible listing as federally endangered (Scharf 1991). Several factors, including loss of habitat due to vegetation encroachment (Scharf 1981), shortages of breeding areas due to high water levels (Scharf 1991), competition with gulls for nesting space (Morris and Hunter 1976, Scharf 1981, Scharf and Shugart 1985, Ludwig 1991), predation (Hatch 1970, Morris and Hunter 1976, Scharf 1981, Ludwig 1991, Burness and Morris 1992), and effects of contaminants (Weseloh et al. 1989), have contributed to the decline of this species.

The decline of common terns throughout the Great Lakes and in the eastern United States has incited researchers to evaluate the minimum population parameters necessary to maintain stable populations of common terns (Austin 1942, Austin and Austin 1956, Nisbet 1978, DiConstanzo 1980, Penning 1993, Millenbah 1997). However, no research has evaluated the viability of common tern populations using a model that simulates both the effects of deterministic forces and stochastic or random events. Deterministic models (life-table analyses) generate long-term projections of population growth or decline but do not reveal fluctuations in population size caused by stochastic processes (Clark et al. 1991, Lacy and Clark 1993, Lindenmayer et al. 1993, Kendall 1998, Forys and Humphrey 1999). A model that incorporates stochasticity is important because a number of interacting demographic, environmental, genetic, and catastrophic processes determine the vulnerability of small populations to extinction (Lacy 1993, Lacy and Clark 1993).

The St. Mary's River, located along the eastern Upper Peninsula of Michigan, currently supports the largest number of common terns in the state (> 50% of breeding pairs; Cuthbert et al. 1997), making it one of Michigan's important nesting areas. Since this area is one of Michigan's strongholds for common terns, it is necessary to understand the current population status, impacts to survival, and long-term survival potential of the common tern colonies in the St. Mary's River. Previous research has shown that colonies in the St. Mary's River are vulnerable to stochastic processes (i.e., predation and flooding; Millenbah and Lamp 1999). Therefore, to adequately evaluate the potential for long-term persistence of the common tern colonies in the St. Mary's River, a population viability analysis (PVA) that models stochastic processes was needed.

PVA is a process for modeling and analyzing the vulnerability of small populations to extinction and comparing alternative management options (Shaffer 1981, Clark et al. 1991, Boyce 1992, Lacy and Clark 1993, Brook and Kikkawa 1998). Extinction probabilities are estimated using computer simulation models that incorporate interacting demographic, environmental, catastrophic, and genetic processes, all of which occur in real populations and determine the vulnerability of a population to extinction (Shaffer 1981, Gilpin and Soule 1986, Boyce 1992, Lacy and Clark 1993). These four extinction processes can be simulated in PVA models, and the effects of deterministic and stochastic forces can be investigated (Clark et al. 1991, Lacy 1993). PVA is used to rank the outcomes of different management options, such as reducing mortality or increasing carrying capacity, and is thus an important planning tool for managing threatened and endangered species (Clark et al. 1990, Brook et al. 1997b).

VORTEX (Miller and Lacy 1999), a computer simulation model for PVA, is one model that incorporates the effects of deterministic forces as well as stochastic events on the dynamics of wildlife populations. The purpose of this project was to use VORTEX to predict the long-term survival potential of common terns in the St. Mary's River and determine which factors have the most significant effects on long-term survival.

OBJECTIVES

1) predict the long-term survival potential of common terns in the St. Mary's River using PVA;
2) determine which factors most affect the long-term survival potential of common terns in the St. Mary's River; and
3) make recommendations for managing common terns in the St. Mary's River.

METHODS

Modeling Method

VORTEX 8.21 (Miller and Lacy 1999) was used to simulate the deterministic and stochastic factors affecting common tern population dynamics. VORTEX, a Monte Carlo simulation written in C programming language, models population dynamics as discrete, sequential events that occur according to random variables based on user-defined distributions. VORTEX simulates a population by following each individual through a series of events that describe the annual cycle of a sexually reproducing diploid organism (Miller and Lacy 1999). I chose VORTEX because it has been widely used for PVA analysis (Lacy 1993, Lacy and Clark 1993) and because it incorporates a wide range of stochastic factors such as environmental variability and catastrophes (Brook and Kikkawa 1998). VORTEX has also been shown to model avian population dynamics realistically (Brook et al. 1997a).

Demographic Input Parameters

Parameter values (see Appendix 1 for a list of VORTEX input values) used in the simulation model were taken either from five years (1997-2001) of breeding season field data collected in the St. Mary's River (Cook 1999, Millenbah and Lamp 1999, Chapter 1 of this document) or from data in published literature regarding common tern population dynamics (Austin 1942, Austin and Austin 1956, Nisbet 1978, DiConstanzo 1980, Penning 1993, Millenbah 1997). Since I did not know the specific age distribution of the St. Mary's River common tern population, I estimated the number of individuals of each age (Appendix 2) by multiplying the initial population size (1997) by the percentage of individuals of each age in a common tern population on the east coast (Austin and Austin 1956). Under the assumption of a 1:1 sex ratio, the number of individuals of each age was divided evenly between males and females.

Based on previous research, I assumed that males and females initially breed at 3 years of age (Austin and Austin 1956, Nisbet 1978, DiConstanzo 1980). No birds were projected to live and breed past 21 years of age. Although birds > 10 years of age comprise only a small portion of the total breeding population in the eastern U. S. (Austin and Austin 1956), those age classes were included in the simulation because the age distribution was based on a population comprised of ages 1-21 (Austin and Austin 1956).

Maximum clutch size (6 eggs) and the percent of clutches with 1, 2, 3, 4, 5, and 6 eggs were based on data collected in the St. Mary's River from 1997-2001. The percentages of clutches with 1, 2, 3, 4, 5, and 6 eggs were calculated for each of the five years of field data and averaged.

Juvenile mortality (0.796) was calculated as 1 minus the average of overall breeding season survival (egg survival*chick survival) for each year. Overall juvenile survival was 0.21, 0.13, 0.70, and 0.51 during 1997 (Cook 1999), 1998 (Cook 1999), 2000 (this study), and 2001(this study), respectively. Overall survival during 1999 is unknown because common terns abandoned known nesting sites (after 266 nests had been laid) due to flooding and predation (Millenbah and Lamp 1999). Since researchers were unable to follow common terns to re-nesting locations, I could not determine survival rates during 1999. The environmental variation (EV) of juvenile mortality was calculated as the standard deviation of the mean of 1997, 1998, 2000, and 2001 overall survivals. EV is defined as the fluctuation in the probabilities of births and death that results from fluctuations in the environment (Miller and Lacy 1999).

It has been estimated that 14.3% of common tern fledglings survive to breeding age (DiConstanzo 1980, Penning 1993). Assuming that survival is constant during the three years until breeding, an annual survival rate of 0.523 is calculated as the cubed root of 0.143. Subtracting 0.523 from 1 gives a mortality rate of 0.477 for age classes 0-1 (fledging to age 1), 1-2, and 2-3 (sub-adults). The EV of mortality (1.38) of each of these age-classes is calculated as the cube root of the standard deviation of survival (2.6; DiConstanzo 1980, Penning 1993).

It has also been estimated that 92% of common tern adults survive annually (DiConstanzo 1980, Penning 1993), giving an adult mortality rate of 8%. The standard deviation of adult survival (1.4; DiConstanzo 1980, Penning 1993) was used as the EV of adult mortality.

Vortex Simulations

Population simulations were projected for 100 years. Each simulation was replicated 1,000 times to minimize standard errors around mean results (Lacy 1993). Reported probabilities of extinction are the average of 1,000, 100-year simulations. The initial population size for all simulations was 1,298 individuals, the population size of common terns in the St. Mary's River in 1997 (Cook 1999).

Initial Population Projections

To determine whether or not density dependent breeding, inbreeding, and flooding were affecting long-term survival and probability of extinction, I ran a series of simulations in which each factor was modeled with the demographic parameters while the other two factors were omitted (Table 1). For example, I ran a simulation with the demographic parameters and only inbreeding. Density dependent breeding and flooding were not incorporated in this simulation.

Density Dependent Breeding

VORTEX models density dependent breeding with an equation that specifies the proportion of adult females breeding as a function of the total population size (Miller and Lacy 1999). Since there was no information regarding density dependent breeding specific to common terns in the literature or from the field data, common tern population dynamics were modeled with two different sets of VORTEX default values (Table 1):

(1) The percent of adult females breeding near N = 0 (N = population size) and at K (carrying capacity) was 100% and 50%, respectively. The exponential steepness (B) was 2, indicating that the percent of females breeding is a quadratic function of N. The Allee effect (A), the decrease in the proportion of females breeding at low densities, was modeled with a magnitude of 1.

(2) The percent of adult females breeding near N = 0 and at K was 100% and 80%, respectively. The exponential steepness (B) was 16, indicating that the percent of females breeding does not begin to decrease dramatically until N is large. The Allee effect (A) was not incorporated in this scenario, which implies that there is no decrease in the proportion of females breeding at low population densities.

Table 1. Initial VORTEX population simulations for common terns in the St. Mary's River. K = carrying capacity. Severity (S) = severity with respect to survival.

Scenario	Values
Demographics only	See Appendix 1
Demographics + density dependent breeding (1)[A]	Max % breeding near 0 = 100%
	% breeding at K = 50%
	exponential steepness (B) = 2
	Allee parameter (A) = 1
Demographics + density dependent breeding (2)[B]	Max % breeding near 0 = 100%
	% breeding at K = 80%
	exponential steepness (B) = 16
	Allee parameter (A) = 0
Demographics + inbreeding[A]	3.14 lethal alleles
	50% of genetic load due to lethal alleles
Demographics + flood (1)	Probability = 52%, Severity (S) = 95%
Demographics + flood (2)	Probability = 11%, Severity (S) = 95%
Demographics + flood (3)	Probability = 52%, Severity (S) = 99%
Demographics + flood (4)	Probability = 11%, Severity (S) = 99%

[A]default values
[B]values from a density dependent breeding curve chosen within VORTEX

Inbreeding Depression

Since there was no information regarding inbreeding depression specific to common terns in the literature or from the field data, common tern population dynamics were modeled with the VORTEX default values (Table 1). The default value of 3.14 lethal alleles per diploid genome is a median value based on a study of 40 captive mammalian populations (Ralls et al. 1988). Studies of *Drosophila* flies and scant data for other species indicate that 50% of the inbreeding effects is due to lethal alleles (Miller and Lacy 1999).

Catastrophes

Since the common tern population in the St. Mary's River experienced severe egg mortality (83%) from flooding during 1999 (Millenbah and Lamp 1999), this event was modeled as a catastrophe. On June 1, 1999, the day of the flooding event, the amount of precipitation recorded at the weather station closest (12 km) to Lime Island (DeTour Village, COOP ID 202094) was 2.44 cm (National Climatic Data Center, National Oceanic and Atmospheric Administration 2001). It is more likely that that amount of rainfall would be catastrophic if it fell in a short period of time (1-2 hours), but there was not enough data available based on hourly precipitation levels to conduct an analysis at that level of detail. Using 2.44 cm as a minimum amount of rainfall causing a flooding event, I calculated the number of breeding seasons during which the daily precipitation exceeded 2.44 cm at least once. This occurred during 28 of 54 years of records (1948-2001), giving a flooding probability within a breeding season of 52%. Although a 52% flooding probability is based on the amount of rainfall that caused the catastrophic flooding event, this percentage may be too high. There may have been other factors such as wind and impermeability of the soil that contributed to the catastrophe. Therefore to examine the effects of a range of flooding probabilities, I calculated the number of breeding seasons during which the daily precipitation exceeded 5.08 cm at least once. This occurred during 6 of 54 years, giving a flooding probability of 11%. Since 83% of the eggs laid in 1999 were lost (Millenbah and Lamp 1999), the severity of flooding with respect to reproduction was 17% (read by VORTEX as an 83% reduction in reproduction). The exact number of adults experiencing mortality directly from the flooding is unknown, so I assumed a low reduction (either 1% or 5%, depending on the simulation) in survival resulting from flooding. Since they can fly, adults can easily leave sites affected by flooding, and only a small percentage would experience direct mortality due to flooding.

I ran a series of four flooding simulations to evaluate the effects of a 52% probability of catastrophe versus an 11% probability of catastrophe and to determine whether or not the long-term survival was different between a 1% reduction (severity = 99%) in survival and a 5% reduction (severity = 95%) in survival (Table 1).

Assumptions

Some assumptions were necessary to assign values to or address a number of input parameters:

(1) Since chicks were not sexed after hatching, I assumed a 1:1 sex ratio at birth.

(2) 91.1% of adult males and females in the population were breeders. This was calculated by determining the percentage of the initial population size

comprised of individuals from ages 3-10, the reproductive cohort of the population (Austin and Austin 1956).

(3) No correlation of environmental variation between reproduction and survival was modeled because the reproduction rate (juvenile survival) is more sensitive to weather and other outside disturbances than adult survival probabilities, which are more stable (Li and Li 1998).

(4) No emigration from or immigration into the population is occurring. Although it is likely immigration and emigration are occurring in this population (J. Spendelow, pers. comm.), there was not enough information for other nearby common tern populations to create a metapopulation model.

(5) The carrying capacity of the St. Mary's River is unknown. Lime Island was the only nesting site used in the St. Mary's River during 1997 and 1998, and nearly 1500 individuals nested on half the available nesting habitat on that site. Therefore, I multiplied 1500 by 2 to obtain a carrying capacity of 3000 for common terns in the St. Mary's River.

Sensitivity Analyses

Sensitivity analysis is used to determine the effects of inaccuracies of parameter estimates on model predictions as well as to target management efforts that would have the greatest impact on increasing population viability (Reed et al. 1998). Sensitivity analyses were performed on four parameters: juvenile mortality, sub-adult mortality, frequency of flooding, and carrying capacity. Juvenile and sub-adult mortalities were chosen for sensitivity analysis because these mortalities are high in comparison to adult mortality and should therefore have a greater effect on population size. Additionally, these parameters were chosen because they were shown to be the most important factors affecting the long-term persistence of another common tern population in Saginaw Bay, Michigan (Millenbah 1997). Since field data and observations from 1999 have shown that catastrophic flooding has a considerable impact on common tern reproduction, sensitivity analyses were conducted on flooding. Carrying capacity was chosen for sensitivity analysis because it is one of the most uncertain yet critical components in the simulation.

To measure the sensitivity of the model to the aforementioned parameters, I used the following sensitivity index (Jorgensen 1986):

$$S_x = (dX/X) \,/\, (dP/P) \qquad (1)$$

where P is the parameter value under normal conditions and X is the dependent variable of interest (population size in this model). dX is the change in the dependent variable caused by the change in parameter value (dP). A larger absolute value of S_x indicates a higher sensitivity of X to a change in P.

To determine the sensitivity of extinction probability in response to changes in juvenile mortality (baseline = 61%), sub-adult mortality (baseline = 47.7%), and frequency of flooding (baseline = 52% or 11%), I increased and decreased the baseline values of the three parameters by 10% and evaluated the model responses. Carrying capacity (baseline = 3,000) was increased and decreased by 1,000 to evaluate the model response to change in carrying capacity. The extinction probability under the increased and decreased values for each of the four parameters was determined. S_x values were calculated using equation 1.

Simulation Experiments

Single-Parameter Manipulations

Since juvenile and sub-adult mortalities were determined to be the most sensitive parameters in the VORTEX analyses (based on sensitivity analyses), these two parameters were manipulated singly to determine how probability of extinction is affected by varying mortality rates. Two sets of simulations were run: one with juvenile mortality rate manipulated by increments of 10% above and below the current rate of 61% and one with sub-adult mortality rate manipulated by increments of 10% above and below the current rate of 47.7%. Including simulations with 0% and 100% mortality, there were a total of 12 simulations for each parameter (juvenile and sub-adult mortality).

Two-parameter manipulations

To determine how extinction probability is affected by manipulating the two most sensitive parameters together, 49 different scenarios involving the simultaneous manipulation of juvenile and sub-adult mortality were run (Table 2). Results from the 49 simulations were plotted as surface graphs in Microsoft Excel to interpolate extinction probabilities between selected rate combinations.

Table 2. Juvenile and sub-adult mortality rate combinations used in the 49 two-parameter VORTEX simulations for common terns in the St. Mary's River.

		Sub-adult Mortality Rate						
		7.7%	17.7%	27.7%	47.7%	57.7%	67.7%	87.7%
Juvenile Mortality Rate	11%	1*	2	3	4	5	6	7
	31%	8	9	10	11	12	13	14
	41%	15	16	17	18	19	20	21
	51%	22	23	24	25	26	27	28
	61%	29	30	31	32	33	34	35
	81%	36	37	38	39	40	41	42
	91%	43	44	45	46	47	48	49

* scenario number for rate combinations

RESULTS

Initial Population Projections

Long-term population projections with density dependent breeding (1), density dependent breeding (2), and inbreeding depression were similar to the projection with only demographic parameters modeled (Fig. 1). These four projections had similar stochastic growth rates (r)[3], ranging from –0.050 to – 0.064 (Table 3), as well as similar extinction probabilities (0.173 - 0.348; Table 3) and mean times to extinction (93.6 - 94.7 years; Table 3).

Projections with a 52% chance of flooding within a breeding season [Flood (2) and Flood (4)] had a greater negative impact on long-term survival than projections with an 11% chance of flooding within a breeding season [Flood (1) and Flood (3)]. Projections with a 52% probability of flooding had lower growth rates, higher extinction probabilities, and shorter mean times to extinction than projections with an 11% probability of flooding (Table 3).

Projections with the same probability of flooding but different severities with respect to survival [Flood (1) vs. Flood (3) and Flood (2) vs. Flood 4)] were not different. Growth rates, extinction probabilities, and mean times to extinction were similar between projections with 52% flooding probability and either 95% or 99% severity with respect to survival as well as between projections with 11% flooding probability and either 95% or 99% severity with respect to survival (Table 3).

I chose to model common tern population dynamics with only demographics parameters and Flood (3) or Flood (4) for all subsequent simulations. Density dependent

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[3] When $r < 0$, the population is declining; when $r = 0$, the population is stable; and when $r > 0$, the population is increasing.

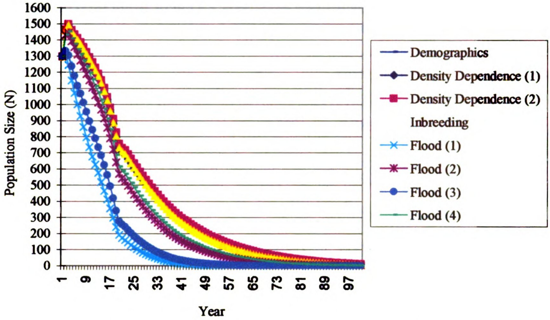


Fig. 1. Initial population projections for common terns in the St. Mary's River. Density dependence (1): max. % breeding at 0 = 100%, % breeding at K = 50%, exponential steepness = 2, Allee parameter = 1. Density dependence (2): max. % breeding at 0 = 100%, % breeding at K = 80%, exponential steepness = 16, Allee parameter = 0. Inbreeding: 3.14 lethal alleles, 50% of genetic load due to lethal alleles. Flood (1): probability = 52%, severity with respect to survival = 95%. Flood (2): probability = 11%, severity with respect to survival = 95%. Flood (3): probability = 52%, severity with respect to survival = 99%. Flood (4): probability = 11%, severity with respect to survival = 99%. **Images in this thesis are presented in color.**

Table 3. Growth rate (r) (SD), probability of extinction (SD), and mean years to extinction (SD) for initial VORTEX population simulations for common terns in the St. Mary's River. Results are based on 1,000 replicates for each 100-year simulation.

Scenario	r	Probability of Extinction	Mean Years to Extinction
Demographics only	-0.064 (0.092)	0.289 (0.44)	93.6 (4.95)
Demographics + density dependent breeding (1)	-0.051 (0.087)	0.196 (0.41)	93.6 (5.20)
Demographics + density dependent breeding (2)	-0.050 (0.084)	0.173 (0.38)	94.7 (4.87)
Demographics + inbreeding	-0.056 (0.094)	0.348 (0.47)	94.1 (4.83)
Demographics + flood (1)	-0.118 (0.168)	1.000 (0.00)	51.5 (7.52)
Demographics + flood (2)	-0.068 (0.132)	0.842 (0.38)	85.0 (8.76)
Demographics + flood (3)	-0.100 (0.151)	0.999 (0.03)	60.5 (8.08)
Demographics + flood (4)	-0.063 (0.122)	0.704 (0.46)	88.1 (7.48)

breeding and inbreeding were not included because the simulations with these factors were similar to the simulation with only demographic parameters included. Flooding was modeled because this is an event known to affect the St. Mary's River population (Millenbah and Lamp 1999). I did not run any further simulations using a 95% severity with respect to survival because it is likely that the effect on adult survival was very low and the severity is probably closer to 99%. Since they can fly, adults can easily leave sites affected by flooding, and only a small percentage would experience mortality due to flooding.

The projection with a 52% probability of flooding and a 99% severity with respect to survival predicts a 99.9% probability of extinction over 100 years [demographics and Flood (3); Table 3]. Under this scenario, mean time to extinction is 60.5 years (SD = 8.08), with the population declining at a rate of 10% each year (Table 3). With a probability of flooding of 11% and a 99% severity with respect to survival, VORTEX predicts a 70.4% probability of extinction within 100 years (Table 3). Mean time to extinction is 88.1 years (SD = 7.48), with the population declining at a rate of 6.3% each year (Table 3).

Sensitivity Analyses

Common tern population size is particularly sensitive to increases in juvenile and sub-adult mortalities and flooding when the probability is 52% (Table 4). Since the absolute values of sensitivity indices for juvenile and sub-adult mortalities were the highest, I focused on juvenile and sub-adult mortalities as the two most sensitive parameters affecting long-term common tern population dynamics.

Table 4. Sensitivity indices for increases and decreases in baseline values for juvenile mortality, sub-adult mortality, carrying capacity, and flooding rates in VORTEX simulations for common terns in the St. Mary's River. Separate sets of simulations were run with probability of flooding = 11% and probability of flooding = 52%.

Parameter (baseline value)	Value		Flooding Probability	Sensitivity Index	
	Increase	Decrease		Increase	Decrease
Juvenile mortality (61%)	71%	51%	11%	-1.72	-3.29
			52%	-0.97	-1.20
Sub-adult mortality (47.7%)	57.7%	37.7%	11%	-1.43	-12.76
			52%	-1.12	-2.84
Carrying capacity (3,000)	4,000	2,000	11%	0.01	0.004
			52%	-0.01	0.03
Flooding (11%)	21%	1%		-0.15	-0.18
Flooding (52%)	62%	42%		-0.61	-0.57

Simulation Experiments

Single-Parameter Manipulations

11% Probability of Flooding

At juvenile and sub-adult mortality rates of ≥ 71% and ≥ 57.7%, respectively, the long-term probability of extinction is 1 (Fig. 2a). If juvenile mortality is decreased to 41%, with all other initial input values remaining the same, probability of extinction is 0 (Fig. 2a). However, r = –0.018. The population does not stabilize over 100 years until juvenile mortality is decreased to at least 30% (r = 0.001). At sub-adult mortality rates ≤ 37.7%, probability of extinction is 0 (Fig. 2a). The population declines at a sub-adult mortality rate of 37.7% (r = -0.006), but at rates ≤ 27.7% r is > 0.

52% Probability of Flooding

At juvenile and sub-adult mortality rates of ≥ 71% and ≥ 57.7%, respectively, the long-term probability of extinction is 1 (Fig. 2b). Probability of extinction does not reach 0 until juvenile mortality is decreased to 0% (Fig. 2b). Even with a 0% juvenile mortality rate the population declines over 100 years (r = -0.008). At sub-adult mortality rates ≤ 27.7%, probability of extinction is 0 (Fig. 2b). The population declines at 27.7% sub-adult mortality (r = -0.005), but at sub-adult mortality rates ≤ 17.7% the population is growing over 100 years (r > 0).

Two-Parameter Manipulations

11% Probability of Flooding

When juvenile and sub-adult mortality rates are approximately ≤ 61% and

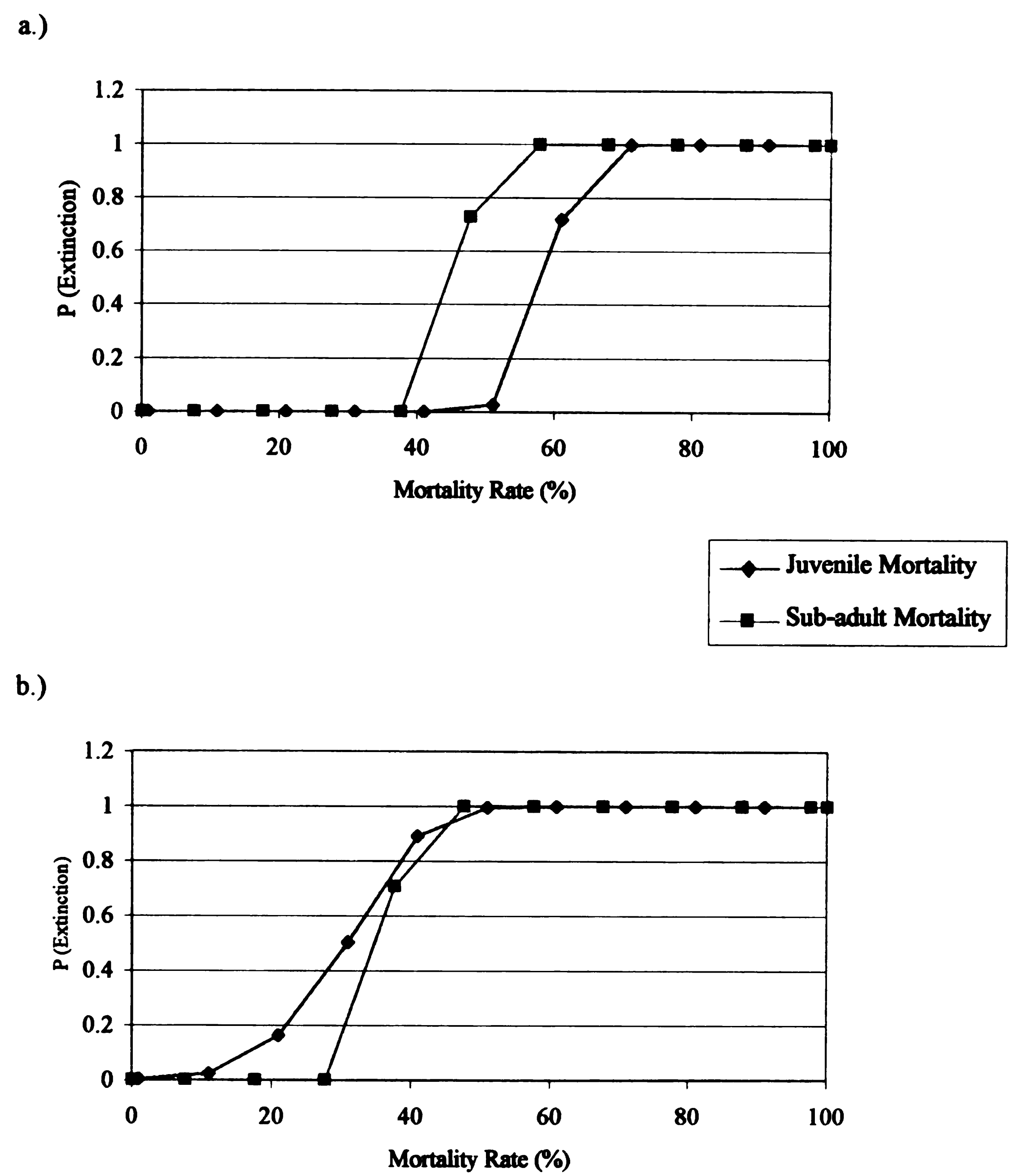


Fig. 2. Probabilities of extinction with increasing juvenile and sub-adult mortality rates for common terns in the St. Mary's River, MI for simulations with an 11% probability of flooding (a) and a 52% probability of flooding (b). The only input value changed in each simulation was either juvenile or sub-adult mortality rate.

≤ 37.7%, respectively, probability of extinction is 0 (Fig. 3a). At juvenile mortality rates ≥ 51% and sub-adult mortality rates ≥ 67.7%, extinction probability is 1 (Fig. 3a). Between areas where probability of extinction is 0 and 1, extinction probability rises steeply for small changes in mortality rates (Fig. 3a).

52% Probability of Flooding

Probability of extinction is 0 when juvenile and sub-adult mortality rates are approximately ≤ 61% and ≤ 35%, respectively (Fig. 3b). Combinations of juvenile mortality rates ≥ 41% and sub-adult mortality rates ≥ 57.7% result in a probability of extinction of 1 (Fig. 3b). Between areas where probability of extinction equals 0 and 1, the probability of extinction rises steeply for small changes in mortality rates (Fig. 3b).

Stable Population

11% Probability of Flooding

With a juvenile mortality rate of 57% and a sub-adult mortality rate of 37.7%, the population grows during the first 15 years, decreases slightly, begins to increase in year 20, and stabilizes during the last 25 years ($r = 0.004$; Fig. 4a). In this scenario, the final population size in year 100 is 1,981 individuals. Modeled with an 11% probability of flooding, the population is either stable or growing over 100 years when mortality rates are ≤ 57% and ≤ 37.7% for juveniles and sub-adults, respectively.

52% Probability of Flooding

With a juvenile mortality rate of 40% and a sub-adult mortality rate of 35%, the population grows during the first 15 years, then decreases slightly and begins to stabilize

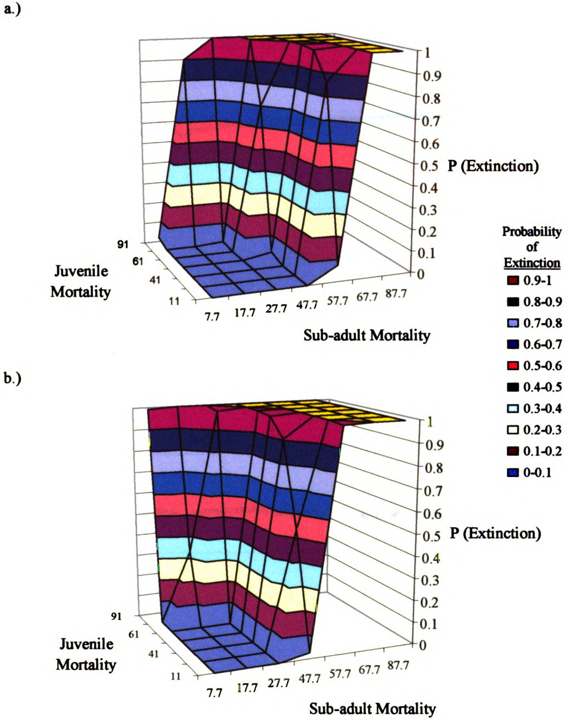
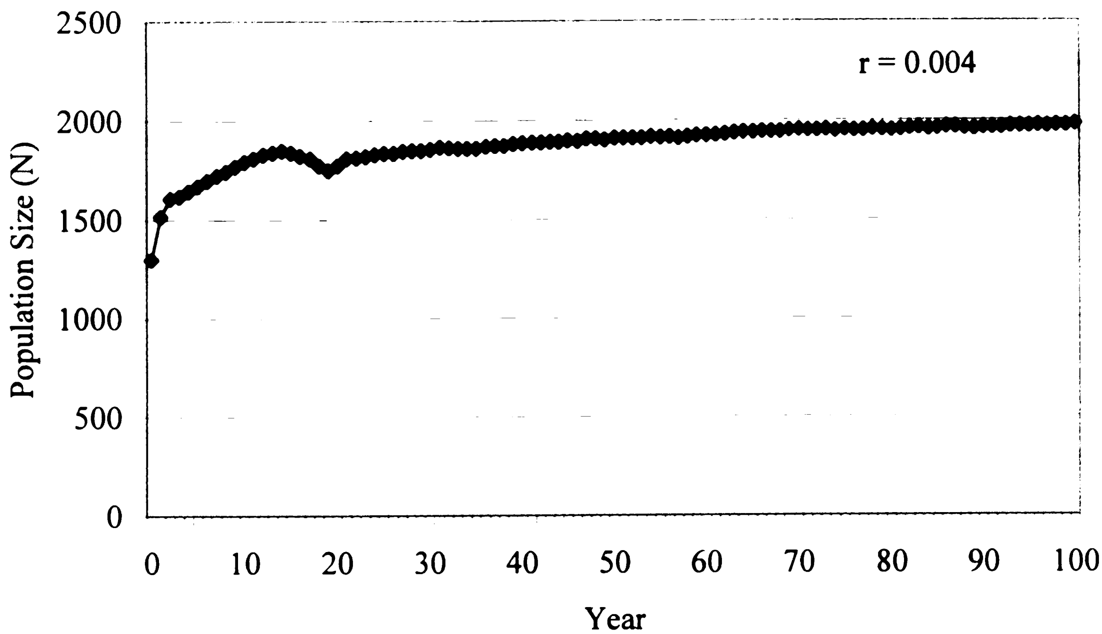


Fig. 3. Targeting 0% extinction and a stable population of common terns in the St. Mary's River. Varying combinations of juvenile and sub-adult mortality rates and resulting probabilities of extinction are shown for simulations with an 11% probability of flooding (a) and a 52% probability of flooding (b).

a.)



b.)

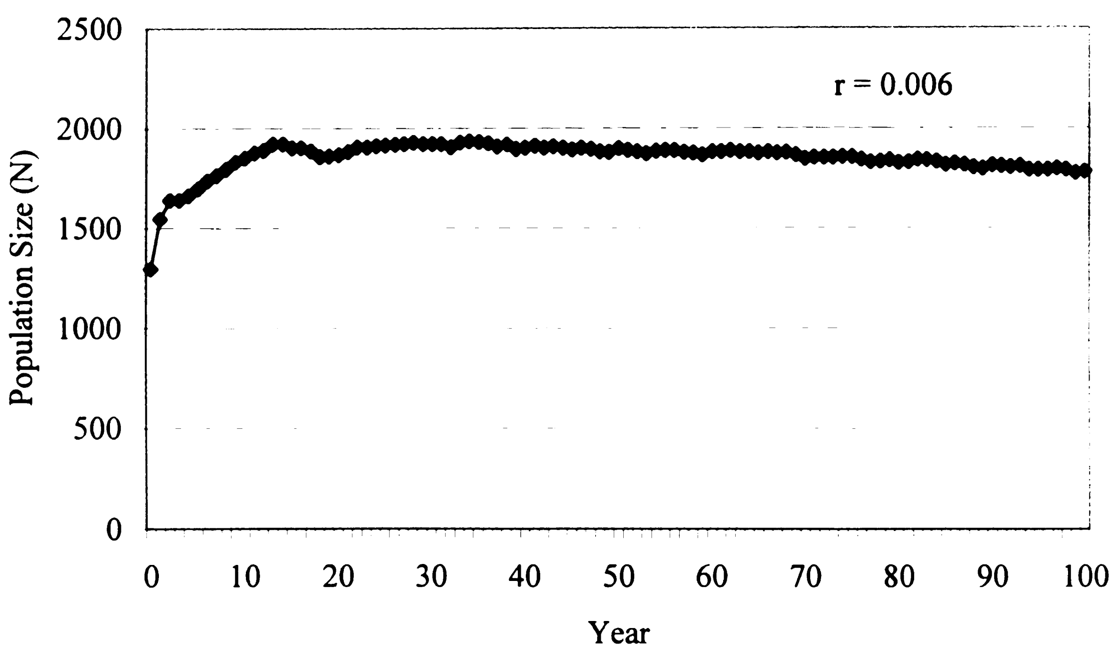


Fig. 4. Stable common tern population in the St. Mary's River for simulations with an 11% probability of flooding (a) and a 52% probability of flooding (b). Juvenile mortality rate = 57% and sub-adult mortality rate = 37.7% (a). Juvenile mortality rate = 40%, sub-adult mortality rate = 35% (b).

near the end of the 100-year simulation ($r = 0.006$; Fig. 4b). The final population size in year 100 is 1,783 individuals. Under a scenario with a 52% probability of flooding, the population is either stable or growing over 100 years when mortality rates are ≤40% and ≤ 35% for juveniles and sub-adults, respectively.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Under existing environmental conditions, the long-term survival potential of common terns in the St. Mary's River appears to be in jeopardy. According to the results of the VORTEX simulations, this population is decreasing at a rate between 6.3% (11% probability of flooding) and 10% (52% probability of flooding) per year. The upper limit of this annual rate of decrease in the St. Mary's River is slightly less than the annual rate of decrease for a different common tern population in Saginaw Bay, Michigan (17% decrease per year; Millenbah 1997).

Sensitivity analyses indicated that the factors with the most significant impacts on population size and persistence in the St. Mary's River are juvenile mortality and sub-adult mortality. To obtain a stable population with a flooding probability of 11%, juvenile mortality needs to be decreased to 30% or sub-adult mortality needs to be decreased to 27.7%. When flooding probability is 52%, a stable population cannot be achieved even when juvenile mortality is reduced to 0%. However, when sub-adult mortality is decreased to at least 17.7%, the population stabilizes over 100 years. It would be difficult to reduce juvenile mortality from the current rate of 61% down to 30% (11% flooding probability). If flooding probability is closer to 52% in the St. Mary's River, a stable population cannot be achieved even if managers could reduce juvenile mortality to 0%. Sub-adult mortality should be decreased from the current rate of 47.7% down to between 27.7% and 17.7% (depending on flooding probability), but it would also be difficult for managers to reduce mortality to these levels.

The difficulty in reducing sub-adult mortality rates lies in the delayed breeding of this cohort. Little can be done in Michigan to impact the survival of sub-adults (ages 1-3), as these birds do not generally return to their breeding grounds until they reach breeding age (≥ 3 years old; Austin and Austin 1956, Nisbet 1978, DiConstanzo 1980). Therefore, through the cooperation of local, national, and international agencies, management must be directed at increasing the survival of sub-adults along migration routes and on over-wintering grounds (Haymes and Blokpoel 1978, Blokpoel et al. 1987).

Since it unlikely managers can reduce either juvenile or sub-adult mortalities singly to levels that ensure long-term survival, both types of mortality should be decreased simultaneously. To obtain a stable population under a scenario with 11% flooding probability, juvenile mortality must be decreased from the current rate of 61% to at least 57.7%; sub-adult mortality must be decreased from the current rate of 47.7% to at least 37.7%. With a 52% flooding probability affecting survival and reproduction, juvenile mortality must be decreased to 40% and sub-adult mortality must be decreased to 35%. Thus, researchers must focus on increasing the survival of the population's juveniles and sub-adults to increase the number of breeding birds.

To decrease juvenile mortality, the overall survival of eggs and chicks must increase. Excess vegetation cover was shown to negatively impact egg and chick survival on Lime Island in 1997 and 1998 (Cook 1999, Cook-Haley and Millenbah 2002). Vegetation encroachment leads to a decrease in visual contact (used to signal the presence of intruders) and makes the movement of young difficult because they become entangled in vegetation. These two factors make young more susceptible to predation (Hatch 1970). After decreasing vegetation cover (through herbiciding) in an experimental area on Lime Island in 1998, it was shown that common tern egg survival was greatest in areas with 40-50% total standing vegetation cover (Cook-Haley and Millenbah 2002). Therefore, it may be possible to reduce overall egg and chick mortality from 61% to between 40% and 57.7% (depending on flooding probability) by decreasing vegetation cover on nesting sites. Herbicide or the addition of substrate such as rocks, sand, or gravel can be used to reduce vegetation cover (Richards and Morris 1984, Morris et al. 1992, Cook 1999). It is important to note that the amount of vegetation manipulations required may depend on the type of nesting site (human-made site vs. naturally occurring island) used, which can be dependent on Great Lakes water levels (Chapter 1 and 2 of this document).

Although predation was not modeled explicitly in VORTEX (deaths due to predation were accounted for in the juvenile mortality rate), predation may potentially have a significant effect on common tern population dynamics. Predation by a single long-tailed weasel in 1997, 1998, and 1999 had a negative impact on common tern survival and reproductive success (Cook 1999, Millenbah and Lamp 1999). If effective predator management is employed it may be possible to reduce or remove this effect on the common tern population in years in which predation is a problem. If common terns return to nest on Lime Island in future years, a proactive approach to predator management should be taken. Conibear trapping was shown to be effective for mammalian predator control of a population of California least terns (Butchko and Small 1992). Therefore, conibear traps should be used on Lime Island as soon as possible after common terns arrive on the nesting site in early May. Although no predation was observed in the common tern colonies on Andrews Reef and Harbor Island Reef in 2000 or 2001, managers should be prepared to employ predator management (if necessary) on nesting sites used in the future.

To increase the power and predictability of the VORTEX simulation model, more field data is required on the St. Mary's River common tern population. One of the limitations of this model is the limited amount of field data available for this particular population. More than four years of data are needed to show long-term fluctuations in demographics and catastrophes. Field research should continue on a yearly basis for at least 10-20 years to show any long-term trends in population dynamics. A PVA conducted with 5 years of field data on Capricorn silvereyes (*Zosterops lateralis chlorocephala*) produced different predictions of extinction risk compared with a PVA based on 15-25 years of data (Brook and Kikkawa 1998). Thus, more comprehensive biological data will provide more accurate parameter estimates and thus greater confidence in VORTEX predictions (Lindenmayer et al. 1993).

Future field research should also be directed at determining inbreeding depression, density dependence, carrying capacity, and immigration and emigration rates. Inbreeding depression could be estimated through genetic analysis conducted on the population. Although population size in the St. Mary's River is currently several times greater than the threshold where inbreeding depression would likely have a considerable effect (i.e., ≤ 50 individuals; Franklin 1980), it would be wise to conduct genetic analyses on the population. Carrying capacity could be better estimated by conducting research on resource (i.e., food and habitat) availability and how common terns used these resources.

To better estimate the age distribution, sub-adult survival rate, and immigration and emigration rates of the St. Mary's River population, adults should be trapped for band recoveries. By determining the year in which a bird was originally banded, a researcher will know the age of a bird and can more reliably estimate age distribution. Since current estimates of common tern sub-adult survival rates are uncertain, more information is required to generate a more accurate estimate. Since sub-adults typically return to their natal sites to breed at age 3 and researchers began banding chicks in the St. Mary's River in 1997, the timing is conducive for trapping adults for band recoveries. It is likely that common terns in the St. Mary's River have permanent emigrants from and permanent immigrants into the population from nearby nesting sites either on the Canadian side of the St. Mary's River or Lake Huron. If immigration and emigration were incorporated into the model, long-term survival potential would be higher than predicted in this study (J. Spendelow, pers. comm.) Movement between neighboring population centers has been shown to have a mitigating effect on extinction probability (Brook and Kikkawa 1998). To determine immigration and emigration rates affecting the common tern population in the St. Mary's River, a long-term, multisite band recovery study should be undertaken. Directing future research at the aforementioned parameters will allow a more empirically based model to be built, thereby better substantiating a number of assumptions and increasing the predictability of the simulation.

As previously mentioned, excess vegetation cover can have a significant negative impact on common tern survival and reproduction (Cook 1999). Therefore, effects of vegetation cover should be modeled with VORTEX. Effects of habitat quality on populations cannot be directly modeled in VORTEX, but they can be modeled indirectly. To indirectly model habitat effects in VORTEX, separate simulations with varying mortality rates related to different percentages of vegetation cover could be run and compared. A model that incorporates habitat quality will allow managers to better predict what level of vegetation cover and vegetation management is required for the greatest common tern reproductive success.

It is important to note that PVA is a prediction tool and not a definitive answer. PVA provides managers with a powerful tool to determine where management should be targeted (such as reducing juvenile and sub-adult mortality rates in this study) and to assess the potential outcome of various management options (Clark et al. 1990, Lindenmayer et al. 1993, Hamilton and Moller 1995). PVA is most effective if applied within an adaptive management framework (Lacy and Clark 1993, Lindenmayer et al. 1993). As better data and better models become available, PVA modeling for common terns in the St. Mary's River should be repeated and reexamined. Used in this manner, VORTEX can be used to better understand and manage common terns for continued existence in the St. Mary's River. It is hoped that these models will allow managers to determine the management scenario that will ensure the continued existence and stability of common terns in the St. Mary's River, Michigan. The models may also prove valuable in protection efforts at other common terns colonies in Michigan and the U. S.

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Appendix 1. Summary of initial VORTEX parameter values and data sources for the common tern population in the St. Mary's River.

Parameter	Value	Data Source
Time span for simulation	100 years	Author specification
Replications	1,000	Lacy 1993
Population number	1	Author specification
Inbreeding depression?	No	Assumption
EV^A (reproduction) correlated with EV (survival)	No	Li and Li 1998
Number of catastrophes	1	Field data 1997-2001
Mating system	Monogamous	Burger and Gochfeld 1991
Female initial breeding age	3	Austin and Austin 1956; Nisbet 1978; Burger and Gochfeld 1991
Male initial breeding age	3	Austin and Austin 1956; Nisbet 1978; Burger and Gochfeld 1991
Maximum breeding age	21	Austin and Austin 1956
Sex ratio at birth	1:1	Assumption
Density dependent breeding	No	Assumption
Maximum clutch size	6	Field data 1997-2001
Percent clutch size 1	15.5%	Field data 1997-2001
Percent clutch size 2	23.94%	Field data 1997-2001
Percent clutch size 3	59.29%	Field data 1997-2001
Percent clutch size 4	1.13%	Field data 1997-2001
Percent clutch size 5	0.11%	Field data 1997-2001
Percent clutch size 6	0.03%	Field data 1997-2001

Appendix 1. (cont'd.)

Parameter	Value	Data Source
Percent females breeding	91.1%	Assumption based on Austin and Austin 1956
Mortality age 0-1*	79.6%	Field data 1997-2001; DiConstanzo 1980; Penning 1993
EV of mortality**	0.5999%	Field data 1997-2001; DiConstanzo 1980; Penning 1993
Mortality age 1-2	47.7%	DiConstanzo 1980; Penning 1993
EV of mortality	1.38%	DiConstanzo 1980; Penning 1993
Mortality age 2-3	47.7%	DiConstanzo 1980; Penning 1993
EV of mortality	1.38%	DiConstanzo 1980; Penning 1993
Adult mortality	8%	DiConstanzo 1980; Penning 1993
EV of mortality	1.4%	DiConstanzo 1980; Penning 1993
Probability of catastrophe (flooding)	52% or 11%	Field data 1997-2001; National Climatic Data Center 2001
Severity to reproduction	0.17	Field data 1997-2001
Severity to survival	0.99	Assumption
All males breeders?	No	Austin and Austin 1956
Percent of males present in breeding pool	91.1%	Assumption based on Austin and Austin 1956
Start at stable age distribution?	No	Austin and Austin 1956

Appendix 1. (cont'd.)

Parameter	Values	Data Source
Age distribution	Appendix 2	Austin and Austin 1956
Carrying capacity (K)	3,000	Field data 1997-2001
EV of K	0	Assumption
Trend in K?	No	Assumption
Harvest?	No	Assumption
Supplement?	No	Assumption

[A]EV = environmental variation
*calculated as 0.61 + (0.39 * 0.477); 0.61 = juvenile mortality (egg-laying to fledging), 0.477 = sub-adult mortality (fledging to age 1).
** property of variances used to calculate value of juvenile mortality SD (0.265) and sub-adult mortality SD (1.38) together

Appendix 2. Assumed age distribution of common terns in the St. Mary's River in 1997 (N = 1,298). Values are based on percentages reported by Austin and Austin (1956).

Age	Number of Individuals (1:1 sex ratio)
1	10
2	34
3	230
4	260
5	196
6	158
7	118
8	84
9	58
10	38
11	30
12	26
13	18
14	14
15	12
16	6
17	4
18	2
19	0
20	0
21	0