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Vegetation Manipulations on the Reproductive Success of
Common Terns (*Sterna hirundo*) on Lime Island
in the St. Mary's River, Michigan

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Betsy S. Cook

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of the requirements for

M.S. degree in Fish. & Wildl.

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**IMPACTS OF VEGETATION MANIPULATIONS ON THE REPRODUCTIVE
SUCCESS OF COMMON TERNS (*STERNA HIRUNDO*)
ON LIME ISLAND IN THE SAINT MARY'S RIVER, MICHIGAN**

By

Betsy S. Cook

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

IMPACTS OF VEGETATION MANIPULATIONS ON THE REPRODUCTIVE SUCCESS OF COMMON TERNS (*STERNA HIRUNDO*) ON LIME ISLAND IN THE SAINT MARY'S RIVER, MICHIGAN

By

Betsy S. Cook

The Common Tern (*Sterna hirundo*) is a State threatened species in Michigan that is declining because of changes in nesting sites due to vegetation encroachment, competition with other avian species for nesting space, and predation. Lime Island's coal dock is home to Michigan's largest common tern population (approximately 700 nesting pairs). However, the coal dock is covered with greater than preferred vegetation cover (81.5%), and could possibly cause entanglement or become a barrier to detecting predators; both of which could reduce reproductive success. In cooperation with the Michigan Department of Natural Resources, vegetation manipulations were performed in summer 1998 to determine if vegetation was affecting common tern survival. Two treatment types (total herbiciding and partial herbiciding) and a control (no vegetation manipulations) were randomly applied to 5 x 5-m plots (n = 17 for each treatment). The control areas were found to promote the highest egg survival (40.9%), and the partial herbicided areas promoted the highest chick survival (43.0%) of the treatment areas. The control areas were composed of 40.9% total cover, 9.1% bare ground and 50.0% litter cover while the partial herbicided areas were composed of 46.6% total cover, 4.7% bare ground, and 48.7% litter cover. More research is needed on vegetation manipulations and the impacts these manipulations have on common tern reproductive success.

To my parents,
Charles and Mary Sue,
for supporting me throughout
this long and tedious process.
Thank you!
I love you both.

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* Deceased

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INTRODUCTION

Status

The common tern (*Sterna hirundo*) is a member of the Order Charadriiformes, Family Laridae, Subfamily Sterninae that can be found inhabiting an extensive range of latitudes throughout North America (Burger and Gochfeld 1991, Morris et al. 1980). In Michigan, nests can be found on all of the Great Lakes with a substantial gap in the nesting distribution on the Lake Michigan shore (Scharf 1991). Few birds nest on inland lakes; most common terns currently prefer human-made islands in the Saint Mary's River in northern Michigan, and in Saginaw Bay of Lake Huron (Scharf and Shugart 1985, Shugart and Scharf 1983). Human-made sites throughout the Great Lakes consist of, but are not limited to, confined disposal facilities (CDF; Millenbah 1997), breakwalls (Morris et al. 1992), and navigational aids (Karwowski et al. 1995)

Common terns in Michigan once numbered over 6,000 breeding pairs in 1960 (Brewer 1991). Current numbers suggest that the population has decreased to an estimated 1,800 breeding pairs (K. Millenbah, Michigan State University, pers. commun.). Several factors have contributed to this decline including alterations of habitat due to vegetation succession, (Scharf 1981), inundation by record high water levels (Project Management Group 1989), competition with ring-billed gulls (*Larus delawarensis*) for nesting sites (Ludwig 1991, Morris and Hunter 1976, Scharf 1981, Scharf and Shugart 1985), predation (Burness and Morris 1992, Hatch 1970, Ludwig 1991, Morris and Hunter 1976, Scharf 1981), and effects of contaminants on eggs, causing shell thinning and deformities in birds of all ages (Weseloh et al. 1989). In 1978,

as a result of these factors, the common tern was officially listed in Michigan as a State threatened species and has recently undergone a status assessment in the Great Lakes for possible listing as Federally endangered (L. Williams, U.S. Fish and Wildlife Service [USFWS], pers. commun.).

Nest-Vegetation Relationships

Common terns prefer nest sites in early stages of plant succession with 10 – 30% vegetation cover (Soots and Parnell 1975). Although this amount of cover is sparse, it offers some visual relief from predators and the elements (e.g., sun, rain, wind; Blokpoel et al. 1978). There are two main advantages of nesting in sparse (10 – 30% cover), tall (0.30 – 0.60 m; Blokpoel et al. 1978, Burger and Gochfeld 1991) vegetation which relate to courtship and colonial nesting. First, a barrier is created decreasing the amount of visual contact between nests thus reducing conflict between neighboring common terns (Burger and Shisler 1978). This barrier also serves to provide needed hiding cover for chicks near the nest (Burger and Shisler 1978). Second, open spaces are used when adult common terns walk around in a “parade” before copulating (Burger and Gochfeld 1991). These open spaces also allow for movement within vegetation without the risk of entanglement.

As vegetation increases annually, common terns may abandon nests if the vegetation becomes too thick ($\geq 30\%$ cover) or too tall (≥ 0.60 m; Burger and Gochfeld 1991, Courtney and Blokpoel 1983, Harris and Matteson 1975, Matteson 1988, Shields and Townsend 1985). Dense vegetation is detrimental to common terns due to: 1) the

birds' inability (i.e., loss of visual contact) to detect predators making them more susceptible to predation and 2) the increased chance of entanglement making them more susceptible to predation because they cannot get untangled (Burger and Shisler 1978). For example, excess vegetation cover ($\geq 30\%$ cover) and height (≥ 0.60 m) has been shown to offer abundant shelter for rats, resulting in a serious threat to common tern reproductive success on the Atlantic coast (Austin, Jr. 1932, 1933; Austin, Sr. 1948; Floyd 1932). Additionally, the reduced visibility results in a reduction of social stimulation among colony members (Palmer 1941). The reduction in social stimulation results in a decrease in mating, thereby decreasing reproductive success (Burger and Gochfeld 1991)

Many researchers have examined how vegetation impacts common tern reproductive success on both natural and human-made sites. Morris et al. (1992) observed two islands in the Eastern Headland of Lake Ontario where common terns have been known to nest since 1970. To determine how vegetation encroachment impacted common tern nesting habits, Morris et al. (1992) cleared the vegetation from the two islands in April and May of 1982. Common tern numbers rose to 218 and 562 breeding pairs from the previous year's number of 13 pairs on each island (26 nests total). In the absence of vegetation control in subsequent years, the terns eventually abandoned both islands due to increased vegetation height and density caused by the annual growth of vegetation (Morris et al. 1992).

Other studies (i.e., Morris et al. 1992, Richards and Morris 1984, Severinghaus 1982) used different types of substrate and vegetation to determine the preferred nesting

sites of common terns. In one such study, Severinghaus (1982) tested common tern nest site selection on Long Island, New York. Strips of four treatments and one control were used. The treatments were 1) large (≥ 5.1 cm), 2) medium (2.5 – 5.1 cm), and 3) small stones (< 2.5 cm) and 4) grass. The grass substrate was strongly favored (21 nests; tested with χ^2 , $p < 0.005$), followed by the control areas, which consisted of various sized stones and dried grass (14 nests). Only after most of the grassy areas were occupied was the stone substrate heavily used (13 nests in the 3 types of stone substrate; Severinghaus 1982).

Richards and Morris (1984) tested the substrate preferences of late-nesting common terns by providing a choice of substrate types on a breakwall in Lake Erie near the terminus of the Welland Canal. The substrates included: 1) controls of bare concrete with scattered concrete chips, 2) enhanced areas covered with a layer of small (< 2.5 cm) rocks and gravel, and 3) super-enhanced areas covered with the small rocks and gravel with clumps of mossy stonecrop (*Sedum acre*) and driftwood randomly distributed on top of the gravel. Terns preferred the super-enhanced areas (103 nests) to the other two substrates (enhanced areas = 48 nests, control areas = 15 nests; Richards and Morris 1984). Additionally, the number of chicks fledged per egg hatched was highest in the super-enhanced areas (73%) and lowest in the enhanced areas (33%)

In a similar study by Morris et al. (1992), large amounts of large (≥ 5.1 cm) rock and material mixed with various sized smaller rocks and gravel were placed over an area of a breakwater in Lake Erie near Port Colbourne, Ontario. The breakwater originally was only bare concrete. Small logs, driftwood and debris were also spread over the

substrate and mossy stonecrop was planted at random intervals. After the manipulations were performed, common tern numbers on the breakwater increased from 906 breeding pairs in 1987 to 1,052 breeding pairs in 1988.

One such area in Michigan that lends itself to the investigation of the impacts of vegetation on common tern reproductive success is Lime Island in the St. Mary's River. Lime Island is owned by the Michigan Department of Natural Resources (MDNR), and supports a large colony of common terns. Biologists from the MDNR suggest that the vegetation cover on Lime Island exceeds the 10 – 30% cover normally preferred by common terns and may be negatively affecting common tern reproductive success.

Lime Island Common Tern Colony

Status on Lime Island

Lime Island, located in the Saint Mary's River along the eastern shore of the Upper Peninsula of Michigan (Figure 1), currently supports the largest colony of common terns in the state of Michigan (approximately 700 breeding pairs in 1998; F. Cuthbert, University of Minnesota, pers. commun.). Lime Island has been used by common terns as a nesting site since the 1920's (D. Dimond, MDNR, pers. commun.).

History of Lime Island

Lime Island served as a major coal dock and refueling station on the Great Lakes until the late-1970's. While this site was an active coal and fuel facility, common terns could be seen in high numbers (> 200 pairs) among the piles of coal. However, little is known about the exact number of birds using Lime Island from the 1920's to mid-1970.

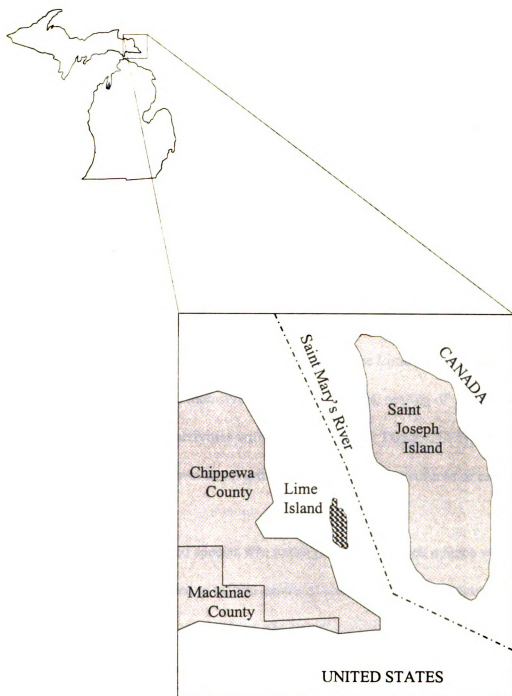


Figure 1. Location of Lime Island, Michigan in the Saint Mary's River.

No common terns nested on Lime Island from 1976 to 1982; 160 nests were counted in 1985 (Michigan Natural Features Inventory 1996). The number of common tern nests from 1986 through 1995 is not known.

In 1989, MDNR Forest Management Division bought Lime Island, which had been sitting virtually unused since the late-1970s. In April 1994, the U.S. Army National Guard, in cooperation with MDNR, covered the existing coal on the coal dock with rocks to keep the coal contained and to prevent any possible contamination of the future topsoil. The rocks were covered with topsoil and seeded to grasses (B. Dimond, MDNR, pers. commun.). Common terns were observed landing on the freshly seeded ground in 1994.

In 1995, USFWS and MDNR biologists from the Seney National Wildlife Refuge and the Newberry Field Office, respectively, monitored the Lime Island common tern colony. Biologists witnessed intensive (> 300 nesting pairs) nesting of common terns at the site as well as predation activities within the colony (M. Tansy, USFWS, letter to MDNR, June 20, 1995). However, no estimates of reproductive success or extent of predation were made.

Realizing a State listed species was nesting on the coal dock a fence was constructed in 1995 and posted to inform people of the common tern nesting area. The fence was erected approximately halfway down the length of the coal dock (Figure 2) and was constructed to keep people from entering the colony and disturbing the common terns. Placement of the fence allowed visitors use of the northern half of the coal dock for a picnic area and docking site. The fence was also placed down the east side of the southern half of the coal dock (Figure 2). The east side of the coal dock is closest to the harbor and boats typically dock along the harbor side of the coal dock when they are too

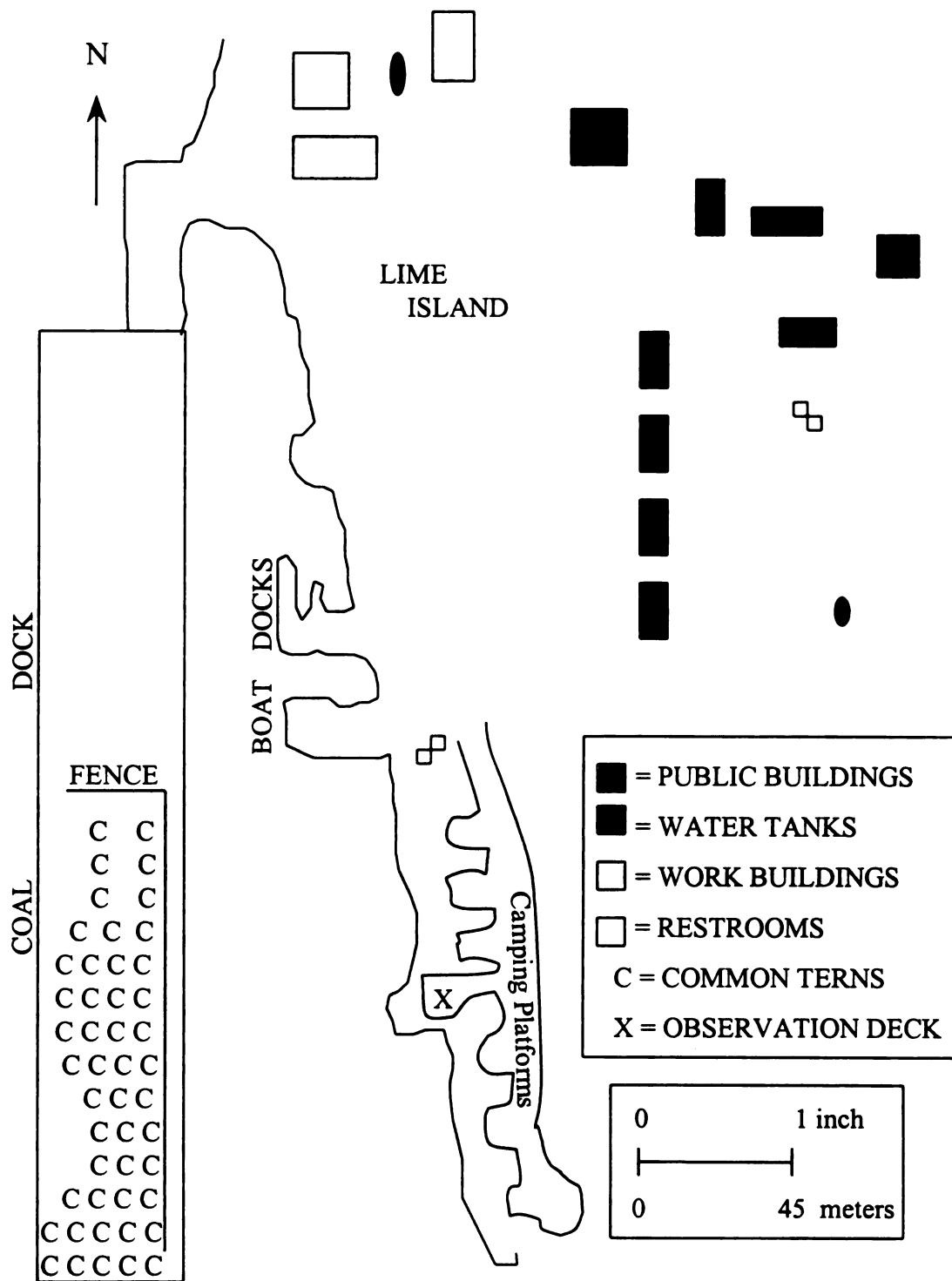


Figure 2. Aerial view of the west side of Lime Island, Michigan, showing the coal dock; placement of houses, cabins, work buildings, boat docks, and camping and observation (X) platforms; location of common tern (C) nests, and placement of fence in 1997 and 1998.

large to tie up to the wooden docks located along Lime Island's shore (Figure 2).

Camping platforms were constructed during the summer of 1996 to give campers a safe location to make camp along the shore. The platforms are situated along the western shore south the of boat docks (Figure 2). An observation platform (Figure 2) was provided for visitors to view the common terns and other nesting birds from a distance without disturbing them.

Large, black circular fuel tanks, remnants of Lime Island's days as a coal dock and refueling station, are still standing along the shore north of the work buildings (which house equipment for up-keep on the island; Figure 2). Six cabins and a host house are also located on Lime Island (Figure 2). A school, Victorian house, and the six cabins (Figure 2) are open to visitors during the summer months, beginning in mid-May.

MDNR activities

The MDNR plans to place interpretive signs on the coal dock north of the colony and next to the observation platform to provide visitors with basic information on common terns and impacts to their reproductive success. Brochures have been printed and distributed to visitors. Visitors can take this material with them and learn more about the efforts of the MDNR to protect the common tern.

Purpose of Research

Research is needed to address the concerns identified on Lime Island by MDNR biologists as it relates to vegetation structure and its correlation to common tern reproductive success. As Michigan is one of three areas left in the Great Lakes region

that supports a significant number of common terns (> 900 breeding pairs; Timmerman 1996), it is imperative that efforts be directed at assessing the current population status and any impacts to reproductive success on Lime Island. Efforts to assess reproductive success are necessary as this site is Michigan's stronghold for nesting common terns. It may be possible that Lime Island supports denser vegetation cover than that normally preferred by common terns. If so, this may result in a negative impact on reproductive success. By assessing the vegetation structure and its effects on reproductive success, management recommendations can be made to continue the further existence of the species. Additionally, as vegetation is often related to predation, identifying impacts of predation at this site is also needed since little is known about predators on the Lime Island colony. Therefore, the purpose of this research is to determine the factors affecting reproductive ecology of common terns on Lime Island; with particular emphasis on impacts of vegetation structure on reproductive success.

OBJECTIVES AND HYPOTHESES

Specific objectives of this study are to:

- 1) **determine the reproductive success of common terns on Lime Island;**
- 2) **quantify vegetation structure (i.e., percent total cover, percent litter cover, percent bare ground) within the common tern colony on Lime Island;**
- 3) **determine the effects of vegetation manipulations on reproductive success of common terns on Lime Island**

H_O: Reproductive success will not change with vegetation manipulations

H_A: Reproductive success will change with vegetation manipulations;

- a) **H_O: Reproductive success will not change within the total herbicided areas**

H_A: Reproductive success will change within the total herbicided areas, and

- b) **H_O: Reproductive success will not change within the partial herbicided areas**

H_A: Reproductive success will change within the partial herbicided areas;

- 4) **identify and correlate frequency of avian, mammalian, and reptilian predation to common tern response and loss of chicks and eggs on Lime Island**

H_O: Frequency of predation does not positively correlate with common tern response and losses of chicks and eggs

H_A: Frequency of predation does positively correlate with common tern response and losses of chicks and eggs; and

- 5) make recommendations for managing common terns for increased reproductive success on Lime Island.**

STUDY AREA

Lime Island is located approximately 1.2 km from the eastern shore of Michigan's Upper Peninsula in Chippewa County (46°05'N 84°01'W; Figure 1). Two areas on Lime Island are currently being used by common terns as nesting sites: 1) an old coal dock (along the west side of Lime Island; Figure 3) and 2) a rock pile adjacent to the coal dock (Figure 3). The coal dock is 0.8 ha in size and is covered with mowed grass. The coal dock is connected at the north end to Lime Island via a bridge which is approximately 5.5 m long and 1.8 m wide (Figure 3). Common terns nest on the southern end of the dock (Figure 3). This area is shared with a small (approximately 70 individuals) colony of nesting ring-billed gulls (Figure 3). The vegetation in the colony area is mowed twice a year—once before the terns arrive in early May (if weather permits) and once after the terns leave in late August. The adjacent rock pile rises 1.5 m out of the water, is circular in shape with a diameter of 7.6 m, and the substrate ranges from cobble to boulders. The vegetation on the rock pile consists mostly of forb species (e.g., slender nettle [*Urtica gracilis*]).

Permanent mammalian residents found on Lime Island include mink (*Mustela vison*), weasels (*Mustela* spp.), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), black bear (*Ursus americanus*), coyote (*Canis lantrans*), white-tailed deer (*Odocoileus virginianus*), voles (*Microtus* spp.), house mice (*Mus musculus*), New World mice (*Peromyscus* spp.), and river otter (*Lutra canadensis*). Avian residents during the summer include ring-billed gulls, osprey (*Pandion haliaetus*), bald eagles (*Haliaeetus*

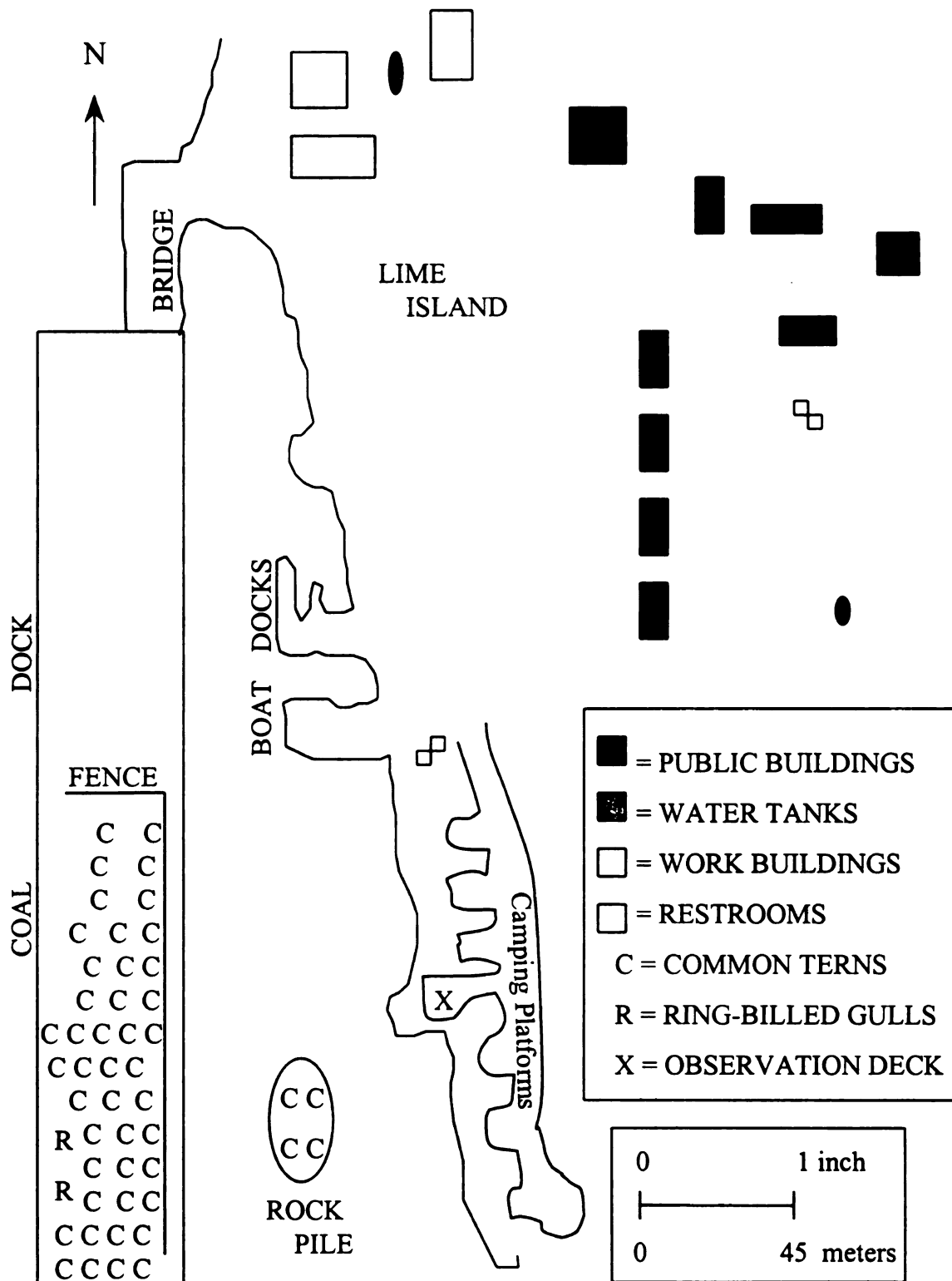


Figure 3. Aerial view of the west side of Lime Island, Michigan, showing the coal dock; rock pile; location of common tern (C) and ring-billed gull (R) nests; and placement of houses, cabins, work buildings, boat docks, and camping and observation (X) platforms, fence, and bridge during the summers of 1997 and 1998.

leucocephalus), spotted sandpipers (*Actitis macularia*), killdeer (*Charadrius vociferus*) and various songbirds.

Precipitation in Chippewa County is well distributed throughout the year, peaking in the summer months. Average annual precipitation is 85.04 cm. Average seasonal snowfall is 291.34 cm. Temperatures range from the winter average of -10.39°C to the summer average of 17.5°C (USDA 1975).

METHODS

Reproductive Success

Nest checks were made every 3 - 5 days from 5 June to 8 August 1997 and 21 May to 1 August 1998, to assist with estimates of reproductive success. Nesting variables recorded at nests included date of egg laying, number of eggs, date of completed clutch, number of eggs lost, 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. Reason for loss was determined by examining the remains of the egg and/or chick. Each nest was given a unique number using a permanent marker on a 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 to 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 after they were completely dry. Appropriate state and federal banding 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 chicks were approved by Michigan State University's All-University Committee on Animal Use and Care (AUF # 09/96-135-00).

Daily and period survival estimates for eggs and chicks were calculated using the Mayfield method (Mayfield 1961). Daily survival is the chance of an individual living until the next day, and period survival is the chance of an individual living until the end of the hatching (for eggs) or fledging (for chicks) period. The Mayfield method uses the

number of exposure days and number of deaths to calculate survival (Mayfield 1961). Survival estimates were calculated for 3 periods: 1) from initiation of incubation to hatching (eggs), 2) from hatching to fledging (chicks), and 3) overall (calculated by multiplying the egg and chick survivals together). Eggs were used as the experimental unit from initiation of egg laying to hatching, and individual chicks were used as the experimental unit from hatching to fledging (Mayfield 1961, 1975). Eggs were used as the experimental unit from initiation of incubation to hatching because eggs are laid and hatched at different times. Chicks were used as the experimental unit from hatching to fledging because they are mobile and do not move in groups. Nests were considered active if at least one egg or chick was present in the nest cup. Abandoned nests were incorporated into the estimate using a maximum of 12 exposure days. Period survival for eggs and chicks was calculated using 24 days (L; Mayfield 1961) as the mean number of incubation days (Burger and Gochfeld 1991) 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 ≥ 18 days old on last capture. Any chick younger than 18 days old at last capture and not found dead in subsequent nest checks was considered censored (or fate unknown).

Vegetation Structure

A 50 X 50 cm modified Daubenmire frame (Daubenmire 1959) was centered at each nest to assist with determining nest site selection preference and to allow for comparisons of vegetation structure between successful and unsuccessful nests.

Vegetation variables were measured as soon as a completed clutch of eggs was present in the nest cup. Vegetation variables included percent total cover, percent live cover, percent dead cover, percent forb cover, percent grass cover, and percent woody cover. Percent bare ground and percent litter cover were also measured. Vegetation variables were collected at 100 nests and random spots in 1997 and 325 nests and random spots in 1998. Paired random points were chosen while in the field and were points where no nests were located. Additionally, paired random points were located within the same treatment area as the paired nest.

Vegetation Manipulations

After consultation with the MDNR and review of the 1997 vegetation data, vegetation manipulations were proposed to determine if the amount of vegetation cover coincided with lower reproductive success of common terns. Manipulations of vegetation were performed at the north end of the colony in 1998, coinciding with the location of fewer nests in 1997. The area was chosen because the common tern is a State threatened species and only a small section of the colony was authorized for manipulations. Manipulations were performed within the first 50 m at the north end of the colony (Figure 4). The area was divided into 5 X 5 m sections. This size was chosen to provide an area big enough for more than five nests and to have multiple replicates of each treatment within the first 50 m of the colony. Each 5 x 5 m section was randomly assigned to one of 2 treatments or a control (Figure 4). Treatments were total herbicide, spraying all of the vegetation within the plot, and partial herbicide, spraying spots of dense vegetation within the plot. The control areas were left unmanipulated and were those areas within

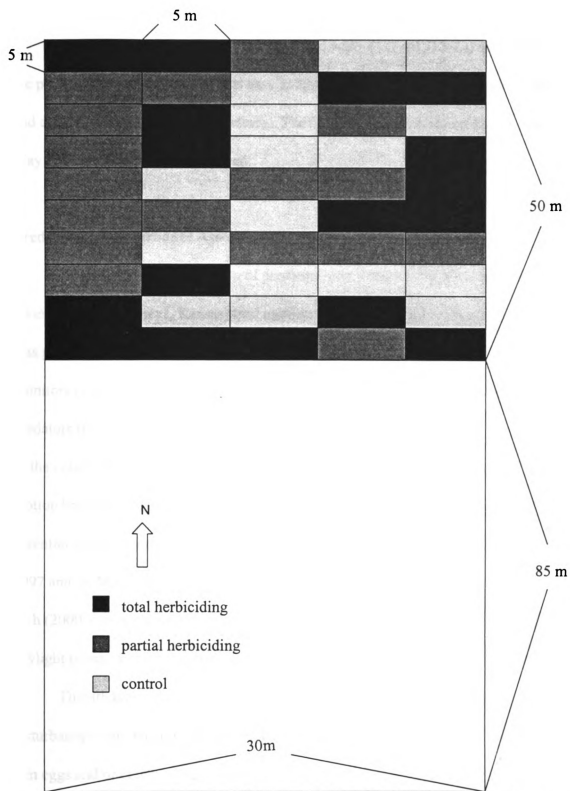


Figure 4. Map of the common tern colony on Lime Island showing the first 50 m where the manipulations were performed and the location of each treatment plot in summer 1998.

the treatment area. Seventeen replicates of each treatment and the control were used.

Herbiciding (mixture of Round-Up® and water (120 mL/3.8 L)) was chosen as the preferred treatment because it is easy to apply, does not take many people to apply it, and can be readily repeated if necessary. The herbicide was applied on 18, 19, and 26 May 1998 using a backpack sprayer.

Predator and Disturbance Assessment

To assist with identification of predators, one Trail-Master (Goodson and Associates, Inc., Lenexa, Kansas) trail monitor connected to an Olympus 35-mm camera was placed on the bridge on the north end of the coal dock and five (1997) or six monitors (1998) were placed within the colony to record movement of terrestrial predators into the colony (Figure 5). The cameras and monitors located at the north end of the colony were arranged side by side to encompass the width of the coal dock. Any motion breaking the infra-red beam signaled the camera to take a picture, thus recording potential predators on 35-mm slide film. Trail monitors were used beginning 10 June 1997 and 18 May 1998 on the coal dock. Cameras were run for 24 hr in the colony and 12 h (2000 – 0800 hr) at the end of the coal dock due to heavy visitor traffic during the daylight hours. Every attempt was made to operate cameras on consecutive days.

Disturbance type, disturbance length, and response of common terns to disturbances were recorded to determine if disturbances correlated with a loss of common tern eggs and/or chicks. Disturbance was defined as any activity resulting in a partial fly-up (less than half of the colony) of common terns from a nesting or loafing site to a mass

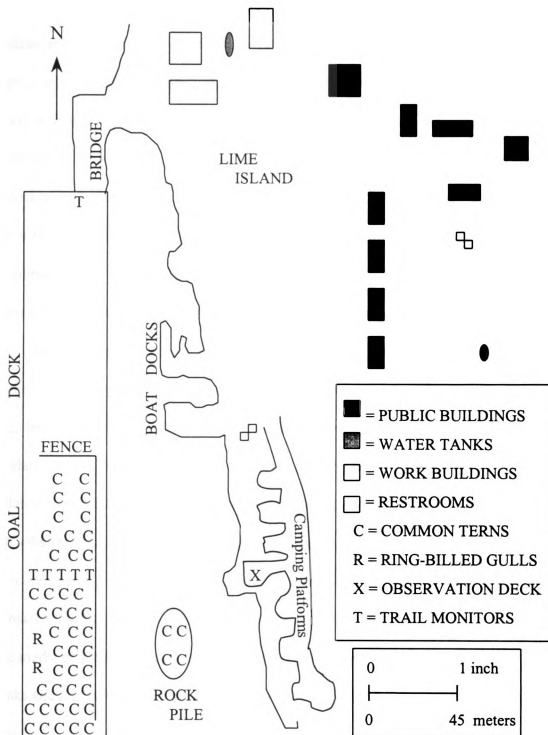


Figure 5. Aerial view of the west side of Lime Island, Michigan, showing the coal dock; rock pile; location of common tern (C) and ring-billed gull (R) nests; and placement of houses, cabins, work buildings, boat docks, and camping and observation (X) platforms, fence, bridge, and trail monitors (T) during the summers of 1997 and 1998.

fly-up (more than half of the colony). Disturbances were classified as mammalian, avian, reptilian, researcher-induced, small watercraft, freighter or ship, or none. Disturbance length was recorded in seconds and was timed from when the disturbance entered the colony area to when it left the colony area. The colony area extended from the fence to the south end of the coal dock and from the north end of the rock pile to the south end of the rock pile. If the common terns flew up without a disturbance being witnessed, the time was measured beginning when the first common terns flew up and ended when the last common terns landed. Disturbances were documented while performing nest observations, nest checks, or working outside away from the colony.

Impacts of predation were documented while working within the colony (i.e., nest checks, vegetation measurements). If the results of predation (i.e., missing or broken eggs, dead chicks and/or adults) were observed in the area of the disturbance, then a correlation could be made to the disturbance. If no disturbance was seen, yet signs of predation were documented while doing nest checks, then no correlation could be made with a disturbance. Eggs, chicks, and adults were examined to determine cause of death and to determine a specific predator, if any. Eggs were considered abandoned if they had not hatched within 25 days and if cold to the touch. Eggs were considered preyed on if poke marks or shell fragments were left in the nest, or if the whole egg was missing. Chicks and adults were considered preyed on if bite or poke marks were found on the body.

Analysis of Data

Definitions

In 1997, no manipulations were performed within the colony. The first 50 m (where the manipulations were performed in 1998) in 1997 was referred to as the “pre-treated area”. The “treated area” was the first 50 m where the manipulations were performed in 1998. The treated area was further divided into the individual treatments (total herbicided, partial herbicided, and control; Figure 4). The control areas were those unmanipulated areas within the treatment area. The unmanipulated area in 1997 was the same as the unmanipulated area in 1998, which was the last 85 m (or the remainder) of the coal dock.

Comparisons

A Mann-Whitney U test (MWU; Mann and Whitney 1947; $P < 0.006$ adjusted with Bonferroni) was used to make comparisons of vegetation variables between nests and random points within 1997 and 1998 to determine if certain vegetation variables could be associated with nest placement within the colony. The MWU is a nonparametric test for significant differences and ranks each observation in order of increasing size. The means are tested to determine whether or not the groups of observations are from the same population (Seigel 1956). A P-value of 0.006 was chosen by using $\alpha = 0.05$ and dividing by the number of vegetation characteristics estimated ($n = 8$; Neter et al. 1996). A MWU ($P < 0.006$ adjusted with Bonferroni) was also used to compare vegetation variables between successful and unsuccessful nests within 1997 and 1998 to determine if

certain vegetation variables could be associated with successful nesters. A nest was considered successful if it hatched at least one young. Unsuccessful nests were those that hatched no young. Additionally, vegetation variables at nests were compared (MWU, $P < 0.006$; Mann and Whitney 1947) between years to determine if vegetation structure changed from 1997 to 1998. Only vegetation data collected from the coal dock was used in the statistical comparisons mentioned above. The only statistical comparison of rock pile data was a comparison of vegetation variables (MWU, $P < 0.006$) between 1997 and 1998.

In 1998, comparisons of vegetation variables between the unmanipulated section of the colony and the manipulated (treatment) area were made to determine if there were any significant differences in the vegetation cover between the treated and untreated areas on the coal dock (MWU, $P < 0.006$; Mann and Whitney 1947). Vegetation variables in the treatment area of the coal dock (Figure 4) were compared among the 2 treatments and control (Kruskal-Wallis [KW], $P < 0.006$; Siegel 1956) to determine if the manipulations caused significant differences in vegetation cover. Comparisons of vegetation variables of successful and unsuccessful nests between the treatment and unmanipulated areas (MWU, $P < 0.006$; Mann and Whitney 1947) and among treatments (KW, $P < 0.006$; Siegel 1956) were also made to determine if there was a significant difference in vegetation structure around nest types (successful and unsuccessful). Finally, vegetation cover was qualitatively compared to common tern reproductive success to determine which vegetation characteristics promoted the best reproductive success on Lime Island. Specific vegetation structure differences, coupled with high reproductive success, can

lead to the determination of preferred vegetation structure for nesting by common terns on Lime Island.

RESULTS

Results from this study will primarily focus on the coal dock because no manipulations were performed on the rock pile. Information gathered on the rock pile will be presented and compared to the coal dock when relevant to support the findings for vegetation structure and reproductive success on the coal dock.

Nest Checks and Banding

Common tern nests were first observed in 1997 on 5 June, and on 21 May in 1998. The greatest number of active nests on a given day (indicating the number of breeding pairs) was 649 in 1997 and 727 in 1998 (Table 1). Chicks were observed on the rock pile before the coal dock in 1997 (13 June and 24 June, respectively; Table 1). Chicks were observed on the coal dock and rock pile on the same day in 1998 (11 June; Table 1). More chicks were banded in 1997 than in 1998 (1475 and 1130, respectively; Table 1). More chicks hatched per pair in 1997 than in 1998 (2.27 and 1.51, respectively), and more chicks fledged/pair in 1997 than in 1998 (0.65 and 0.21, respectively; Table 1). Common terns vacated Lime Island in mid-September 1997 (D. Dimond, pers. commun.) and 1 August 1998 (J. Warner, MDNR, pers. commun.; Table 1).

1997 Vegetation Measurements

The vegetation structure for the Lime Island coal dock in 1997 consisted of 81.5% total cover, 7.8% bare ground and 10.7% litter cover (Table 2). There was more live

Table 1. Date chicks first observed, greatest number of nests on a given day* and the date of the count, total number of chicks banded, date common terns left the colony, number of chicks hatched per pair, and number of chicks fledged per pair for Lime Island common tern colony during summers 1997 and 1998. * This value gives the number of breeding pairs within the colony.

Year	Greatest Number of Nests on a Given Day	Date of Greatest Number of Nests	Date Chicks				Total Number of Chicks Banded	Date Common Terns Left	Number of Chicks Hatched per Pair	Number of Chicks Fledged per Pair
			First Observed							
			Rock Pile	Coal Dock						
1997	649	6/24	6/13	6/24		1475	mid-Sept.	2.27	0.65	
1998	727	6/14	6/11	6/11		1130	8/1	1.51	0.21	

Table 2. Mean (SE) vegetation characteristics around common tern nests on the coal dock on Lime Island, Michigan in summer 1997.

Characteristics	$\bar{x}$ Percent (n=80)
% Total Cover	81.5 (2.4)
% Live Cover	65.9 (2.4)
% Grass Cover	63.1 (2.5)
% Forb Cover	2.8 (1.0)
% Woody Cover	0.0 (0.0)
% Dead Cover	15.6 (1.6)
% Bare Ground	7.8 (1.9)
% Litter Cover	10.7 (1.4)

cover than dead cover (65.9% and 15.6%, respectively), while the live cover was dominated by grass cover (63.1%; Table 2). In comparison, in 1997, the rock pile supported 20.5% total cover and 19.6% live cover, which consisted mostly of forbs (16.7%; Table 3). Percent bare ground was 71.4% on the rock pile and percent litter cover was 8.2% (Table 3). No height measurements of vegetation were taken in 1997.

Common vegetation species found on the coal dock in 1997 included (in no particular order) black-eyed Susan (*Rudbeckia serotina*), oxeye daisy (*Chrysanthemum leucanthemum*), wild red raspberry (*Rubus idaeus*), wild strawberry (*Fragaria virginiana*), red clover (*Trifolium pratense*), poison ivy (*Toxicodendron radicans*), red-osier dogwood (*Corus stolonifera*), yellow sweet clover (*Melilotus officinalis*), and white sweet clover (*M. alba*; Appendix Table 1).

Comparisons of vegetation variables between successful and unsuccessful nesters in 1997 yielded no significant differences ($P > 0.006$) for any vegetation variable (Table 4). No statistical comparisons were made between the pre-treated area and the unmanipulated area in 1997 due to low sampling numbers in the pre-treated area ($n = 1$; Table 5). The unmanipulated area supported greater, although not statistically tested, percent total cover (81.8%) and lower percent bare ground (7.7%) and litter cover (10.4%) than the pre-treated area (55.0%, 15.0%, and 30.0%, respectively; Table 5).

Nests and random points were also compared on the coal dock in 1997 to determine if there were any differences between areas where common terns nested and areas where there were no nests. Only litter cover was found to be significantly greater at random points than nest sites ($P < 0.001$; Table 6).

Table 3. Mean (SE) vegetation characteristics of common tern nests for rock pile on Lime Island in summers 1997 and 1998.

Characteristics	1997 (n=20)	1998 (n=100)
% Total Cover	20.5 (3.4)	12.7 (1.1)
% Live Cover	19.6 (3.4)	11.3 (1.0)
% Grass Cover	2.0 (2.0)	0.1 (0.0)
% Forb Cover	16.7 (2.9)	11.2 (1.0)
% Woody Cover	1.0 (1.0)	0.0 (0.0)
% Dead Cover	0.9 (0.4)	1.4 (0.3)
% Bare Ground	71.4 (4.1)	70.5 (1.4)
% Litter Cover*	8.2 (1.9)	16.8 (1.1)

* significantly different between years (Mann-Whitney U, $P < 0.006$)

Table 4. Mean (SE) vegetation characteristics between common tern nests that were successful (hatched at least one chick) and unsuccessful (those that failed to hatch a chick) on the coal dock on Lime Island, Michigan, in summer 1997.

Characteristics	Successful (n=37)	Unsuccessful (n=43)
% Total Cover	83.1 (3.8)	80.1 (3.0)
% Live Cover	68.9 (3.6)	63.3 (3.3)
% Grass Cover	67.1 (3.6)	59.6 (3.3)
% Forb Cover	1.8 (0.6)	3.7 (1.7)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	14.2 (1.9)	16.9 (2.4)
% Bare Ground	8.5 (3.5)	7.3 (1.9)
% Litter Cover	8.4 (1.7)	12.6 (2.1)

Table 5. Mean (SE) vegetation characteristics of common tern nests in pre-treated (first 50 m) and unmanipulated (last 85 m) areas of the Lime Island coal dock in summer 1997.

Characteristics	Pre-treated (n=1)	Unmanipulated (n=79)
% Total Cover	55.0 (0.0)	81.8 (2.4)
% Live Cover	50.0 (0.0)	66.1 (2.5)
% Grass Cover	45.0 (0.0)	63.3 (2.5)
% Forb Cover	5.0 (0.0)	2.8 (1.0)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	5.0 (0.0)	15.8 (1.6)
% Bare Ground	15.0 (0.0)	7.7 (1.9)
% Litter Cover	30.0 (0.0)	10.4 (1.4)

Table 6. Mean (SE) vegetation characteristics of common tern nests and random points for coal dock on Lime Island in summer 1997.

Characteristics	Nests (n=80)	Random Points (n=80)
% Total Cover	81.5 (2.4)	73.1 (2.9)
% Live Cover	65.9 (2.4)	55.1 (2.9)
% Grass Cover	63.1 (2.5)	54.0 (3.0)
% Forb Cover	2.8 (1.0)	1.1 (0.5)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	15.6 (1.6)	18.1 (1.6)
% Bare Ground	7.8 (1.9)	5.8 (1.7)
% Litter Cover*	10.7 (1.4)	21.1 (2.5)

*** significantly different between locations (Mann-Whitney U, $P < 0.006$)**

1998 Vegetation Measurements and Manipulations

Mean vegetation structure around common tern nests on Lime Island in 1998 consisted of 41.3% total cover, 6.3% bare ground, and 52.4% litter cover (Table 7). There was more live cover than dead cover (28.7% and 12.6%, respectively; Table 7), with live cover dominated by grass cover (26.9%; Table 7). In comparison, the rock pile supported 12.7% total cover in 1998, with 11.3% live cover (Table 3). Percent bare ground on the rock pile was 70.5%, and the percent litter cover was 16.8% (Table 3). Percent total cover was significantly greater around successful nests (44.4%) than unsuccessful nests (33.3%; Table 8).

Treatments and unmanipulated area

In 1998, the treatment area (treatments and control included) had significantly less total cover (32.7%) and significantly more litter cover (60%) than the unmanipulated area (57.8% and 37.9%, respectively; Table 9). The unmanipulated area supported significantly more live cover (51.2%) and significantly less dead cover (6.6%) than the treatment area (17.0% and 15.7%, respectively; Table 9).

Nests that successfully hatched at least one young in the treatment area (regardless of treatment) had significantly less total cover (36.8%), live cover (18.7%), and grass cover (16.9%), and significantly more dead cover (18.1%) and litter cover (56.9%) than successful nests in the unmanipulated area (Table 10). Unsuccessful nests in the treatment area also had significantly less total cover (23.7%) and live cover (13.3%; Table 11) than the unmanipulated area. Percent forb cover was significantly greater at unsuccessful nests in the treatment area than in the unmanipulated area (2.5% and 0%,

Table 7. Mean (SE) vegetation characteristics of common tern nests in summer 1998 on the coal dock on Lime Island, Michigan.

Characteristics	$\bar{x}$ Percent (n=225)
% Total Cover	41.3 (1.8)
% Live Cover	28.7 (1.8)
% Grass Cover	26.9 (1.8)
% Forb Cover	1.8 (0.4)
% Woody Cover	0.0 (0.0)
% Dead Cover	12.6 (1.0)
% Bare Ground	6.3 (0.8)
% Litter Cover	52.4 (1.8)

Table 8. Mean (SE) vegetation characteristics on coal dock between successful (those that hatched at least one chick) and unsuccessful nests (those that did not hatch a chick) on Lime Island, Michigan, in summer 1998.

Characteristics	Successful (n=162)	Unsuccessful (n=63)
% Total Cover*	44.4 (2.0)	33.3 (3.4)
% Live Cover	30.7 (2.1)	23.6 (3.4)
% Grass Cover	28.9 (2.1)	21.7 (3.5)
% Forb Cover*	1.8 (0.6)	1.8 (0.4)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	13.6 (1.3)	9.8 (1.2)
% Bare Ground	5.6 (0.9)	8.0 (2.0)
% Litter Cover	50.0 (2.0)	58.6 (3.6)

* significantly different between nest type (Mann-Whitney U, $P < 0.006$)

Table 9. Mean (SE) vegetation characteristics of unmanipulated and treatment area common tern nests on the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Unmanipulated (n=77)	Treatment Area (n=148)
% Total Cover*	57.8 (2.9)	32.7 (1.9)
% Live Cover*	51.2 (3.0)	17.0 (1.5)
% Grass Cover*	49.8 (3.0)	15.0 (1.5)
% Forb Cover*	1.4 (1.1)	2.0 (0.4)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover*	6.6 (1.1)	15.7 (1.3)
% Bare Ground	4.3 (0.9)	7.3 (1.2)
% Litter Cover*	37.9 (2.7)	60.0 (2.0)

* significantly different between areas (Mann-Whitney U, $P < 0.006$)

Table 10. Mean (SE) vegetation characteristics of successful nests (those that hatched at least one chick) in the unmanipulated and treatment areas of the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Unmanipulated (n=61)	Treatment Area (n=101)
% Total Cover*	56.8 (3.2)	36.8 (2.3)
% Live Cover*	50.6 (3.3)	18.7 (1.8)
% Grass Cover*	48.8 (3.4)	16.9 (1.8)
% Forb Cover	1.8 (1.4)	1.8 (0.5)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover*	6.2 (1.3)	18.1 (1.8)
% Bare Ground	4.7 (1.1)	6.2 (1.2)
% Litter Cover*	38.5 (3.0)	56.9 (2.4)

* significantly different between areas (Mann-Whitney U, $P < 0.006$)

Table 11. Mean (SE) vegetation characteristics of nests that did not successfully hatch any young in the unmanipulated and treatment areas on the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Unmanipulated (n=16)	Treatment Area (n=47)
% Total Cover*	61.6 (6.6)	23.7 (2.8)
% Live Cover*	53.7 (6.8)	13.3 (2.6)
% Grass Cover*	53.7 (6.8)	10.8 (2.6)
% Forb Cover*	0.0 (0.0)	2.5 (0.6)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	7.8 (2.5)	10.4 (1.4)
% Bare Ground	3.1 (1.2)	9.7 (2.5)
% Litter Cover*	35.3 (6.5)	66.6 (3.6)

* significantly different between areas (Mann-Whitney U, $P < 0.006$)

respectively), as well percent litter cover (66.6% and 35.3%, respectively, Table 11).

Individual treatments and unmanipulated area

A significant difference was found among all treatment areas (total herbicided, partial herbicided, control, and unmanipulated) in all vegetation characteristics except percent woody cover and percent bare ground in 1998 (Table 12). Percent total cover was significantly lower in the total herbicided areas than in any other area on the coal dock (Table 12). Similarly, live cover was significantly lower in the total herbicided areas (8.9%), while the unmanipulated area had significantly greater live cover (51.2%) than any of the treatment areas on the coal dock in 1998 (Table 12). The total herbicided areas had significantly lower grass cover (6.7%) than any of the other areas on the coal dock (Table 12). Grass cover was significantly greater in the unmanipulated area (49.8%) than in the individual treatment areas (Table 12). Forb cover in the total herbicided areas (2.2%) was significantly greater than the partial herbicided areas and unmanipulated areas (0.5% and 1.4%, respectively; Table 12). The total herbicided, partial herbicided, and control areas had significantly greater dead cover (15.6%, 18.4%, and 11.5%, respectively) than the unmanipulated area (6.6%; Table 12). Litter cover was significantly greater in the total herbicided areas (67.6%) than in the partial herbicided, control, and unmanipulated areas of the coal dock (Table 12).

Comparisons of vegetation structure among treatment areas for those nests that successfully hatched at least one young were significantly different in all characteristics except percent woody cover and percent bare ground (Table 13). Percent total cover was not significantly different ($P > 0.006$) between total herbicided and control areas, and the

Table 12. Mean (SE) vegetation characteristics of nests, and amount of edge and total area in the total herbicided, partial herbicided, control, and unmanipulated areas of the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Total (n=87)	Partial (n=38)	Control (n=23)	Unmanip (n=77)
% Total Cover*	24.4 (2.2) ^A	46.6 (3.3) ^{BC}	40.9 (4.8) ^B	57.8 (2.9) ^C
% Live Cover*	8.9 (1.3) ^A	28.2 (3.0) ^B	29.3 (4.2) ^B	51.2 (3.0) ^C
% Grass Cover*	6.7 (1.2) ^A	27.6 (3.0) ^B	25.7 (4.2) ^B	49.8 (3.0) ^C
% Forb Cover*	2.2 (0.4) ^A	0.5 (0.4) ^{BC}	3.7 (1.4) ^{AB}	1.4 (1.1) ^C
% Woody Cover	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
% Dead Cover*	15.6 (1.9) ^A	18.4 (2.3) ^A	11.5 (1.5) ^A	6.6 (1.1) ^B
% Bare Ground	8.0 (1.8)	4.7 (1.2)	9.1 (1.6)	4.3 (0.9)
% Litter Cover*	67.6 (2.6) ^A	48.7 (3.1) ^B	50.0 (4.4) ^B	37.9 (2.7) ^B

* significantly different among areas (KW, $P < 0.006$). Within a row, means having the same letter are not significantly different (KW multiple comparison test, $P < 0.006$).

Table 13. Mean (SE) vegetation characteristics of successful nests (those that hatched at least one young) in the total herbicided, partial herbicided, control, and unmanipulated areas of the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Total (n=47)	Partial (n=33)	Control (n=21)	Unmanip (n=61)
% Total Cover*	28.3 (3.5) ^A	46.4 (3.3) ^B	41.0 (5.1) ^{AB}	56.8 (3.2) ^B
% Live Cover*	8.2 (1.8) ^A	27.0 (2.7) ^B	29.3 (4.4) ^B	50.6 (3.3) ^C
% Grass Cover*	6.6 (1.7) ^A	26.4 (2.7) ^B	25.2 (4.3) ^B	48.8 (3.4) ^C
% Forb Cover*	1.6 (0.6) ^{AB}	0.6 (0.4) ^{AB}	4.0 (1.6) ^A	1.8 (1.4) ^B
% Woody Cover	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
% Dead Cover*	20.1 (3.2) ^A	19.4 (2.5) ^A	11.7 (1.7) ^A	6.2 (1.3) ^B
% Bare Ground	6.1 (2.3)	4.8 (1.4)	8.8 (1.8)	4.7 (1.1)
% Litter Cover*	65.7 (3.8) ^A	48.8 (3.1) ^B	50.2 (4.7) ^B	38.5 (3.0) ^B

* significantly different among areas (KW, $P < 0.006$). Within a row, means having the same letter are not significantly different (KW multiple comparison test, $P < 0.006$).

control areas were not significantly different in percent total cover from the partial herbicided and unmanipulated areas (Table 13). Percent live cover was significantly lower in the total herbicided areas (8.2%) and significantly higher in the unmanipulated area (50.6%) than in all other areas (Table 13). Percent grass cover was significantly greater in the unmanipulated area (48.8%) than in any other area on the coal dock for successful nesters (Table 13). The control (25.2%) and partial herbicided (26.4%) areas were not significantly different from each other in percent grass cover (Table 13), whereas the total herbicided areas had significantly lower percent grass cover (6.6%) than any other area on the coal dock (Table 13). The unmanipulated area had significantly lower percent dead cover (6.2%) around successful nests than any of the treatment areas (Table 13). Percent litter cover was significantly greater in the total herbicided areas than anywhere else on the coal dock (65.7%; Table 13).

The unmanipulated area supported significantly greater percent total cover (61.6%), percent live cover (53.7%), percent grass cover (53.7%), and significantly lower percent litter cover (35.3%) than the total herbicided areas for unsuccessful nests (Table 14).

Nests and random points

Vegetation variables between nests and random points on the coal dock were compared for the 1998 Lime Island common tern colony to determine if there were specific vegetation characteristics common terns selected for nest placement. Nests had significantly greater percent dead cover (12.5%) than the random points (10.2%; Table 15). However, no other vegetation variables were significantly different between nests

Table 14. Mean (SE) vegetation characteristics of nests that did not successfully hatch any young in the total herbicided, partial herbicided, control and unmanipulated areas of the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Total (n=40)	Partial (n=5)	Control (n=2)	Unmanip (n=16)
% Total Cover*	19.9 ^A (2.3)	48.0 ^{AB} (13.6)	40.0 ^{AB} (20.0)	61.6 ^B (6.6)
% Live Cover*	9.6 ^A (1.8)	36.0 ^{AB} (15.0)	30.0 ^{AB} (20.0)	53.7 ^B (6.8)
% Grass Cover*	6.7 ^A (1.8)	36.0 ^{AB} (15.0)	30.0 ^{AB} (20.0)	53.7 ^B (6.8)
% Forb Cover*	2.9 ^A (0.7)	0.0 ^{AB} (0.0)	0.0 ^{AB} (0.0)	0.0 ^B (0.0)
% Woody Cover	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
% Dead Cover	10.3 (1.6)	12.0 (4.9)	10.0 (0.0)	7.8 (2.5)
% Bare Ground	10.2 (3.0)	4.0 (2.4)	12.5 (2.5)	3.1 (1.2)
% Litter Cover*	69.9 ^A (3.7)	48.0 ^{AB} (12.0)	47.5 ^{AB} (17.5)	35.3 ^B (6.5)

* significantly different among areas (KW, $P < 0.006$). Within the same row, means having the same letter are not significantly different (KW multiple comparison test, $P < 0.006$).

Table 15. Mean (SE) vegetation characteristics of nests and random points for coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Nests (n=225)	Random Points (n=225)
% Total Cover	41.3 (1.8)	42.6 (2.1)
% Live Cover	28.7 (1.8)	32.0 (2.0)
% Grass Cover	26.9 (1.8)	29.7 (1.9)
% Forb Cover	1.8 (0.4)	2.3 (0.6)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover*	12.5 (1.0)	10.2 (1.1)
% Bare Ground	6.3 (6.3)	10.3 (1.6)
% Litter Cover	52.4 (1.8)	47.6 (2.0)

* significantly different among site locations (Mann-Whitney U, $P < 0.006$)

and random points in 1998 (Table 15). A comparison of nests and random points in the unmanipulated area resulted in no significant differences between any vegetation variables (Table 16). Additionally, no significant differences were detected between nests and random points within the treatment area of the coal dock (Table 17). However, comparisons suggest that nests had significantly greater percent total cover (24.4%) than the random points (18.6%) within the total herbicided areas (Table 18). No other vegetation variables were significantly different within the total herbicided areas between nests and random points (Table 18). Random points had significantly greater percent total cover (63.2%), percent live cover (46.1%), and percent grass cover (45.4%) than nests (46.6%, 28.2% and 27.6%, respectively) within the partial herbicided areas (Table 19). Nests had significantly greater percent litter cover (48.7%) than random points (33.7%) within the partial herbicided areas (Table 19). Within the control areas, no significant differences were detected between nests and random points (Table 20).

1997 – 1998 Vegetation Comparisons

Rock pile

In 1998, the rock pile supported a significant greater amount of litter cover (16.8%) than in 1997 (8.1%; Table 3). No other vegetation characteristics were significantly different between 1997 and 1998.

Table 16. Mean (SE) vegetation characteristics of nests and random points for unmanipulated area on the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Nests (n=77)	Random Points (n=77)
% Total Cover	57.8 (2.9)	57.2 (3.2)
% Live Cover	51.2 (3.0)	52.4 (3.1)
% Grass Cover	49.8 (3.0)	48.5 (3.1)
% Forb Cover	1.4 (1.1)	3.8 (1.6)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	6.6 (1.1)	4.8 (1.1)
% Bare Ground	4.3 (0.9)	4.5 (1.9)
% Litter Cover	37.9 (2.7)	38.2 (3.0)

Table 17. Mean (SE) vegetation characteristics of nests and random points for treatment area on the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Nests (n=148)	Random Points (n=148)
% Total Cover	32.7 (1.9)	34.3 (2.4)
% Live Cover	17.0 (1.5)	21.4 (2.0)
% Grass Cover	15.0 (1.5)	19.9 (2.0)
% Forb Cover	2.0 (0.4)	1.5 (0.4)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	15.7 (1.3)	12.9 (1.5)
% Bare Ground	7.3 (1.2)	13.3 (2.2)
% Litter Cover	60.0 (2.0)	52.4 (2.6)

Table 18. Mean (SE) vegetation characteristics of nests and random points for total herbicided areas on the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Nests (n=87)	Random Points (n=87)
% Total Cover*	24.4 (2.2)	18.6 (2.4)
% Live Cover	8.9 (1.3)	5.9 (0.9)
% Grass Cover	6.7 (1.2)	4.4 (0.8)
% Forb Cover	2.2 (0.4)	1.5 (0.4)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	15.6 (1.9)	12.7 (2.3)
% Bare Ground	8.0 (1.8)	18.1 (3.5)
% Litter Cover	67.6 (2.6)	63.3 (3.5)

*** significantly different between locations (Mann-Whitney U, $P < 0.006$)**

Table 19. Mean (SE) vegetation characteristics of nests and random points for partial herbicided areas on the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Nests (n=38)	Random Points (n=38)
% Total Cover*	46.6 (3.3)	63.2 (3.3)
% Live Cover*	28.2 (3.0)	46.1 (3.7)
% Grass Cover*	27.6 (3.0)	45.4 (3.9)
% Forb Cover	0.5 (0.4)	0.7 (0.5)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	18.4 (2.3)	17.1 (1.8)
% Bare Ground	4.7 (1.2)	3.2 (0.9)
% Litter Cover*	48.7 (3.1)	33.7 (3.1)

*** significantly different between locations (Mann-Whitney U, $P < 0.006$)**

Table 20. Mean (SE) vegetation characteristics of nests and random points for the control areas on the coal dock on Lime Island, Michigan, in summer 1998.

Characteristics	Nests (n=23)	Random Points (n=23)
% Total Cover	40.9 (4.8)	46.3 (5.7)
% Live Cover	29.3 (4.2)	39.1 (4.8)
% Grass Cover	25.7 (4.2)	36.5 (4.3)
% Forb Cover	3.7 (1.4)	2.6 (1.6)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover	11.5 (1.5)	7.2 (1.9)
% Bare Ground	9.1 (1.6)	11.5 (4.5)
% Litter Cover	50.0 (4.4)	42.2 (5.8)

Coal dock - treated and unmanipulated areas

The coal dock was divided into the pre-treated and unmanipulated areas for 1997 and the treated and unmanipulated areas for 1998. Statistical comparisons could only be made between unmanipulated areas between years because only one nest was sampled for vegetation characteristics in the pre-treated area in 1997. In 1997, the unmanipulated area had significantly greater percent total cover (81.8%) and significantly less percent litter cover (10.4%) than in 1998 (57.8% and 37.9%, respectively; Table 21). Additionally, the unmanipulated area had significantly greater percent live cover (66.1%), percent grass cover (63.3%) and percent dead cover (15.8%) in 1997 than in 1998 (51.2%, 49.8%, and 6.6%, respectively; Table 21).

Reproductive Success

Nest numbers

The number of nests established on the coal dock was greater in 1997 with 980 nests than in 1998 with 907 (Table 22). The number of nests in the unmanipulated area decreased from 924 (1997) to 688 (1998; Table 22). However, the number of nests in the treatment area increased from 56 (1997) to 219 (1998; Table 22). The total herbicided areas supported the greatest number of nests within the treatment area (125). The control area supported the second greatest number of nests (49), followed by the partial herbicided area (45; Table 22). In 1998, the number of nests on the rock pile increased from 158 to 165 (Table 22).

Table 21. Mean (SE) vegetation characteristics of nests in unmanipulated area of the coal dock on Lime Island, Michigan, in summers 1997 and 1998.

Characteristics	1997 (n=79)	1998 (n=77)
% Total Cover*	81.8 (2.4)	57.8 (2.9)
% Live Cover*	66.1 (2.5)	51.2 (3.0)
% Grass Cover*	63.3 (2.5)	49.8 (3.0)
% Forb Cover*	2.8 (1.0)	1.4 (1.1)
% Woody Cover	0.0 (0.0)	0.0 (0.0)
% Dead Cover*	15.8 (1.6)	6.6 (1.1)
% Bare Ground	7.7 (1.9)	4.3 (0.9)
% Litter Cover*	10.4 (1.4)	37.9 (2.7)

* significantly different between years (Mann-Whitney U, $P < 0.006$)

Table 22. Common tern egg, chick, and overall period survival percentages for eggs on the rock pile and coal dock, along with treatment and unmanipulated areas, for summers 1997 and 1998 on Lime Island, Michigan. Number of nest in each area also provided.

	Number of Nests	Egg Survival	Chick Survival	Overall Survival
1997	1138	0.24	0.86	0.21
Rock Pile	158	0.38	0.74	0.28
Coal Dock	980	0.22	0.88	0.20
Pre-Treated	56	0.18	0.94	0.17
Unmanip	924	0.22	0.86	0.19
1998	1062	0.31	0.42	0.13
Rock Pile	165	0.38	0.78	0.30
Coal Dock	907	0.30	0.25	0.08
Treated	219	0.32	0.32	0.10
Total Herb.	125	0.25	0.25	0.06
Partial Herb.	45	0.39	0.43	0.17
Control	49	0.41	0.29	0.12
Unmanip	688	0.29	0.22	0.06

Nests in the treatment area were located mainly along the eastern edge, or the harbor side, of the coal dock (Figure 6). Only three nests were located near the western edge of the coal dock and were all located in control plots (Figure 6).

Egg survival

Period egg survival (survival from initiation of incubation to hatching) for the 1997 Lime Island colony was 0.24 (Table 22). Egg survival on the rock pile was higher than the egg survival on the coal dock in 1997 (0.38 and 0.22, respectively; Table 22). Egg survival was higher in the unmanipulated area than in the pre-treated area in 1997 (0.22 and 0.18, respectively; Table 22). Approximately 12 – 13% of nests monitored in 1997 were considered censored, meaning their fate could not be determined (Table 23).

In 1998, period egg survival for the Lime Island colony was 0.31 (Table 22). Egg survival on the rock pile was higher than the egg survival on the coal dock in 1998 (0.38 and 0.30, respectively; Table 22). Egg survival in the treated area was higher than the egg survival in the unmanipulated area in 1998 (0.32 and 0.30, respectively; Table 22). Within the treated area, egg survival was highest in the control areas (0.41), and lowest in the total herbicided areas (0.25; Table 22). Patterns in egg survival were investigated among all treatments and the control (Figure 6). No patterns in egg survival were observed. In other words, there was no central point where egg survival was highest and surrounding areas decreased in survival accordingly (Figure 6). Egg censoring was under 1% for all areas except the rock pile, which had 3% censoring (Table 23).

In general, common tern period egg survival for Lime Island was lower in 1997 than in 1998 (0.24 and 0.31, respectively; Table 22). Additionally, egg survival remained

T N = 0	T N = 0	P N = 0	C N = 0	C N = 3 0.29 0.00 0.00
P N = 0	P N = 0	C N = 0	T N = 7 0.20 0.09 0.02	T N = 8 0.12 0.00 0.00
P N = 0	T N = 0	C N = 0	P N = 7 0.41 0.54 0.22	C N = 7 0.73 0.16 0.12
C N = 0	P N = 0	C N = 2 0.48 1.00 0.48	C N = 5 0.38 0.35 0.14	T N = 15 0.28 0.41 0.11
P N = 0	C N = 0	P N = 4 0.15 1.00 0.15	P N = 9 0.53 0.34 0.18	T N = 19 0.28 0.48 0.13
P N = 0	P N = 0	C N = 2 0.53 1.00 0.15	T N = 14 0.34 0.08 0.03	T N = 20 0.18 0.08 0.01
P N = 0	C N = 2 0.26 1.00 0.26	P N = 2 0.51 1.00 0.51	P N = 3 0.71 0.00 0.00	P N = 7 0.50 0.15 0.07
P N = 0	T N = 0	C N = 0	C N = 5 0.58 0.08 0.05	C N = 8 0.66 0.10 0.07
T N = 0	C N = 1 0.12 0.00 0.00	C N = 3 0.54 0.53 0.29	T N = 15 0.36 0.05 0.02	C N = 11 0.38 0.00 0.00
T N = 0	T N = 0	T N = 10 0.28 1.00 0.28	P N = 13 0.40 0.37 0.15	T N = 17 0.29 0.00 0.00

N
↑

Figure 6. Diagram of the treatment area on the coal dock showing nest numbers, treatment type (T = total herbicided, P = partial herbicided, C = control), number of nests (N), and survival probabilities for egg (top), chick (middle), and overall (bottom) periods for each treatment square in 1998.

Table 23. Common tern nest and chick censoring percentages for eggs on the rock pile and coal dock, along with treatment and unmanipulated areas, for summers 1997 and 1998 on Lime Island, Michigan.

	Nest Censoring (%)	Chick Censoring (%)
1997	12.9	66.1
Rock Pile	12.0	39.2
Coal Dock	13.2	70.2
Pre-Treated	13.6	60.0
Unmanipulated	13.2	69.4
1998	0.9	65.2
Rock Pile	3.0	43.8
Coal Dock	0.5	71.5
Treated	0.0	69.8
Total Herbicide	0.0	71.8
Partial Herbicide	0.0	71.0
Control	0.0	65.5
Unmanipulated	0.7	71.9

approximately the same on the rock pile between years (0.38 in 1997 and 0.38 in 1998; Table 22) and increased on the coal dock between years (0.22 in 1997 and 0.30 in 1998; Table 22). Egg survival in the unmanipulated area was lower in 1997 than in 1998 (0.22 and 0.29, respectively; Table 22). The 1998 treated area egg survival was higher than the egg survival for the pre-treated area in 1997 (0.32 and 0.18, respectively; Table 22). No statistical comparisons of survival probabilities between years were performed because survival probabilities are absolute values, not means.

Chick survival

The 1997 common tern period chick survival for Lime Island was 0.86 (Table 22). Chick survival was higher on the coal dock than on the rock pile in 1997 (0.88 and 0.74, respectively; Table 22). On the coal dock in 1997, chick survival was higher in the pre-treated area than in the unmanipulated area (0.94 and 0.86, respectively; Table 22). The fate of 66.1% of common tern chicks in 1997 was unknown (Table 23). Censoring was 39.2% on the rock pile and 70.2% on the coal dock in 1997 (Table 23).

Common tern period chick survival for Lime Island in 1998 was 0.42 (Table 22). Chick survival was higher on the rock pile than on the coal dock in 1998 (0.78 and 0.25, respectively; Table 22). Chick survival in the treated areas on the coal dock was higher than chick survival in the unmanipulated area in 1998 (0.32 and 0.22, respectively; Table 22). Within the treated area, chick survival was higher in the partial herbicided than in the control and total herbicided areas (0.43, 0.29, and 0.25, respectively; Table 22). For each individual treatment square, chick survival was highest on the western edge of the nests (Figure 6). Patterns in chick survival were investigated among all treatments and

the control (Figure 6). No patterns in chick survival were observed. In other words, there was no central point where chick survival was highest and surrounding areas decreasing in survival accordingly (Figure 6).

The fate of 65.2% of common tern chicks was unknown in 1998 (Table 23). The rock pile had lower censoring in 1998 than the coal dock (43.8% and 71.5%, respectively; Table 23). On the coal dock, the unmanipulated area had slightly higher censoring than the treatment area (71.9% and 69.8%, respectively; Table 23). Within the treatment area, the control area had the lowest chick censoring (65.5%), while the total herbicided areas had the highest censoring (71.8%; Table 23).

In general, the 1997 chick survival was greater than the 1998 chick survival (Table 22). In 1997, the chick survival on the coal dock was 0.88, while in 1998 the chick survival was 0.25 (Table 22). There was also a large decrease in survival in the treated and unmanipulated areas from 1997 to 1998 (Table 22). Chick survival for the pre-treated area in 1997 was 0.94, while the chick survival for the treated area in 1998 decreased to 0.32 (Table 22). The unmanipulated area chick survival was 0.86 in 1997 and 0.22 in 1998 (Table 22).

Overall survival

Overall survival was egg survival multiplied by chick survival. In 1997, the overall survival was 0.21 (Table 22). Overall survival on the rock pile was higher than the overall survival on the coal dock in 1997 (0.28 and 0.20, respectively; Table 22). On the coal dock, overall survival in the unmanipulated area was higher than the overall survival in the pre-treated area (0.19 and 0.17, respectively; Table 22).

In 1998, the overall survival for Lime Island was 0.13 (Table 22). Overall survival was higher on the rock pile than on the coal dock in 1998 (0.30 and 0.08, respectively; Table 22). On the coal dock, overall survival in the treated area was higher than the overall survival in the unmanipulated area (0.10 and 0.06, respectively; Table 22). Within the treatment area, overall survival in the partial herbicided areas was highest with 0.17, second highest in the control areas (0.12) and lowest in the total herbicided areas (0.06, Table 22). Patterns in overall survival were investigated among all treatments and the control (Figure 6). No patterns in overall survival were observed. In other words, there was no central point where overall survival was highest and surrounding areas decreasing in survival accordingly (Figure 6).

Overall survival was higher in 1997 than overall survival in 1998 (Table 22). Overall survival for the rock pile between years was similar (0.28 in 1997 and 0.30 in 1998; Table 22), while the overall survival was lower on the coal dock in 1998 than in 1997 (0.08 and 0.20, respectively; Table 22). In the pre-treated area, the overall survival was 0.17 in 1997, which was greater than the overall survival for the treated area in 1998 (0.10; Table 22). Overall survival for the unmanipulated area on the coal dock was greater in 1997 than in 1998 (0.19 and 0.06, respectively; Table 22).

1997 Vegetation and Survival

Pre-treated and unmanipulated areas

In 1997, the pre-treated area was dominated by a lower percentage of total cover (> 50%) and some litter cover (> 20%), which coincided with greater chick survival (> 0.90) and lower egg survival (< 0.20) than the unmanipulated area (Figure 7). Care

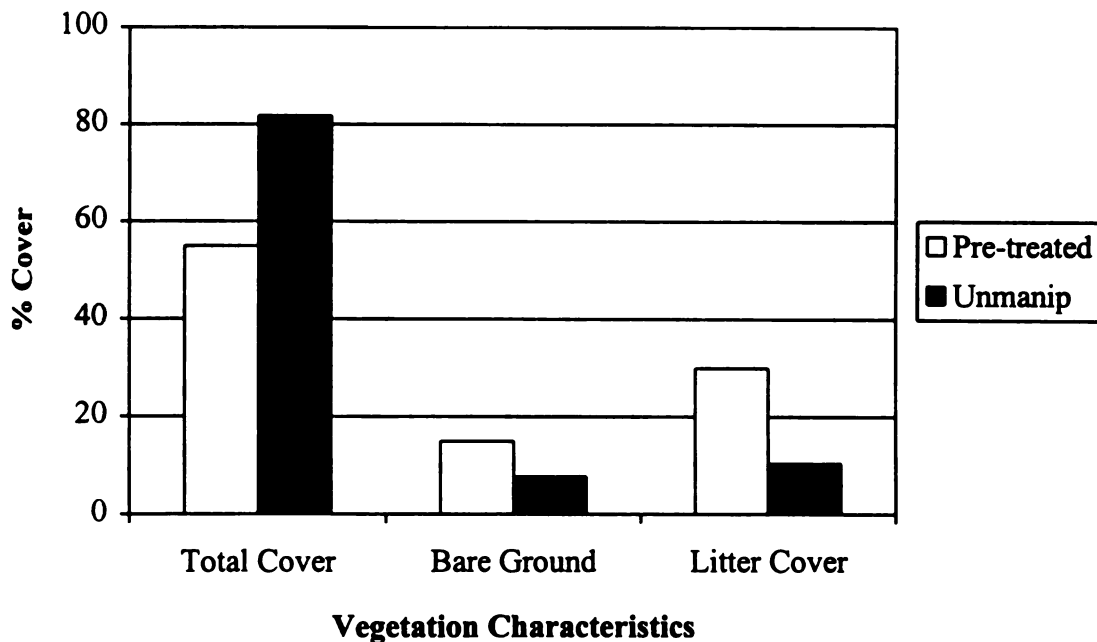
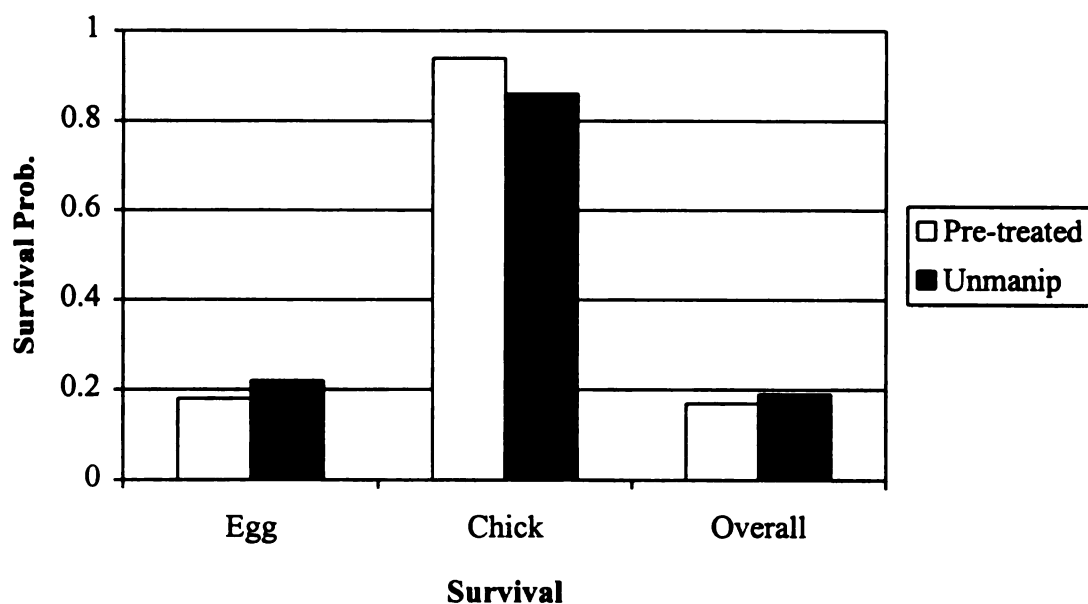


Figure 7. Common tern survival probabilities and vegetation cover percentages for the pre-treated and unmanipulated areas on the Lime Island coal dock, summer 1997.

should be taken when interpreting results from the pre-treated area in 1997 as the vegetation characteristics were collected at only one nest. However, egg, chick, and overall survival were estimated using all nests established within the pre-treated area and can be compared without hesitation to the unmanipulated area in 1997.

1998 Vegetation and Survival

Treatment and unmanipulated areas

Survival and vegetation structure were compared between the unmanipulated and treatment areas on the coal dock in 1998 (Figure 8). The unmanipulated area had significantly greater percent total cover and significantly less litter cover (Table 7), and supported lower common tern egg and chick survival than the treatment area (Figure 8).

Common tern survival and vegetation structure were also compared within each treatment area on the coal dock (Figure 9). The partial herbicided areas had a similar composition (approximately 47%) of total cover and litter cover and supported similar survival (approximately 40%) for common tern egg and chicks (Figure 9). Control areas were slightly more dominated by litter cover (50%) than by total cover (41%) and supported similar egg survival to partial herbicided areas (40%) but much lower chick survival (0.30; Figure 9). Total herbicided areas were dominated by litter cover (68%) and had the lowest egg and chick survivals (0.25) of the treatment types (Figure 9). It should be noted that the two treatment and control areas supported similar percent bare ground (approximately 7%; Figure 9).

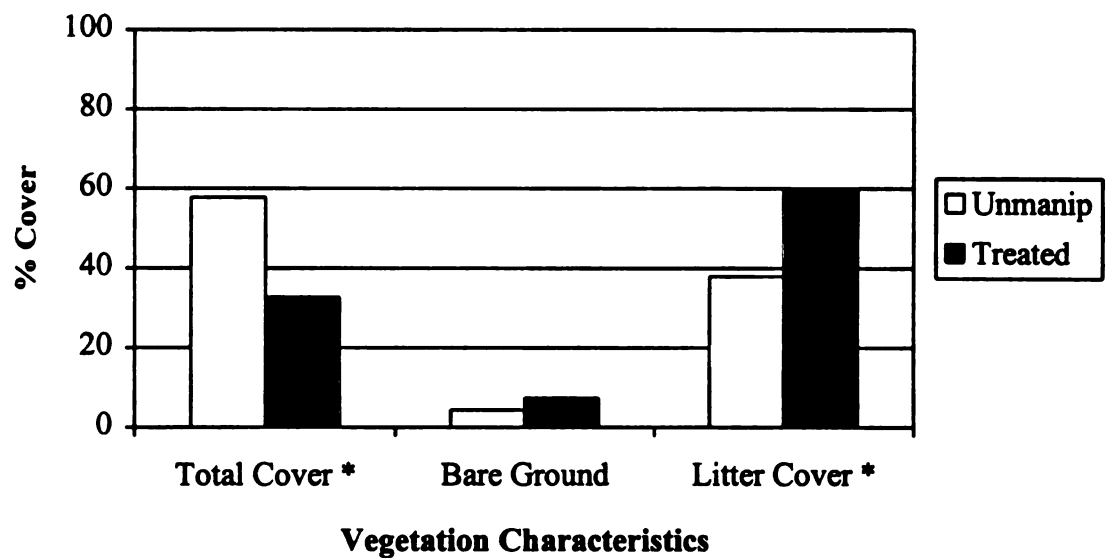
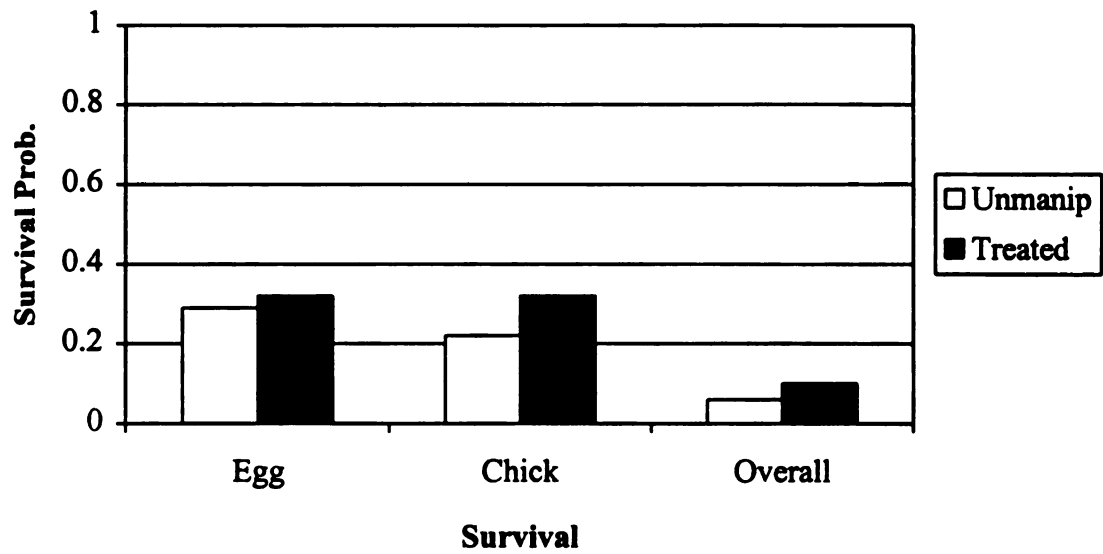


Figure 8. Common tern survival probabilities and vegetation cover percentages for unmanipulated and treatment areas on the coal dock on Lime Island, Michigan, in summer 1998. * = significantly different between areas (MWU, $P < 0.006$).

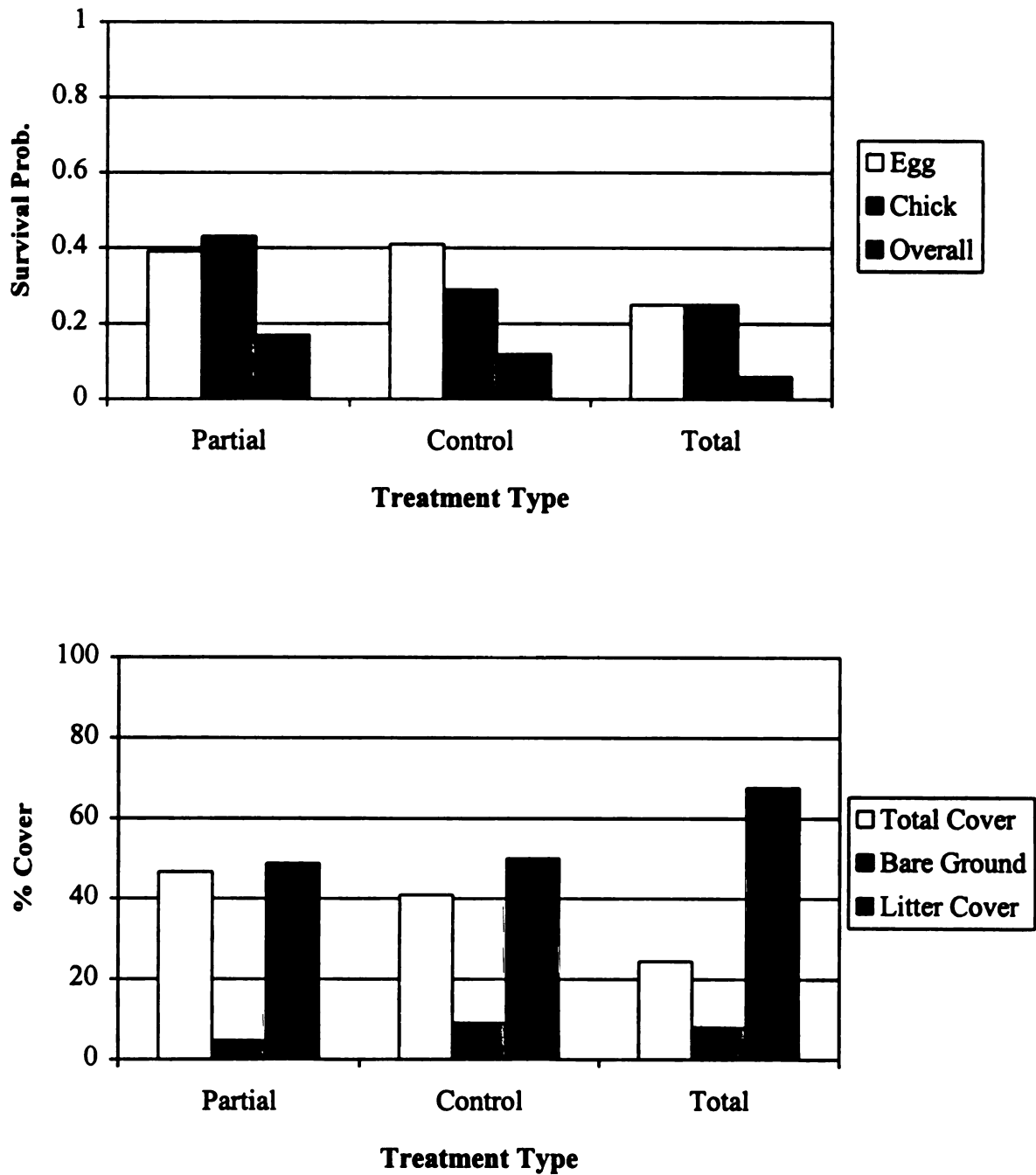


Figure 9. Common tern survival probabilities and vegetation cover percentages for each treatment type on the coal dock in summer 1998.

1997 – 1998 Vegetation and Survival

Unmanipulated areas

No comparisons between the pre-treated and treated area vegetation in relation to survival could be made due to the low number of vegetation samples taken in the pre-treated area in 1997 and because of the vegetation manipulations that were performed in 1998. Vegetation structure and survival were compared for the unmanipulated area in 1997 and 1998 to determine if changes in vegetation structure between years could be associated with changes in survival between years (Figure 10). In 1997, higher chick survival tended to be associated with areas that were dominated by total cover (80%), while greater egg survival in 1998 tended to be associated with areas that supported a mix of total cover (58%) and litter cover (38%; Figure 10).

Predator and Disturbance Assessment

Disturbance assessment

Number of disturbances and disturbance types within the common tern colony were graphed in relation to the reaction from common terns (Figure 11). Disturbance types that were documented were avian, boats (personal), human, ship/freighter, none (nothing was seen entering or leaving the colony nor did the birds flock to one area as if something was on the ground), and unknown (the birds flocked to one area hovering over something on the ground; Figure 11). Reactions were categorized as: 1) mass-fly ups (MFU) in which more than half of the common terns flew off their nests/out of the colony at one time; 2) partial fly-ups (PFU) in which less than half of the common terns flew off their nests/out of the colony at one time; and 3) none, in which the common terns had no

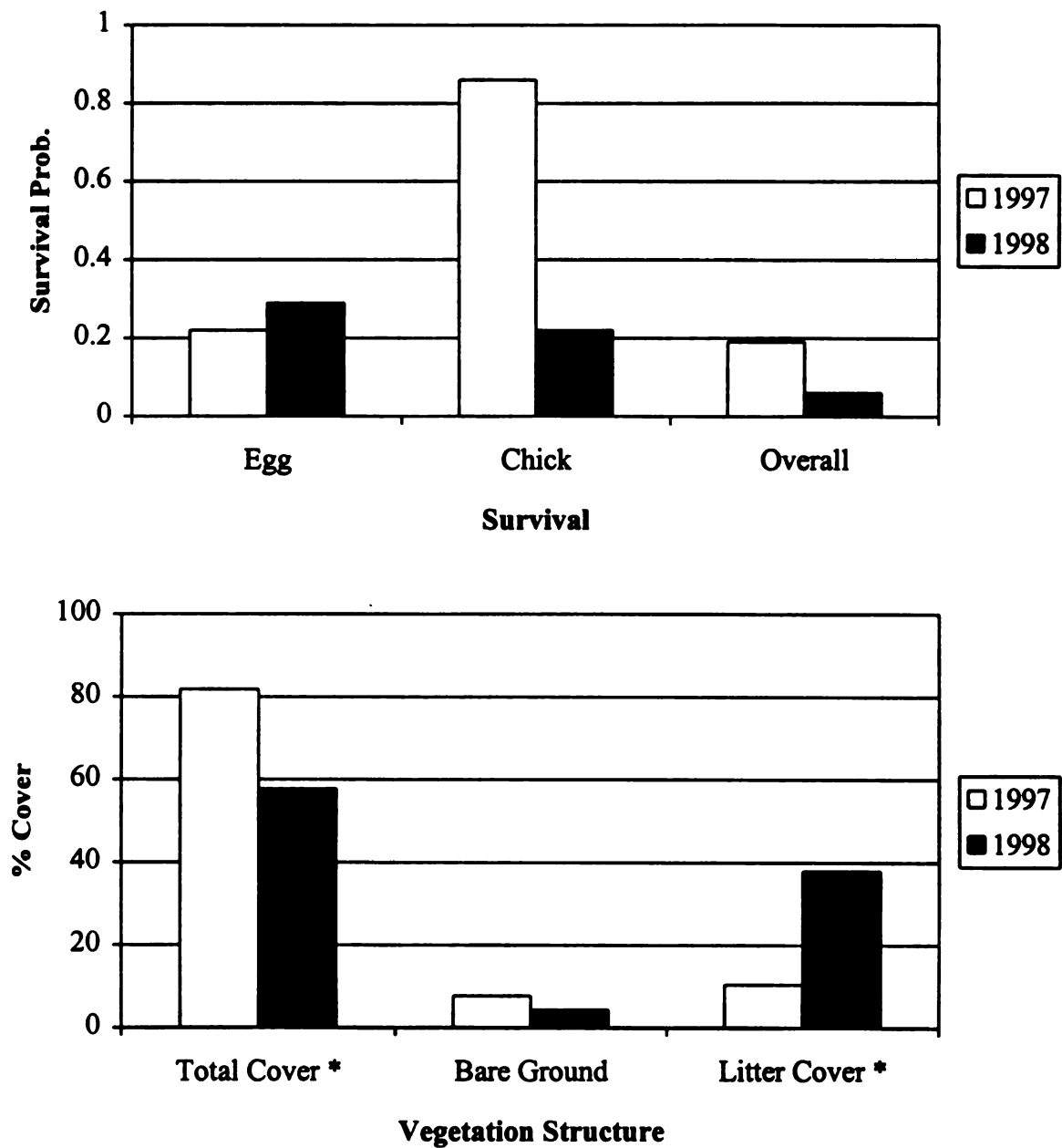


Figure 10. Common tern survival and vegetation cover percentages for the unmanipulated areas on the Lime Island coal dock, in summers 1997 and 1998.
 * = significantly different between years (MWU, $P < 0.006$).

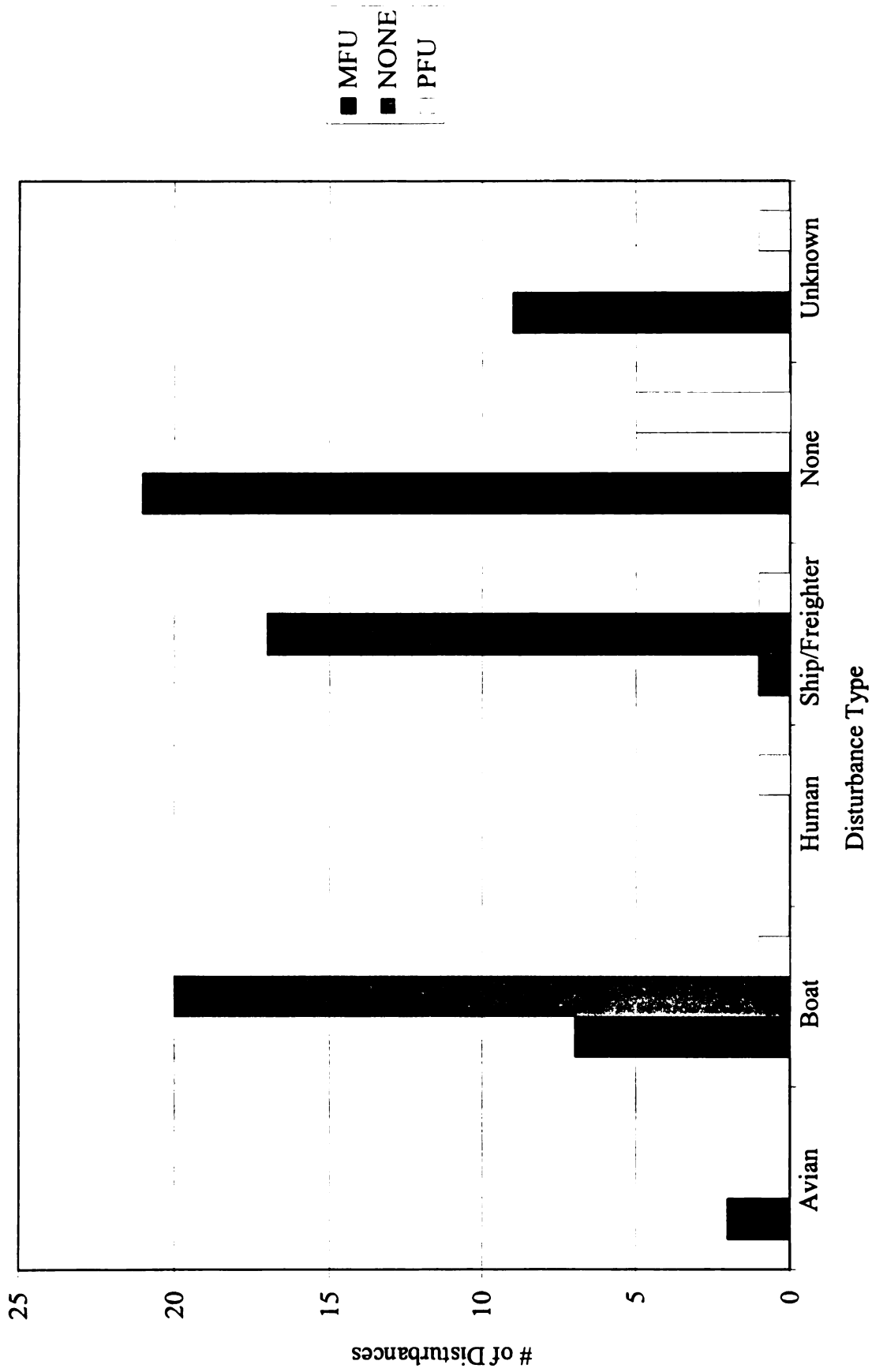


Figure 11. Graph showing type and number of disturbances and reaction (mass-fly ups [MFU], partial fly-ups [PFU], and no reaction [NONE]) from common terns in summers 1997 and 1998 on Lime Island.

reaction to an obvious disturbance. Two avian disturbances caused mass fly-ups (MFU; Figure 11) and were caused by ring-billed gulls flying through the colony. More than half (52.5%) of the MFUs were caused by undetected disturbances (or none; Appendix Table 2). The next highest percentage of MFUs was caused by unknown sources (22.5%; Appendix Table 2). Partial fly-ups (PFUs) were caused mostly by undetected disturbances (62.5%; Appendix Table 2). Boats and ships/freighters caused no disturbances within the colony 52.6% and 44.7% of the time, respectively (Appendix Table 2).

Specific examples of disturbances included instances where boats were docked next to the colony and the owners were asked to move. A U.S. Coast Guard ship docked next to the colony in 1997, and lines were tossed into the colony; however, no nest damage was observed. Another human disturbance was noted in 1998 when a sailboat docked next to the colony; approximately 5 nests were stepped on in the process of moving the boat to the north of the colony. While walking along the shore to start nest checks on the rock pile, it was noted that the common terns would fly off the rock pile. Other humans were noted to have the same effect on the common terns when they walked along the same path.

Due to the fact that I could not always determine the type of predator nor could I always see every disturbance, predation attempts could not be correlated with disturbance. Most predation impacts (i.e., dead chicks/adults, cracked/broken eggs) were noticed after periods of time when I could not be or was not in the field (i.e., after a storm, after a weekend off the island).

Predator assessment

All five (or six) trail monitors continued to function until the end of the field season. Because cameras were placed by the bridge and at the north end of the colony on the coal dock, the information collected on film only indicates potential predators to the colony. No predation attempts were recorded on film. The most common species recorded on film include ring-billed gulls, common terns, killdeer, Canada geese (*Branta canadensis*), and humans. The complete list of species captured on film can be found in Appendix Table 3.

Species not recorded on film, yet seen within the colony in 1997 and 1998, included garter snakes (*Thamnophis sirtalis*) and ants (*Tetramorium caespitum* and *Lasius neoniger*). In 1997, a garter snake was seen chasing a chick across the coal dock. In 1997 and 1998, garter snakes were seen within the colony with bulges in their bodies suggesting they had just recently fed on either an egg or a chick. Ants were seen in both years climbing in and out of newly pipped eggs. Ants were also found climbing all over new chicks (up to 5 days old), holding the beak closed and biting the chicks in their eyes.

While no mammalian predation was observed in 1997 or 1998, scat was found within the colony in both years. In 1997, scat was found from a feral dog or coyote. The scat did not contain avian bone fragments or anything that would suggest predation within the colony. In 1998, scat was found from a muskrat (*Ondatra zibethicus*) and a weasel. Additionally, five holes, with diameters ranging from 10 cm to 15 cm, were found along the fence line. Near three of the holes a pile of scat was found, 5 whole, empty eggshells, and 2 dead chicks. The scat was identified as weasel, indicating that the holes belonged to weasels. Twelve adult common terns were found dead in one day on

the coal dock from a bite to the head and/or neck potentially as a result of the weasel. A trail monitor was subsequently placed near the holes to try to capture the weasel on film, however, the weasel was not captured on film. Most eggs that were lost were lost as whole eggs with no fragments left in the nest in 1997 and 1998 (Appendix Table 4). A complete list of egg losses for 1997 and 1998 can be found in Appendix Table 4. Most chicks were last observed ≤ 9 days old in 1997 and 1998 (Appendix Table 5). A complete list of last observed ages of chicks can be found in Appendix Table 5.

Ring-billed gulls were observed picking up common tern chicks, flying approximately 2 m above the ground, and then dropping the chicks in 1997. Chicks were found dismembered suggesting predation by great horned owls (*Bubo virginianus*; Morris and Wiggins 1986). Spotted sandpipers and ruddy turnstones (*Arenaria interpres*) were observed entering the colony. Upon later nest checks, eggs were found with holes pecked in them, suggesting predation by an avian species, such as sandpipers or ruddy turnstones (Alberico et al. 1991, Faraway et al. 1986, Morris and Wiggins 1986).

DISCUSSION

Nest Checks and Banding

Common tern nests were likely established before the first observed dates in 1997 and 1998, but due to weather, I could not arrive on Lime Island before 5 June 1997 and 18 May 1998. Common tern chicks hatched first on the rock pile in 1997 (Table 1). This may have been because the rock pile had more preferred vegetation structure (20.5% total cover, 71.3% bare ground, and 8.1% litter cover; Table 3; Burger and Gochfeld 1991) than the coal dock (81.5% total cover, 7.8% bare ground, and 10.7% litter cover; Table 2) and was subsequently selected first for nesting. Additionally, since the rock pile is an isolated island in the harbor, the site is less susceptible to mammalian predation, providing an ideal nesting site for common terns (Austin, Jr. 1929). In 1998, chicks were observed on both the coal dock and rock pile on the same day (Table 1), which may be due to synchronous nesting (Burger and Gochfeld 1991, Burger and Shisler 1978), however, this cannot be confirmed because I was not on Lime Island when nesting began.

DiCostanzo (1980) found that common tern colonies require 1.1 fledged young/pair to maintain a stable population. In 1997, 0.65 young/pair were fledged from the colony (Table 1). In 1998, only 0.21 young/pair were fledged from the colony (Table 1). The colony did not support the required young/pair in either 1997 or 1998, therefore indicating that the colony may be declining. More research is needed to confirm or refute this statement.

More chicks were banded in 1997 than in 1998 (Table 1). Fewer chicks were banded in 1998 because of deaths due to predation soon after hatching. Eggs were also

taken from the nests, causing lower hatching rates (1.51 young hatched/pair; Table 1).

This decrease caused the number of chicks hatched/pair to be lower in 1998 than in 1997 (Table 1). Deaths due to predation also caused the number of chicks fledged/pair in 1998 to be lower than that in 1997 (Table 1).

Common terns left Lime Island in mid-September of 1997 (Table 1). More nests could be established during this longer summer, coinciding with increased number of chicks hatched. Common terns typically vacate colony sites by August, but remain in that area for up to two months (Austin 1953, Haymes and Blokpoel 1978, Blokpoel et al. 1987). Common terns left on 1 August 1998 which may be attributed to constant predation. Common terns have been noted to abandon an area when disturbed by predators (Burger and Gochfeld 1991; Cuthbert and Timmerman 1997).

The distribution of common tern nests on the coal dock shifted from the unmanipulated area in 1997 to the treatment area in 1998 (Table 22). This shift could have been caused by the manipulations that were performed in 1998. Another possible reason for this shift could be the spray from waves during storms or periods of high winds, that could cause damage to eggs. Spray from waves can disturb common terns and possibly damage eggs (i.e., cracking, lowering temperature), if left unprotected (Burger and Gochfeld 1991).

1997 Vegetation Measurements

Common terns nested in areas with significantly lower percent litter cover (10.7%) than in areas where they did not nest (random points; 21.1%) in 1997 (Table 6). Avoidance of litter cover may be due to an increased likelihood of common terns getting

tangled, leading to death by predation or starvation (Burger and Shisler 1978). Common terns also tended to nest in locations with slightly more live cover than in areas where no nests were located (65.9% and 55.1%, respectively; Table 6). It may be possible that common terns can tolerate greater amounts of cover than predicted by the literature (10 – 30%; Burger and Gochfeld 1991, Soots and Parnell 1975).

Burger and Gochfeld (1991) studied common terns on the east coast and found 10 – 30% total cover provided the best cover for highest survival. Soots and Parnell (1975) reported common terns had a preference for 10 – 30% total cover around nests on dredge islands in North Carolina. Since these studies were performed on the east coast, the results may not apply to Lime Island because it is in the Great Lakes and not susceptible to the same weather conditions (i.e., hurricanes) and may have different substrates than the east coast.

Three other habitat studies on common terns (Blokpoel et al 1978, Morris et al. 1992, Richards and Morris 1984) were located within the Great Lakes. Blokpoel et al. (1978) measured a range of 30 – 50% vegetation cover around common tern nests ($n = 49$, $\bar{x} = 44\%$) on a human-made peninsula in the Eastern Headland of Lake Ontario. The vegetation on this site was not manipulated, and survival was not calculated or related to the vegetation cover around the nests (Blokpoel et al. 1978). Richards and Morris (1984) and Morris et al. (1992) studied a common tern colony on a breakwall in Lake Erie. Both studies determined that when common terns nested close to vegetation or objects the survival was higher than for those nests that were not established near any vegetation or objects (Morris et al. 1992, Richards and Morris 1984). No measurements of total cover

were performed in either study (Morris et al. 1992, Richards and Morris 1984). Since these studies were performed on human-made sites in the Great Lakes, the results may be better associated with common terns nesting on other human-made sites within the Great Lakes, such as the Lime Island coal dock. Therefore, common terns may utilize greater vegetation cover (30 – 50%; Blokpoel et al. 1978) when establishing a colony on human-made sites within the Great Lakes.

Another explanation for high percent total cover around common tern nests on the Lime Island coal dock could be from nest site competition with ring-billed gulls. Approximately 33 ring-billed gulls nested on the coal dock in 1997. Ring-billed gulls tend to nest earlier than common terns (Burger and Gochfeld 1991, Courtney and Blokpoel 1983, Morris and Hunter 1976), and may have usurped those area (10 – 30% cover) that are more preferred by common terns. However, since no vegetation variables were collected in the ring-billed gull nesting area, this conclusion is speculative and probably unlikely since other vegetation measurements suggest that the coal dock vegetation is highly uniform.

In 1997, there were no significant differences in vegetation variables between successful and unsuccessful nests on the coal dock (Table 4), thus suggesting that vegetation variables measured did not positively or negatively affect the nesting success of common terns. However, the appropriate vegetation variables may not have been measured for depicting minute differences between successful and unsuccessful nests.

1998 Vegetation Manipulations and Measurements

Coal dock

No significant differences were found between nests and random points in 1998 (Table 15). This suggests that common terns were not focusing on any specific vegetation structure for nesting locations and/or that the coal dock supported uniform vegetation composition.

Comparisons of successful and unsuccessful nests on Lime Island's coal dock in 1998 suggest that a greater percentage of total cover (44.4%) was associated with successful nests (Table 8). Percent total cover around successful nests in 1998 was expected to be greater than the 10 – 30% total cover found in literature (Burger and Gochfeld 1991, Soots and Parnell 1975) because the total cover exceeded this value in 1997 (81.5%; Table 2). The total cover around successful nests in 1998 falls within the 30 – 50% total cover measured by Blokpoel et al. (1978) at a human-made site and adds further support to the theory that common terns may prefer greater than 10 – 30% total cover when nesting on human-made sites within the Great Lakes.

Percent bare ground was slightly lower around successful nests than around unsuccessful nests (5.6% and 8.0%, respectively; Table 8), which was not expected. Greater percent bare ground was expected around nests for use in courtship displays and easier detection of predators (Burger and Gochfeld 1991, Burger and Shisler 1978, Palmer 1941). More bare ground and less total cover would enable common terns to walk without the risk of entanglement (Burger and Shisler 1978) and would provide a landing area close to the nest (Palmer 1941). However, the values of percent bare ground and litter cover were extremely close between successful and unsuccessful nests,

suggesting that the vegetation was the same between nest types (successful and unsuccessful).

Treatment and unmanipulated area

Manipulations were performed to determine how changes to vegetation structure would impact survival of the common terns on the coal dock. The treatment area had significantly lower total cover (32.7%), and greater litter cover (60.0%) than the unmanipulated area (57.8% and 37.9%, respectively; Table 9). This result was expected because many areas ($n = 34$) were partially or totally herbicided within the treatment area, which killed vegetation and added to litter cover. Litter cover was not physically removed (i.e., raked) from the herbicided areas. Additionally, the unmanipulated area may have supported greater total cover because this area was more susceptible to wave spray (i.e., more water promotes growth of vegetation). Because the treatment area is a combination of all the treatments (total herbicided, partial herbicided, and control), to truly understand how the unmanipulated area differed from the treatment area, each treatment must be examined separately.

Individual treatments

Percent total cover was significantly lower in the total herbicided areas (24.4%) than in the other areas (Table 12), which was expected since the total herbicided areas were completely sprayed with herbicide. The percent total cover in the other treatment areas was greater than the preferred 10 – 30% vegetation cover (Burger and Gochfeld 1991, Soots and Parnell 1975), and was expected given the 1997 vegetation cover was tall

and dense (2 m and 60%, respectively; pers. observ.)

Trends between unsuccessful and successful nests can be seen in the percent total cover for all treatment areas (Tables 13 and 14). For example, successful nests in the total herbicided areas had greater total cover (28.3%; Table 13) than the unsuccessful nests in those areas (19.9%; Table 14). However, successful nests in the partial and unmanipulated areas had less total cover (46.4% and 56.8%, respectively; Table 13) than unsuccessful nests in these areas (48.0% and 61.6%, respectively; Table 14). Therefore, percent total cover tended to be greater around successful nests when the total cover around unsuccessful nests in the same treatment area was $\leq 20\%$. Percent total cover tended to be lower around successful nests when total cover around unsuccessful nests in the same treatment area was $\geq 50\%$. Therefore, the preferred range of percent total cover for common terns nesting on Lime Island may be 20 – 50%.

Percent litter cover was greater in the total herbicided areas than in the other nesting areas (Table 12). Litter cover was expected to be greater in the total herbicided areas since the vegetation was sprayed with herbicide and killed. The dead vegetation remained in the area as litter cover since it was not physically (i.e., raked) removed from the site. However, litter cover was not significantly different between the partial herbicided and control areas (Table 12). The partial herbicided areas were expected to support significantly greater percent litter cover than the control areas since the partial herbicided areas were sprayed with herbicide. The herbiciding should have resulted in more dead vegetation within the partial herbicided areas, therefore, resulting in more litter cover on the ground within these areas.

Trends between unsuccessful and successful nests can also be seen in the percent litter cover for all treatment areas (Tables 13 and 14). For example, successful nests in the total herbicided area had less litter cover (65.7%; Table 13) than the unsuccessful nests in those areas (69.9%; Table 14). However, successful nests in the partial, control and unmanipulated areas had greater percent litter cover (48.8%, 50.2%, and 38.5%, respectively; Table 13) than unsuccessful nests in these areas (48.0%, 47.5%, and 35.3%, respectively; Table 14). Therefore, percent litter cover tended to be greater around successful nests when the litter cover around unsuccessful nests in the same area was $\leq 50\%$ (Tables 13 and 14). Percent litter cover also tended to be lower around successful nests when the litter cover around unsuccessful nests in that area was $\geq 70\%$ (Tables 12 and 13). This presents a 20% range for litter cover around nests (50 – 70%). Using the range for percent total cover established earlier (20 – 50%) and the litter cover range (50 – 70%), the preferred vegetation structure around nests may be tending toward a 40% total cover : 60% litter cover ratio.

1997 – 1998 Vegetation Comparisons

The 1998 treated area was expected to have significantly less percent total cover than the 1997 pre-treated area due to manipulations in this area in 1998. Because very few nests were established in the pre-treated area in 1997 by the time vegetation measurements were made, statistical comparisons between 1997 pre-treated and 1998 treated areas could not be performed. However, the 1998 treated area did have less vegetation (pers. observ.) than the 1997 pre-treated area. The unmanipulated areas for

1997 and 1998 were not expected to be significantly different since no vegetation manipulations were performed in this area (Table 21). Since the unmanipulated area in 1997 supported significantly greater percent total cover than in 1998 (Table 21), these differences may have been caused by weather-related impacts (i.e., more rain) and/or by annual succession of vegetation in the unmanipulated area.

Reproductive Survival

Nest numbers

In 1998, more of the coal dock was utilized for nesting than in 1997 (Table 22). This may have been a result of the manipulations performed in 1998 that altered the vegetation in the treatment area of the colony area on the coal dock. In 1997, only 56 nests were observed within the pre-treated area of the colony, while 219 nests were established in this area in 1998. Some of the vegetation within the pre-treated area was approximately 1 m tall in 1997 (pers. observ.). In 1998, none of the vegetation within the treatment area reached this height (pers. observ.). The tall vegetation in 1997 may have prohibited common terns from nesting within the pre-treated area and reduced visibility of colony members, resulting in a reduction of social stimulation (Palmer 1941), increasing risk of entanglement (Burger and Shisler 1978), and decreasing the chance of detecting predators (Burger and Shisler 1978). Common terns have been found to abandon nest sites when vegetation becomes too tall (≥ 0.61 m; Burger and Gochfeld 1991, Courtney and Blokpoel 1983, Harris and Matteson 1975, Matteson 1988, Morris et al. 1992, Shields and Townsend 1985). The manipulations may have promoted shorter

vegetation (although this was not quantified) that was more preferred for nesting by common terns.

Egg survival

Comparisons of the coal dock egg survival suggest that the unmanipulated area had the greatest survival in 1997 (0.22; Table 22). The unmanipulated area was the first area of the coal dock the common terns nested on in 1997 (pers. observ.), and supported more nests than the pre-treated area (Table 22). One reason to explain this trend is that common terns begin nesting closer to the water when nesting on a peninsula to remain as far from potential land predators as possible (Austin 1948). In 1998, after the manipulations were performed, the treated area had the greatest survival (0.32), when compared to the unmanipulated area (Table 22). The unmanipulated area again was the first area of the coal dock nested on in 1998 (pers. observ.). However, more nests were abandoned within the unmanipulated area after storms or heavy predation attempts (pers. observ.), resulting in lower egg survival for the unmanipulated area.

The unmanipulated area supported approximately the same survival from 1997 to 1998 (approximately 0.25; Table 22). However, when comparing the pre-treated area (1997) to the treated area (1998), egg survival increased from 0.18 to 0.32, respectively (Table 22). This suggests that the manipulations may have had a positive impact on egg survival.

None of the differences in egg survival were related to high censoring of nests, i.e., high censoring did not result in over estimation of egg survival. The Mayfield method is an accurate estimate of survival if the amount of censored individuals is less

than 10% (Mayfield 1961). The nest censorship in 1998 was under 10%, while the censorship in 1997 was slightly higher than the 10% required by Mayfield (Table 23).

Chick survival

The lower chick survival in 1998 was the result of high predation. Chick censorship was high for the coal dock in 1998 (71.5%; Table 23). This high censorship resulted from predation within the colony since chicks may have been eaten whole or stockpiled in a hole for later eating (Whitaker 1996). The high chick censorship resulted in an overestimation of survival. Based on chick survival estimates from the rock pile (Table 22), a similar pattern of an increase for chick survival from 1997 to 1998 was anticipated on the coal dock. Therefore, the coal dock may have supported a greater number of chicks in 1998 than in 1997 since the 1998 rock pile supported higher chick survival. However, the weasel predation resulted in lower chick numbers and survival on the coal dock in 1998.

Even though chick survival decreased within the first 50 m (treatment area) from 1997 to 1998, the treatments appeared to have a positive impact on survival because the treatment area chick survival (0.32) was higher than the chick survival in the unmanipulated area in 1998 (0.22; Table 22). The partial herbicided areas had the greatest chick survival (0.43) within the treatment area, with the control and total herbicided areas supporting lower chick survival (0.29 and 0.25, respectively; Table 22). This suggests that the partial herbicided areas had the most positive impact on chick survival within the treatment area. The control areas were expected to have the same chick survival as the unmanipulated area; however, the control areas had greater chick

survival (0.29) than the unmanipulated area (0.22; Table 22). The control areas may have provided more open spaces for unrestricted movement and easy detection of predators (Burger and Shisler 1978, Palmer 1941) than the unmanipulated area due to uneven distribution of vegetation across the coal dock.

Overall survival

The rock pile survival was higher than the coal dock survival because of the low egg survival on the coal dock in 1997 (Table 22). The pre-treated area on the coal dock had lower overall survival than the unmanipulated area because of the low egg survival within the pre-treated area in 1997 (Table 22). Therefore, the overall survival in 1997 was dependent on the egg survival since chick survival was high (0.88) and the egg survival was low (0.22; Table 22).

In 1998, the rock pile overall survival was much greater than the coal dock overall survival (Table 22) due to lower predation rates on the rock pile. Unlike 1997, the treated area had greater overall survival than the unmanipulated area in 1998 (Table 22). The unmanipulated area may have supported too much vegetation cover (> 50%), resulting in increased mortality from entanglement and lower visibility of predators leading to increased predation (Burger and Shisler 1978).

The overall survival of common terns was greater in 1997 than in 1998 due to the low chick survival in 1998 (Table 22). All areas had much lower survivals in 1998 than in 1997 except the rock pile (Table 22) due to the predation by the weasel in 1998. The high chick censorship in both 1997 and 1998 increased chick survival, making overall survival higher than what it may actually have been.

1997 Vegetation and Survival

While the high percent total cover ($> 80\%$) supported high chick survival (> 0.80) in 1997, egg and overall survival were low in 1997 (< 0.25 ; Figure 7). The high percent total cover may have provided the needed hiding cover for chicks, but may also have provided cover for predators, such as garter snakes, thus, making the predators undetectable by adult common terns (Burger and Shisler 1978, Palmer 1941). The lower egg survival in the pre-treated area may have been the result of abandonment due to increased vegetation cover (Morris et al. 1992). Therefore, egg and overall survival would be expected to decrease as vegetation cover increases.

1998 Vegetation and Survival

The unmanipulated area in 1998 had lower survival for egg, chick, and overall periods than the treatment area, and higher percent total cover and lower percent bare ground and litter cover (Figure 8). Since the treatment area had greater survival and less total cover than the unmanipulated area, lower percent total cover may promote higher survival. On average (all treatments combined), 33% total cover was found in the treatment area (Figure 8). This falls within the range determined to be important for nesting common terns (Blokpoel et al. 1978). Therefore, the preferred total cover around common tern nests on Lime Island likely falls within 30 – 50%.

The individual treatment vegetation structures and survival were compared to determine whether or not the vegetation manipulations had any impact on survival on the coal dock (Figure 9). The total herbicided area had the lowest survival for all 3 survival periods, while the partial herbicided areas had the highest survival for the survival periods

except in egg survival (Figure 9). The partial herbicided areas had less litter cover and more total cover than the other treatments, and promoted lower egg survival and higher chick and overall survival than the control areas (Figure 9). Both the partial and control areas had similar percentages of total cover and litter cover (Figure 9). The partial and control areas may have had similar vegetation covers due to the way in which manipulations were performed in the partial herbicided areas. The control areas may have had less vegetation than the partial herbicided areas before the herbicide was applied. When the vegetation that was in clumps and/or random spots were sprayed with herbicide in the partial herbicided areas, the vegetation would become similar in the partial herbicided and control areas. The total cover in the control and partial herbicided areas was 40.9% and 46.6%, respectively (Table 12). The average vegetation cover measured around nests on a peninsula in Lake Erie by Blokpoel et al. (1978) was found to be 44%. Therefore, the partial herbicided and control areas may have supported the preferred total cover for common terns, which may have resulted in the higher survival in these two areas.

Predation and Disturbance Assessment

Disturbance assessment

Since the majority of disturbances were unknown or none, it was virtually impossible to correlate a disturbance with the reaction (Figure 11). Therefore, no correlation could be made between reaction of common terns and type of disturbance.

Predator assessment

Literature indicates that chicks are most susceptible to death within 5 days of hatching (Langham 1972, LeCroy and Collins 1972, Matteson 1988). Data collected in this study supports this finding with > 50% of chick deaths or last age observations occurring at ≤ 5 days old (Appendix Table 5) in 1998. Although the chicks are semi-precocial, most stay in or close to the nest for 1 – 3 days after hatching. Therefore, the loss of these chicks is likely due to predation rather than an inability of the researcher to relocate the chicks.

Although no predation attempts were captured on film, scat from a feral dog or coyote, weasel and a muskrat were found within the colony on the coal dock. The muskrat is a herbivore and is therefore not a threat to the colony, except for the possibility of crushing eggs. The feral dog or coyote scat did not suggest predation within the colony because no avian bones were found in the scat. However, weasels have been documented as predators of common terns (Chestney 1970; Lemmetyinen 1973, Nisbet 1975, Palmer 1941), and 12 adult common terns were found dead in one day on the coal dock from a bite to the head and/or throat. This bite is typical of weasels as they wrap their bodies around the large prey to hold them, resulting in the weasel's head being next to the prey's neck (Whitaker 1996). The weasel scat did contain avian bone and egg fragments, suggesting predation on common tern eggs and chicks.

Many garter snakes were seen within the colony in both years. No snakes were documented taking a chick or an egg, but they were seen with big bulges in their bodies,

suggesting they had just fed. One incident was recorded of a garter snake chasing a chick across the coal dock. Garter snakes have been documented taking chicks on the CDF in the Saginaw Bay, MI (Millenbah 1997). Additionally, many eggs disappeared from nests with no fragments left behind. The removal of whole eggs by garter snakes has been documented in other common tern colonies in northern Michigan (Cuthbert 1980).

Ring-billed gulls are suspected predators of common terns (Burness and Morris 1992, Hatch 1970). A few incidences on Lime Island were observed where gulls were seen picking up common tern chicks, flying approximately 2 m above the ground, and dropping the chicks. Other avian predators suspected of entering the colony were great horned owls (Morris and Wiggins 1986), spotted sandpipers (Alberico et al. 1991), and ruddy turnstones (Faraway et al. 1986, Morris and Wiggins 1986). Body parts of chicks were found in the colony both years. These parts had been snipped clean from the body suggesting predation by great horned owls (Morris and Wiggins 1986). Eggs with single holes were found suggesting predation by spotted sandpipers (Alberico et al. 1991) and ruddy turnstones (Faraway et al. 1986, Morris and Wiggins 1986); both species were seen entering the colony.

Ants are another predator on common terns (Burger and Gochfeld 1991), especially on young chicks and pipping eggs, and were seen climbing on and smothering young chicks (≤ 5 days old). Ants can smother chicks by blocking mouth and nasal passages and blind chicks by getting in their eyes (Burger and Gochfeld 1991). Ants have also been documented killing chicks before they completely hatch from the egg (Burger and Gochfeld 1991), thereby decreasing egg and chick survival. Ants were

observed climbing in and out of freshly pipped eggs in the Lime Island common tern colony.

Trail monitors were only useful in identifying potential predators since they were placed at the north end of the colony and at the bridge onto the coal dock from Lime Island. While no predation attempts were captured on film, signs of predation (i.e., dead chicks and adults, broken and missing eggs) and scat found within the colony were observed. Of those captured on film, only ring-billed gulls and spotted sandpipers can be linked to broken eggs and dead chicks. Of the potential predators captured on film, none are a likely threat to common terns.

CONCLUSIONS

Vegetation may be a limiting factor in common tern survival on Lime Island.

Vegetation manipulations appeared to increase egg survival on the coal dock, but further research needs to be performed to support or refute the data collected in 1997 and 1998.

Vegetation differed between years with percent total cover being higher in 1997 and percent litter cover being greater in 1998. Egg survival increased from 1997 to 1998, while chick survival severely decreased from 1997 to 1998. The treatment area (or first 50 m of the coal dock) resulted in higher survival than the unmanipulated area in 1998 on the coal dock. Thus, the treatment areas possibly provided a mixture of vegetation structure that common terns preferred. The partial herbicided plots resulted in the highest chick and overall survival of any area on the coal dock, and may have provided the best mixture of vegetation structure for promoting high common tern survival (30 - 50% total cover : 50 - 70% litter cover). The treatment area (as a whole) and the partial herbicided areas had positive impacts on common tern survival.

Heavy predation on the coal dock in 1998 altered conclusions about the impacts of the vegetation manipulations on common tern survival. The decrease in chick survival from 1997 to 1998 may have been a result of the predation, or the lower chick survival may have been exacerbated by the removal of hiding cover due to herbiciding. Although no predation was captured on film, evidence of weasel predation (i.e., scat, bite marks on chicks and adults, holes in the ground, and stockpiles of eggs and chicks) was found within the colony. This predation could have altered the survival of the common terns.

No correlation between type of disturbance and reaction of common terns could

be determined. Therefore, no actions can be taken to protect the common terns from a specific type of disturbance.

RECOMMENDATIONS

Due to the increase in survival in the manipulated areas, continuation of the 1998 vegetation manipulations may ultimately be the best procedure for increasing common tern survival in the Lime Island colony. Research needs to be continued in the area of vegetation manipulations on Lime Island's coal dock to determine which treatment provides the best survival for common terns. The preferred vegetation structure determined from further research could potentially be used at other common tern nesting sites across the Great Lakes region.

The nesting area should be sprayed with herbicide before the common terns arrive on Lime Island to provide a variety of vegetation structures at first nesting. If the common terns nest in the treated area before the unmanipulated area, then the treatment area may support the preferred vegetation for nesting for common terns. If the common terns nest in the unmanipulated area first, it may just be instinct to nest in the area furthest from possible mammalian predation or it may be related to the vegetation structure early in the spring as compared to later in the summer. Therefore, future researchers may want to manipulate the south end of the coal dock to determine how the treatments impact survival in that area.

Since this was a short term study, more research needs to be completed to support my findings. The coal dock supports different vegetation covers from south to north (densest at the south end, thinnest at the north end of the colony). Due to this variation in vegetation, instead of manipulating just a single section at the north end of the colony, 3 sections of treatments should be used, possibly applying herbicide in the north, middle

and south ends of the colony. I would still recommend using 5 x 5 m squares for each treatment area, but the treatments should be more scattered and no more than 2 squares of the same treatment adjacent to each other. This scattering will allow for determining the effect of one square at once and not multiple squares. Buffers should also be placed between each square to reduce the effect of more than one type of treatment on a nest. Caution should be taken before manipulating the entire coal dock. Since this was a short term study, more data needs to be collected before the preferred vegetation cover for common terns on Lime Island can be determined. Approximately 10 more years of study are needed. This would allow the return of banded chicks to the colony as adults and to determine if there is a cycle in the predator effects on common tern survival. Weather impacts would also be determined in this amount of time.

How frequently herbiciding should be performed depends on how rapidly the vegetation grows back. If any vegetation grows back by the next year, then herbiciding should be performed every year. If vegetation takes two or more years to grow back (≥ 5 cm), then herbiciding should be performed when the vegetation grows back. The frequency of herbiciding needs to be determined by the researcher(s) working on Lime Island. The litter should be raked out of approximately half of the herbicided areas to determine the impact of the increased litter on common tern survival. The raking would assist in the effect of litter cover on entanglement of chicks, and subsequently death.

Predation needs to be decreased within the colony to ensure increased survival of the common terns. Actions need to be taken to remove the weasels and garter snakes from within the colony before the entire common tern colony is exterminated. If traps are

used, live traps would be best to prevent common tern chicks from dying when seeking protection from predators and researchers. To rid the coal dock of weasels, replacing the current topsoil with loose sand and washed gravel may work (J. Warner, per. commun.). When the weasels try to dig a hole, the gravel will collapse on them. This could result in lower death rates of common terns, but not rid the colony of all weasel predation. However, this “resurfacing” may not be economically or physically feasible, as the substrate would have to be transported from the mainland by boat, resulting in many trips back and forth across the St. Mary’s River. This would also destroy all the vegetation on the coal dock and may not be the best solution for increasing common tern survival. Intense predator removal efforts could be performed to remove all predators on the coal dock. This would entail extra researchers, many traps, and would be a great expense. To prevent garter snakes from entering the colony, rough (sharp, unwashed) gravel should be placed around the edges and at the bridge entrance to the coal dock (J. Warner, MDNR, pers. commun.). The garter snakes will not cross the sharp stones because the stones will cut their skin. A fence that restricts entrance into the colony by all land-moving creatures could be placed across the width of the coal dock at the north end of the colony to aid in prevention of predation.

Ring-billed gull nest numbers need to be reduced on the coal dock before they prevent the common terns from nesting on the coal dock. Ring-billed gull numbers doubled from 1997 to 1998 (pers. observ.). If this trend continues, they will be nesting on half of the colony area within the next two years, and utilizing the whole colony within 4 years. Ways to deter ring-billed gulls from nesting include owl decoys, wire grid over the whole area approximately 0.6 m above the ground, and ribbons which flap

in the wind. This removal system may also deter the common terns from nesting on the coal dock.

Another system for taking pictures or a different camera placement needs to be implemented to obtain pictures of potential predators, not of grass. A solution to this problem would be to raise the camera off the ground so the camera views the area between the monitors from either directly above or from a 2 m distance. The vegetation between the trail monitor and the camera should be cut on a regular basis, but this would result in another manipulation other than the herbiciding within the colony, altering vegetation cover which could potentially be used as hiding cover by common tern chicks. These cameras would be more effective and cost-efficient if they could be placed all the way across the coal dock. With cement walkways on either side of the vegetation, there is no place to anchor a camera, allowing mammalian predators to enter and leave the colony undetected. Therefore, another means of determining predators to the colony should be used.

Placing larger, easier to read signs along the fence can prevent possible disturbances caused by personal boats. If possible, a plastic, removable fence should be placed along the harbor side of the colony to prevent people from getting onto the coal dock, thereby deterring boaters from docking there. For humans who decide to approach the colony from the north, a warning sign about getting dived and pecked by the common terns as they approach the fence and an informational sign about the common terns need to be placed on the coal dock away from the colony. A sign should also be placed along the shore path, which runs below the observation deck. When people walk along this path, it disturbs the common terns on the rock pile. These signs are economically feasible

and would reduce human disturbance to the colony. Another aid in disturbance reduction would be continued distribution of the informational brochures on common terns. This material can be provided to the public so they can read and learn about common terns and the efforts by the MDNR to increase their survival.

With future research, carrying capacity of the coal dock needs to be determined for common terns. By determining carrying capacity, we can determine if Lime Island is currently supporting the most nests or if more nests can be supported. Once the best treatment for increasing survival has been determined, the research techniques should be applied to other common tern nesting sites throughout the Great Lakes to increase common tern survival on these sites.

APPENDIX

Appendix Table 1. Vegetation species found growing on the Lime Island coal dock in 1997 and 1998. All species were found on the Lime Island coal dock in both 1997 and 1998.

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

Appendix Table 2. Common tern reactions (partial fly-ups (PFU), mass fly-ups (MFU), and none), type of disturbance and length of disturbance within the Lime Island common tern colony in 1997 and 1998.

Reaction (PFU, MFU, None)	Type of Disturbance (Mammalian, Human, Reptilian, Personal Boat, Ship/Freighter, None Seen)	Length of disturbance (in sec.)
MFU*	Avian	30
MFU*	Avian	60
MFU**	Boat	60
MFU*	Boat	90
MFU*	Boat	90
MFU**	Boat	90
MFU*	Boat	130
MFU*	Boat	600
MFU*	Boat	780
MFU*	Ship/Freighter	300
MFU**	None	10
MFU**	None	13
MFU**	None	15
MFU**	None	15
MFU**	None	15
MFU**	None	16
MFU**	None	30
MFU**	None	3

Appendix Table 2 (cont'd).

Reaction (PFU, MFU, None)	Type of Disturbance (Mammalian, Human, Reptilian, Personal Boat, Ship/Freighter, None Seen)	Length of disturbance (in sec.)
MFU**	None	45
MFU**	None	60
MFU**	None	60
MFU**	None	60
MFU**	None	60
MFU**	None	60
MFU**	None	60
MFU**	None	60
MFU**	None	70
MFU**	None	120
MFU**	None	120
MFU**	None	120
MFU**	None	180
MFU*	Unknown	30
MFU*	Unknown	30
MFU*	Unknown	40
MFU*	Unknown	45
MFU*	Unknown	60
MFU*	Unknown	60

Appendix Table 2 (cont'd).

Reaction (PFU, MFU, None)	Type of Disturbance (Mammalian, Human, Reptilian, Personal Boat, Ship/Freighter, None Seen)	Length of disturbance (in sec.)
MFU*	Unknown	60
MFU*	Unknown	60
MFU*	Unknown	120
NONE**	Boat	20
NONE*	Boat	30
NONE*	Boat	30
NONE*	Boat	30
NONE*	Boat	30
NONE*	Boat	30
NONE*	Boat	30
NONE**	Boat	30
NONE**	Boat	30
NONE**	Boat	35
NONE*	Boat	90
NONE*	Boat	90
NONE*	Boat	90
NONE*	Boat	90
NONE*	Boat	90
NONE*	Boat	90

Appendix Table 2 (cont'd).

Reaction (PFU, MFU, None)	Type of Disturbance (Mammalian, Human, Reptilian, Personal Boat, Ship/Freighter, None Seen)	Length of disturbance (in sec.)
NONE**	Boat	90
NONE*	Boat	120
NONE*	Boat	120
NONE**	Boat	120
NONE**	Ship/Freighter	130
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE*	Ship/Freighter	180
NONE**	Ship/Freighter	180
NONE**	Ship/Freighter	180
NONE**	Ship/Freighter	180

Appendix Table 2 (cont'd).

Reaction (PFU, MFU, None)	Type of Disturbance (Mammalian, Human, Reptilian, Personal Boat, Ship/Freighter, None Seen)	Length of disturbance (in sec.)
NONE**	Ship/Freighter	180
NONE**	Ship/Freighter	180
PFU*	Boat	180
PFU*	Human	180
PFU*	Ship/Freighter	180
PFU**	None	15
PFU**	None	30
PFU**	None	180
PFU**	None	240
PFU**	None	300
PFU*	Unknown	30

* 1997 observation

** 1998 observation

Appendix Table 3. Species photographed with the Trail Master trail monitors on Lime Island in 1997 and 1998.

Common Name	Scientific Name
Common tern***	<i>Sterna hirundo</i>
Ring-billed gull***	<i>Larus delawarensis</i>
Canada goose**	<i>Branta canadensis</i>
Eastern starling*	<i>Sturnus vulgaris</i>
Killdeer*	<i>Charadrius vociferous</i>
Spotted sandpiper**	<i>Actitis macularia</i>
White-footed mouse**	<i>Peromyscus maniculatus</i>
Toad**	<i>Rana spp.</i>
Dog***	<i>Canis domesticus</i>
Human***	<i>Homo sapien</i>

* 1997 only

** 1998 only

*** 1997 and 1998

Appendix Table 4. Description of egg losses and number lost in each category of the coal dock on Lime Island, Michigan.

Year	Whole Egg Lost	Shell Fragments	Egg Shell Empty	Egg Shell With Yolk	Abandoned
1997	1643	1	1	12	169
1998	423	30	7	166	459

Appendix Table 5. Number of chicks last observed in each age class (aged according to criteria presented by Nisbet and Drury (1972)) on the coal dock on Lime Island, Michigan.

Year	Age (days)								
	0 – 1	2 – 5	6 – 9	8 – 12	12 – 15	15 – 18	17 – 23	21 – 24	24 +
1997	127	268	186	193	113	109	116	76	27
1998	126	386	230	56	28	40	12	0	1

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