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Nest-Site Selection, Nocturnal Nest Desertion, and Productivity in a Common Tern (*Sterna hirundo*) Colony at Detroit River, Michigan

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NEST-SITE SELECTION, NOCTURNAL NEST DESERTION, AND PRODUCTIVITY IN
A COMMON TERN (*STERNA HIRUNDO* L.) COLONY AT DETROIT RIVER,
MICHIGAN

by

Gregory J. Norwood

Thesis

Submitted to the Department of Biology

Eastern Michigan University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Biology with a concentration in Ecology and Organismal Biology

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ABSTRACT

Common terns are declining in the Great Lakes region and represent a population relatively distinct from that of eastern North America. On an artificial site, I studied the substrate and vegetation preference and productivity of nesting terns at two scales: general habitat and nest-site. Terns nested later and less successfully in large river rock (13 to 25-cm diameter) compared to more diverse substrate and limestone (2.5-5.0 cm) when it was free of dead vegetation. Within a habitat, terns chose to nest where substrate was most diverse in rock size, soil, and non-vegetative debris. Percent standing cover did not affect hatching success, but did have a positive effect on fledging success. I monitored predation and nocturnal desertion and determined the behavior was variable between pairs and the detection of a black-crowned night heron (*Nycticorax nycticorax*) predating chicks at night did not lengthen the nocturnal nest desertion time of common terns.

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CHAPTER 1: INTRODUCTION

1.0. Background

Many organizations and government agencies have directed resources into the management of the common tern (*Sterna hirundo*) population in the Great Lakes region for decades. The colonies are much smaller than those of the eastern seaboard; furthermore, Great Lakes region populations are genetically differentiated from the Atlantic coast colonies, and even individual nesting sites appear significantly differentiated (Szczyt et al. 2009). Therefore, active management of the Great Lakes region common tern population is important (Cuthbert et al. 2003; Morris et al. 2010).

Prior to the 19th-century in North America, most terns and other waterbird populations were predominantly affected by habitat availability (influenced by water levels and plant succession; Nisbet 1973a; Courtney and Blokpoel 1983), food (Bollinger 1994; Massias and Becker 1990; Burger and Gochfeld 1991; Moore et al. 2000), long and short-term weather patterns (Burger and Gochfeld 1991; Becker and Specht 1989), predator populations (e.g., Cuthbert et al. 2003; Morris and Wiggins 1986; Nisbet 1975; Nisbet and Welton 1984; Holt 1994), and anthropogenic hunting (Burger and Gochfeld 1991). There was a major decline in the common tern population, and many other colonial waterbirds, in North America in the late 19th and early 20th centuries from the millinery trade (Daughy 1971), non-native mammalian predators (Austin 1948), alteration of coastal nesting habitat (Courtney and Blokpoel 1983; Sharf 1981), organochlorine contaminants (see review in Nisbet 2002), and increased populations of gulls and other nest competitors (Burness and Morris 1992; Morris et al. 1980; Morris et al. 1992; Sharf 1983).

Prior to the 1970s, population trends for common terns were incompletely documented across the Great Lakes region. Ludwig (1962) documented common tern nests

from 1960–1962 only on U.S. waters of the Great Lakes, and found wide variation, with 1,895 in 1961 and 5,855 in 1962. Over the last three decades, common tern nests have decreased in number (–19.1%) and colony sites (–23.2) across the Great Lakes region, with decreases in the last ten years (–9.7%) in the North Channel of Lake Huron and in Canadian waters of Lake Ontario and St. Lawrence River (–31.7; Morris et al. 2010).

In the lower Great Lakes region (Lakes Erie, Ontario, and associated waterways), there were 4,000 to 7,000 nests between 1900 and 1920, increasing to 16,000 by the 1960s (Courtney and Blokpoel 1983). This increase was due to the construction of canals and piers, and the creation of many islands from dredge spoils to make way for shipping and other industrial activities in the 1940s and 1950s, which encouraged common tern nesting at artificial sites (Shugart and Scharf 1983), and the 1960s was the period with the largest recorded population of common terns in the industrial lower Great Lakes region (Courtney and Blokpoel 1983; Kleen 1977; Simpson 1972; Blokpoel and McKeating 1978; Ludwig 1962). For instance, the Detroit River had three major breeding colonies in the 1960s that were not present in the earliest records (Butler 1912), including Belle Isle, Mud Island, and Bob-lo islands (Courtney and Blokpoel 1983). The colony at Belle Isle was on an artificial peninsula, while Mud Island was an artificial dredge site and Bob-lo was established through vegetative control from human activities on the island. Belle Isle recorded 600 to 1,200 pairs, Mud Island contained “several thousand chicks,” and Bob-lo had 1,500 pairs (Courtney and Blokpoel 1983).

Terns declined in the lower Great Lakes region during the 1970s (Blokpoel 1977; Blokpoel and McKeating 1978) and continued to decline through 1998 (Morris et al. 2010). The degradation of artificial nesting sites through plant succession, erosion, and human

disturbance caused many sites to become abandoned by nesting common terns (Sharf 1981). Furthermore, the expansion and population growth of ring-billed gull (*Larus delawarensis*; Ludwig 1962), contaminants (Szczechowski 2007), and high predation (e.g., Burness and Morris 1992; Cuthbert et al. 2003; Millenbah and Winterstein 1999) contributed to the decline of the Great Lakes region common tern. There was a 36.9% decrease of nests in Lake Erie (and associated waterways) and a 22.6% increase in Lake Ontario (and associated waterways) during this period, resulting in a 13.7% decrease overall in the lower Great Lakes region (Morris et al. 2010).

The common tern is now listed as a state threatened species by the Michigan Department of Natural Resources. In the Great Lakes region, the common tern is designated by the U.S. Fish and Wildlife Service as a species of concern. The common tern population is considered a high conservation priority in all regions of the Great Lakes under the Upper Mississippi Valley / Great Lakes Waterbird Conservation Plan (UMV / GL Waterbird Conservation Plan; Wires et al. 2010). This plan calls for increasing the common tern population in the Great Lakes region to the same size that was present during 1960 or 1930 in some areas where there is no near-term opportunity to increase habitat. Furthermore, the Detroit River and Western Lake Erie are of medium and high priority for conservation for common terns, respectively. The UMV / GL Waterbird Conservation Plan recommends a focus on improving management techniques at existing colony sites rather than creating new sites, creation of new island sites in the same geographic area, site enrichment, protective structures, predator control, interspecific competitor removal, and restrictions on human access at sites with high potential for long-term use and high productivity. Furthermore, “management at artificial sites known to be productive for common terns should be

expanded, monitored, managed, and protected. Predators and nest-site competitors should be managed where they are significant limiting factors” (Wires et al. 2010).

Management of Great Lakes region common terns requires regular breeding population assessments, data on the population structure, and an effective strategy on where and how to invest most effectively in reversing the decline in the number of nesting common terns and colony sites. Much of the potential for increasing productive colony sites may be at artificial islands, piers, jetties, and breakwalls. Most of the colonies in the lower Great Lakes region (50 of 89) are on artificial substrates and many are the longest-occupied (Morris et al. 2010). Artificial islands present the most opportunity in the lower Great Lakes region for new sites that can be managed over a long period where partnerships between landowners and managers can be established. Last, artificial sites provide a wide range of different substrate and vegetation characteristics (Sharf 1981 and Karwowski et al. 1995). This range of habitat types on artificial sites presents an opportunity to test how different features may impact productivity, which can help prioritize and implement habitat creation or enhancement projects in different areas of the Great Lakes region. Productivity data collected in a standardized way across years at these artificial sites will determine where breeding terns are declining and what characteristics these sites have in common that contribute to poor productivity. Finally, it is important to investigate whether a greater investment in substrate “enrichment” and more intensive manipulation of vegetation would elicit a higher likelihood of establishment at created sites and promote higher productivity where colonies already exist.

Predation can cause severe reproductive failure in a colony by direct consumption of eggs or chicks. In addition, terns are known to abandon their nests at night when there is

disturbance from a predator. Relatively little is known on how variation in predators and the severity of predation affect nocturnal nest desertion across a colony at night. Little data exist on the frequency, duration, and synchrony of nocturnally deserting terns in response to different levels of disturbance. Putting this behavior in context will help managers appropriately assess the level of nocturnal disturbance at a colony. Furthermore, relatively few studies have investigated the indirect impacts of nocturnal nest desertion on individual nest productivity (Arnold et al. 2006; Holt 1994; Nisbet and Welton 1984), and no studies have linked duration of nocturnal desertion with productivity.

Managers of common terns in the Detroit River are attempting to increase the number of breeding pairs and their productivity. Today, the common tern population of the Detroit River is approximately 135 to 300 pairs located in the Trenton Channel of the Detroit River where they nest under two bridges onto Grosse Ile, Michigan (Cuthbert and Wires 2008; Norwood 2009). Data were provided from an artificial site in the Detroit River where habitat differed and predation was high. I investigated what habitat features terns prefer at the general habitat and nest-site scale, and where and what features promote the most nesting success. I also focused on the relationship between nocturnal predation and nocturnal nest desertion and determined whether the duration of nocturnal nest desertion negatively affected hatching success. This research is a response to the recommendation to further explore the relationships between vegetation cover, overall reproductive success, predation, and the differences between artificial and natural nesting sites (Lamp et al. 2003). It also provides research in support of the most effective management at existing sites, as recommended in the UMV / GL Waterbird Conservation Plan.

1.1. Study site

I studied a common tern colony located on two bridge protection piers underneath the Grosse Ile Free Bridge, which spans the Trenton Channel of the Detroit River and connects the city of Trenton and Grosse Ile Township (42.127° N, -83.174° W; Figs. 1.1 and 1.2) in Wayne County, southeast Michigan. The south pier is approximately 40 m long by 17 m wide and the north pier is 40 m long by 12 m wide.

Nests were located within four main habitat types differing in substrate and vegetation characteristics (Cobble, Limestone, North Complex, South Complex). The cobble habitat was composed of 13 to 25-cm diameter river rock with orange touch-me-not (*Impatiens capensis*) and American germander (*Teucrium canadense*) as dominant plant species. Limestone habitat was composed of 2.5-5.0 cm long limestone chips with scattered tall boneset (*Eupatorium altissimum*), goldenrods (*Solidago* sp.), and numerous minor plant associates. The North and South Complex habitats were composed of a combination of rock sizes and significantly more available soil than cobble or limestone. Both consisted mostly of tall boneset and goldenrods, but the north complex had a more contiguous dense plant cover, including associates.

Twelve 2.4 m plots were established in cobble and north complex, and 15 in south complex and limestone. Limestone and south complex were supplemented with 24 m² of bare soil in 2010 to further diversify those habitats.

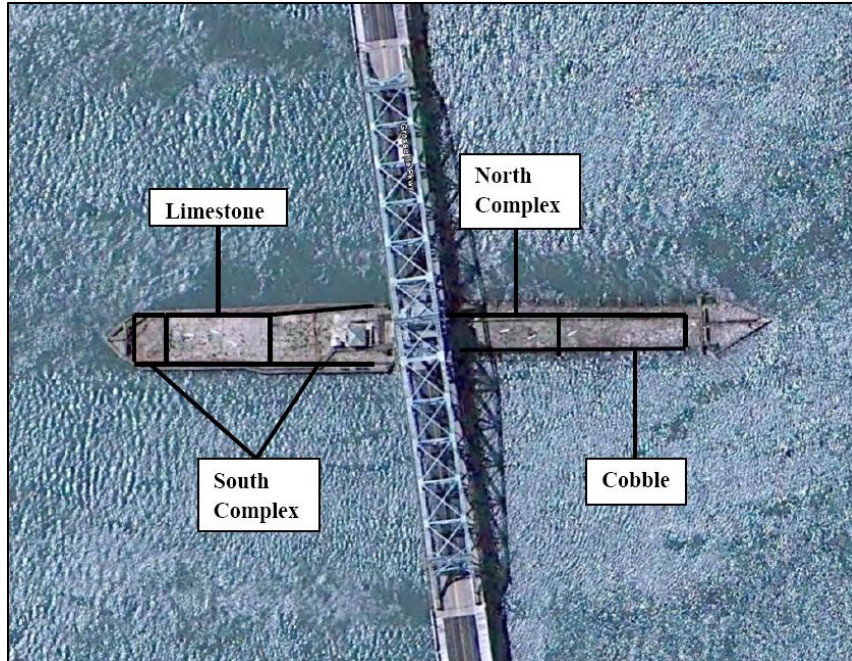


Figure 1.1. Four habitats for common terns (*Sterna hirundo*) at the Grosse Ile Free Bridge, Wayne County, Michigan.

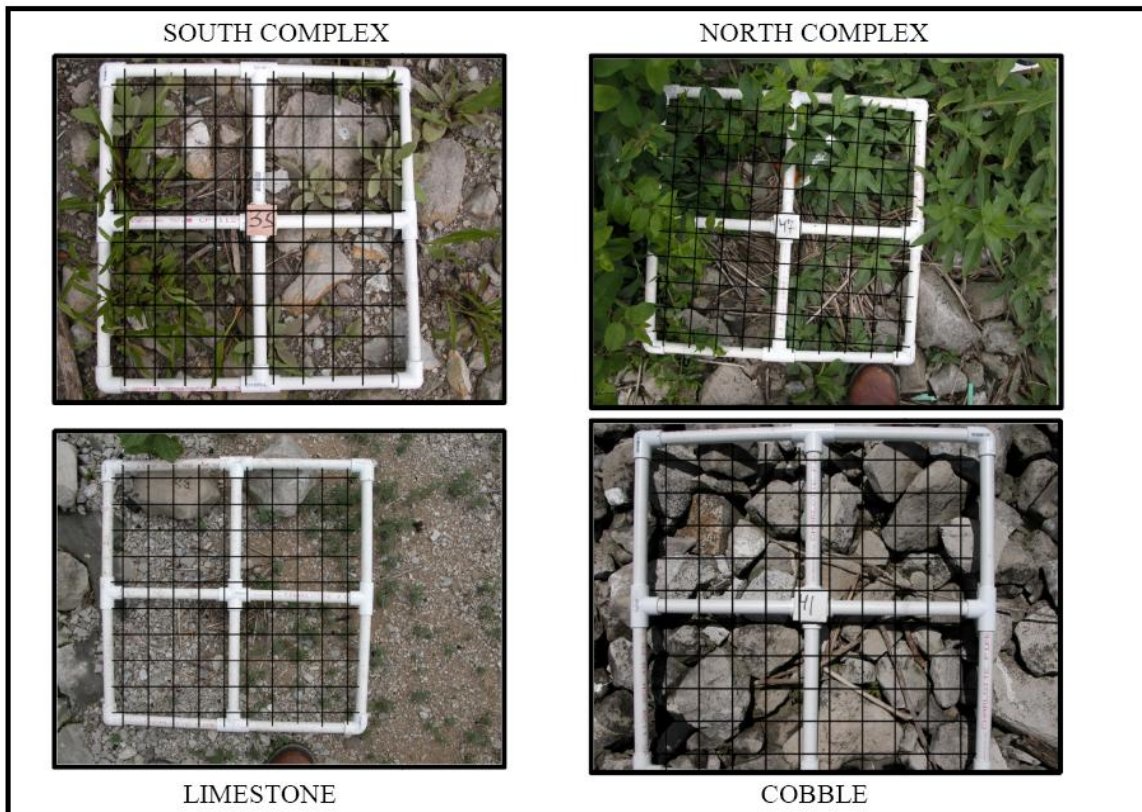


Figure 1.2. Sample images taken during incubation showing general habitat characteristics at the scale of a nest within four habitats at Grosse Ile Free Bridge, Wayne County, Michigan.

1.2. Nest-site selection

Common terns (*Sterna hirundo*) nest in colonies of varying size near fresh and marine water-bodies, and the type of substrate and vegetation in use is highly variable. For example, terns nest on cordgrass (*Spartina*) and sandy beaches (Burger and Gochfeld 1991), flattened reed (*Phragmites*) in the Great Lakes region (L. Williams, U.S. Fish and Wildlife Service, pers. commun.), rocky areas (e.g., Morris et al. 1992), and storm-deposited shell piles (Rounds et al. 2004). Vegetation is equally diverse, with some sites nearly free of vegetation (MacFarlane 1977) and others with more than 50% (Cook-Haley and Millenbah 2002). Despite this high adaptability, habitat preference can be documented in terns by showing that the habitat in use is different from what is generally available (Burger and Gochfeld 1991). In some studies, nest preference led to a measurable increase in productivity (Richards and Morris 1984; Severinghaus 1982). Therefore, a small-scale nest-site selection study can provide local managers a realistic and cost-effective benchmark for enhancing existing sites and creating more habitat – one that shows if and what habitat characteristics are preferred and whether these preferences lead to higher productivity.

Common terns vary their use of artificial nesting sites based on water levels. Terns use artificial sites during years when natural sites are flooded in the St. Mary's River, Michigan (Lamp et al. 2003; Scharf 1991). These artificial sites generally contain more vegetation than natural sites. Therefore, vegetation preference may be shown within one habitat or between years as water levels fluctuate, but it does not offer a true test of substrate and vegetation preference because all options are not available at one time. Confounding this is that terns tend to nest where they were successful in the past, despite the habitat changing over time (Burger 1982). To mitigate this, investigators must measure nest preference where

substrate and vegetation amount varies widely, and test whether preference actually results in higher productivity over numerous seasons.

The spatial scale at which terns are choosing nest sites within an established colony is unclear. Richards and Morris (1984) and Severinghaus (1982) showed preference for habitats that could hold dozens of tern nests, while Cook-Haley and Millenbah (2002) found more fine-scale selection can occur, although the latter showed that preference did not equate with where terns hatched more young. Furthermore, the relationship between substrate and vegetation is unclear; it is unknown whether substrate and vegetation are separate drivers of nest-site selection, or whether there is preference for a particular combination.

Vegetation at most artificial sites is herbaceous perennial plants where woody species eventually establish in the absence of periodic cutting or burning. Managers must remove this vegetation to maintain nesting habitat for terns and prohibit the establishment of an old field community. However, tern nests lack the protective benefits of standing cover early in the season if it is removed during the early part of the nest initiation period. Therefore, it would be helpful to test if terns prefer some standing cover from previous growing seasons.

I investigated nest-site selection at two scales; the first at a habitat level (71.4 to 89 square meters) and the second at the scale of a tern nest (50 cm X 50 cm) within the four distinct habitat types differing in vegetation and substrate characteristics. Vegetation in these habitats differed in amount each year and provided terns a wide range of choice.

I predicted that more terns would use a habitat in 2009 than 2008 after the previous year's vegetation was removed because standing cover may be too high by the period when chicks are hatching. I also predicted that terns would colonize the complex habitats first, followed by the two less complex habitats, according to Richards and Morris (1984) and

Severinghaus (1982). The complex habitats may enhance nest camouflaging and alleviate temperature and weather stress.

Also, I predicted that within a single habitat type, tern nest sites are more diverse in substrate characteristics (rock size, soil amount, and non-vegetative debris) than average. Finally, I predicted that tern nest sites would show less variation in standing cover than control sites and be in areas with a moderate amount of vegetation (15-30% standing cover) based on other studies at artificial substrates in the Great Lakes region (Cook-Haley and Millenbah 2002; Lamp et al. 2003).

1.3. Nocturnal nest desertion patterns

Colonial waterbirds may temporarily abandon their nests at night to avoid being harmed by nocturnal predators. This behavior would serve to increase fitness of adults by enabling them to reproduce in future years when predation is less severe. This should be especially apparent in long-lived species where disinvestment in the current year's clutch has a smaller reduction in fitness than short-lived species where a single breeding season is more important. Specific predators that instigate this behavior in terns and gulls have been documented with differing certainty, including mink (Burger 1974), great horned owl (Arnold et al. 2006), short-eared owl (Holt 1994), long-eared owl (Wendeln and Becker 1999), black-crowned night heron (Shealer and Kress 1991), red fox (Patton and Southern 1977), and skunk (Southern and Southern 1979); furthermore, nest attendance increases when the predator is eliminated (See Kress and Hall 2004). Despite effective protection of the colony during the day, terns and gulls seem to lack defense mechanisms from many predators at night. Southern and Southern (1979) suggest that the primary predator defense

strategy of gulls is by avoidance through the use of less accessible sites (islands, peninsulas, etc.), not physical defense.

Tern and gull colonies that are chronically disturbed by nocturnal predators have been characterized by simultaneous nightly departure of individuals that circle above the colony, followed by abandonment of the entire colony area, presumably to roost somewhere nearby (Chardine and Morris 1983; Hebert and McNeil 1999; Holt 1994; Southern and Southern 1979; Marshall 1942; Hunter and Morris 1976; Shealer and Kress 1991). Previous studies have shown that common terns depart their nests from an average of 54 minutes (Arnold et al. 2006) to 8 hours (Nisbet and Welton 1984). Furthermore, Arnold et al. (2006) found that a sample of terns from ten nests each night were more likely to depart on nights when there were indications that a great horned owl was predating chicks than nights when an owl was not present.

Nocturnal nest desertion can cause catastrophic mortality or chronic reduction in egg and chick survival through the breeding season. Incubation length is prolonged to as much as ten days (Nisbet 1975), leading to exposure of eggs and young chicks to weather, and predators that are normally not a threat when protected by an incubating adult (Holt 1994; Nisbet and Welton 1984; Shealer and Kress 1991). For example, studies have found ants, other gulls, and weather to reduce hatching success (Nisbet and Welton 1984; Shealer and Kress 1991).

On the other hand, Chardine and Morris (1983) suggest that nocturnal desertion is of relatively low cost in long-lived species; additionally, they show nocturnal desertion serves not only to protect against predators of adult ring-billed gulls (*Larus delawarensis*), but is a contributor to higher hatching synchrony for early nests when food is more abundant, which

enhances the chances of fledging a third egg. Nocturnal desertion in the gull colony declined in late nests, which contributed to more asynchronous hatching that may be an adaptation to more unpredictable food resources when all members of the clutch would take-up resources, but are less likely to survive (Lack 1966, 1968). Therefore, it is important to specifically test how disturbance affects patterns of nocturnal desertion.

The goal of common tern managers is to reduce the impact of one or a small number of individual predators on a disproportionately large number of eggs and chicks. Managers may try to eliminate nocturnal desertion, which would serve to decrease the time that clutches are in the egg stage and reduce the threats from weather and more benign predators that are deterred from incubating adults. However, there has been only one study that has attempted to link predator visitation patterns with the occurrence of nocturnal nest desertion in individual terns (Arnold et al. 2006). Therefore, I studied a common tern colony that was regularly disturbed at night by a black-crowned night heron (*Nycticorax nycticorax*) during the 2010 breeding season. I used cameras and temperature sensors placed in nests to link the frequency of heron predation (or any other predator) with duration, frequency, and synchrony of the nocturnal incubation/desertion of 35% of the total nests from prior to egg laying and until all chicks were fledged. I predicted that terns would depart longer on nights when a heron was detected. I also predicted that most terns would depart and arrive at the same time.

1.4. The effects of nest-site selection and nocturnal nest desertion on productivity

Common terns nest in a wide range of habitat types in fresh and salt water environments. Productivity has been shown to differ across habitat types within a season (Richards and Morris 1984; Severinghaus 1982; Cook-Haley and Millenbah 2002; Rounds et

al. 2004). Reasons for this include risk of flooding (Storey et al. 1988), ease of access to predators (Burger and Gochfeld 1991), and food availability (Nisbet 1973b). Additionally, the density of nests may impact productivity. For instance, habitats with a lower density of nests may be more productive during some predation events because nests are more difficult to find (Barbour et al. 2000; Cook-Haley Millenbah 2002). Furthermore, larger and more stable colonies have been shown to be more productive than smaller colonies (Burger and Gochfeld 1991). In addition to habitat type, food abundance (Moore 2000; Nisbet 1973b) and contaminants (see review in Nisbet 2002) influence productivity.

Some studies have shown that terns actively select habitats that increase productivity (Richards and Morris 1984; Severinghaus 1982). Great Lakes region common terns seem to have higher nest success in natural sites than artificial sites (Cook-Haley and Millenbah 2002), with natural sites having significantly less standing vegetative cover than artificial sites. Furthermore, Cook-Haley and Millenbah (2002) showed that terns exhibit the highest hatching success in artificial sites containing approximately 40% standing vegetation, even though more terns nest in areas of 10–30% standing vegetation.

The decline of common terns in the Great Lakes region is attributed mostly to lack of suitable nesting sites (Cuthbert et al. 2003). In general, common terns require habitats that are free from flooding and contain some scattered vegetation and other debris and are relatively isolated from predators and inter-specific competition (Cuthbert et al. 2003). The sites used consistently over the last three decades were further characterized by a combination of relatively small number of pairs, artificial substrate, and isolation from ring-billed gulls (Morris et al. 2010). Many artificial sites could serve this purpose in the Great Lakes region (Karwowski et al. 1995; Sharf 1981; Scharf 1978). Managers of common terns

require information on how to create the most productive substrate and vegetation characteristics that promote the highest productivity most years in their area.

I compared the hatching and fledging success within the four habitat types in an area where flooding and weather have not generally contributed to egg or chick mortality. I determined if hatching and fledging success was influenced by substrate diversity and the amount of standing cover. I predicted that the two complex habitats would have higher hatching success because of a greater likelihood of nest camouflage during predation. I also predicted that fledging success would be highest in the complex habitats because of the greater number of potential hiding places for chicks. Finally, I predicted that substrate diversity and standing cover at the nest site would increase hatching and fledging success by lowering exposure to predators.

CHAPTER 2: Methods

2.0. Nest-site selection

2.0.0 Habitat selection

I determined whether terns exhibited habitat preference by observing the sequence of nest initiations in the four habitat types in 2009 and 2010. Presumably, the most preferred habitats would have a higher number of nests first, followed by habitats with the less preferred substrate (Richards and Morris 1984; Severinghaus 1983). A chi-square test (4 x 2 contingency table) was used to determine if there was a relationship between the number of tern nests in the four habitat types during the first and second half of the nest initiation period for that year.

I tested the effect of weeding the previous year's standing cover by manipulating the North Complex habitat. In 2008, dead standing cover was not removed. All standing cover was then removed in 2009 and 2010, and we recorded the sequence of nest initiation in relation to the other habitats and the total number of nests in North Complex between the two years.

2.0.1. Nest-site selection

A digital photograph was taken of each nest and random control point in each of the four habitats in 2009 and 2010 with a 50 cm x 50 cm modified Daubenmire frame (Daubenmire 1959) placed on top of the nest. Each nest photograph was taken during the incubation period, and controls were taken at about the same time in the season to keep vegetation amount constant. Each of 100 "intersections" from a digital grid was categorized to one of four substrate and two vegetative types (refer to Fig. 1.2):

Substrate: Cobble (> 10 cm²), Small Stone (≤ 10 cm²), Non-Vegetative Debris, Bare Soil

Vegetative: Standing Cover, Vegetative Debris

A Simpson's diversity index (Simpson 1949) was calculated for the substrate of each nest and associated control.

$$D = 1 - \sum (n/N)^2$$

n= total number of points of a single substrate

N= total number of points in all four substrate types

Using this formula, the most diverse site would be D=0.75 and the least diverse would be D=0. A paired *t*-test was used to test for differences between nests and controls in substrate diversity and standing cover.

2.1. Nocturnal nest desertion

2.1.0. Predator surveillance

Predators in a 78-pair colony of common terns were monitored from 22 April to 10 August 2010 with two continuously running time-lapse cameras (RapidFire RC55; Reconyx, Inc., Holmen, WI) and five motion-activated cameras (Trophy Cam; model: 119405; Bushnell Outdoor Products, Overland Park, KS) placed strategically throughout the colony to maximize detection of predators and tern nests at night. The motion-activated cameras were set to capture images within one second of any movement from approximately one hour before sunset and one hour after sunrise. Each motion-activated camera's range was 0 to 15 m at night. The time-lapse cameras were set to capture images from 0 to 18 m away every 5 minutes from approximately one hour before sunset to one hour after sunrise.

All detections each night from both camera types were time-stamped. The time between the first detection and the last detection was the estimate of arrival and departure of the predator each night. Daytime predation was monitored from the bridgekeeper's office approximately 12 m above the colony while searching for new nests and tracking chicks at least three times per week and every third day after hatching began.

2.1.1. Nocturnal nest desertion

Nocturnal nest desertion patterns from 11 nests in 2009 and 55 nests in 2010 were documented with the use of Thermocron iButtons (model DS 1922L, Maxim Integrated Products, Inc., Sunnyvale, CA), and supplemented with data generated from the time-lapse cameras. iButtons were modified by sewing a piece of 1-mm thick black polyester over each device (Hartman and Oring 2006) and gluing it to the top of a 2.5 cm nail. Each modified iButton was inserted at the bottom of each nest so that the iButton protruded 5 mm above the surface of each nest between eggs. A control iButton was placed outside the nest within 50 cm at the same height above ground in similar substrate. Temperatures were recorded every three minutes at a precision of 0.001 °C.

Terns were determined absent at the first 3-minute interval that nest temperatures declined toward the control temperature. A bird was determined absent only if the decrease in nest temperature toward or reaching the control was sustained for at least 15 minutes and resulted in a subsequent increase in nest temperature upon a bird's return that did not occur in the control. Time-lapse cameras were also used to monitor nocturnal nest desertion behavior for 50 departures and 75 arrivals. A departure and arrival time was the beginning of the five-minute segment that showed the absence or presence of an incubating bird. I compared the

two methods (iButtons and cameras) by calculating the difference in departure and arrival times. Nocturnal nest desertion time was calculated by subtracting the time of arrival by the time of departure. The synchrony of departing and arriving terns was measured by subtracting the time from the final arrival from the time of the first departure. In 2010, differences in the duration of nocturnal desertion of terns between nights with and without heron detections and the synchrony between departing and arriving terns were tested with a two-sample *t*-test.

2.2. The effects of nest-site selection and nocturnal nest desertion on productivity

2.2.0. The effect of habitat on productivity

The number of breeding pairs was determined by recording the highest number of incubating adults or those tending chicks (including recently failed nests before re-nesting could occur) and indicates the most conservative estimate of the number of breeding pairs. Nests were located through observation of adults and during colony visits at least three times per week and every third day after hatching began. Mean clutch size, hatching, and fledging success were determined for each nest in the four habitats.

A chick was determined fledged if it was seen in flight or known to survive 21 days of age. Fledglings from clutches were identified from similar hatching dates and band re-sightings, as well as the spacing of nests on the piers, natural territory boundaries, and favorite chick-feeding sites. In 2008, the exact number of eggs ranged from 117 to 120, so the more conservative number was used in analyses. There were seven nests of the 98 initiated in 2009 in which clutch size was unknown. The mean clutch size was used for these nests in the analyses. Incubation period was calculated in 2010 from the day the first egg was

laid until the day the first egg hatched. Differences in hatching and fledging success in the four habitats were tested with a chi-square test (4 x 2 contingency table).

2.2.1. The effect of nest-site characteristics and nocturnal nest desertion on productivity

Two sets of multiple logistic regressions in SAS 9.2 (PROC LOGISTIC; SAS Institute Inc. 2009) were used to test the effect of nest-site selection and the duration of nocturnal nest desertion on hatching and fledging success. Each set had two separate tests with hatching and fledging success as dependent variables (full, partial, or no success). The first set included all nests from 2009 and 2010 and the second used only nests from 2010 from which at least some nocturnal nest desertion data were collected from 35% of nests in the colony.

The independent variables in the first set were year, standing cover, nest diversity, and nest initiation date. Independent variables in the second set were duration of nocturnal nest desertion, standing cover, nest diversity, and nest initiation date. Collinearity of the independent variables was tested in the models (PROC REG with VIF and TOL). Individual regression coefficients were evaluated on their Wald chi-square statistics (Peng et al. 2002).

CHAPTER 3: RESULTS

3.0. Nest-site selection

3.0.0. Habitat selection

Vegetation removal had a positive effect on the number of nests initiated in the north complex. The percentage of the total nests in the north complex increased from 16.3% in 2008 (N = 49) to 33.3% in 2009 (N = 87), followed by 26.7% in 2010 (N = 116; Fig. 3.1 – 3.2). Terns initiated more quickly in north and south complex versus limestone and cobble habitats in 2009. The first 16 nests were initiated in those two habitats (10 and 6, respectively) by 4 May 2009, while limestone and cobble had 0 initiated nests. In 2010, however, limestone and north complex were the first habitats used; and density of nests was higher in those two habitats with 0.69, 1.06, 1.08, and 0.75 nests per square meter (N = 116) in cobble, limestone, north complex, and south complex, respectively (Fig. 3.3).

Habitat use did not differ between nests initiated before and after the mid-point of the nest initiation period in 2008 ($\chi^2 = 3.30$, $df = 3$, $P = 0.347$) and 2010 ($\chi^2 = 0.789$, $df = 3$, $P = 0.852$). However, terns nested more in limestone after the mid-point and less in north complex in 2009 ($\chi^2 = 14.33$, $df = 3$, $P = 0.002$).

3.0.1. Nest-site selection

Tern nests had higher Simpson's diversity index values than controls ($t = -4.98$, $df = 181$, $P < 0.0001$; Fig. 3.4). Nest sites had higher diversity values in South Complex and North Complex in both 2009 and 2010 (Table 3.1). Limestone nests were more diverse than controls in 2009, and Cobble was more diverse than controls in 2010. Nests had more vegetative debris (mean = 16.55 points, $SD = 10.45$, $N = 183$) than controls (mean = 5.78, $SD =$

7.54, N= 183; $t= 11.59$, $df= 182$, $P < 0.0001$). The addition of 24 m² of bare soil to the limestone and south complex habitat in 2010 resulted in an increase in control site diversity from 0.08 (± 0.03) to 0.20 (± 0.04) and 0.29 (± 0.05) to 0.30 (± 0.05) between 2009 and 2010 in the two habitats, respectively.

Tern nest sites did not differ from control sites in the amount of standing cover ($t= 1.18$, $df= 182$, $P= 0.240$; Fig. 3.5). Variance in standing cover also did not differ between nests (mean = 26.05 points, SD = 19.64, N = 183) and controls (mean = 23.37, SD = 24.29, N = 183). Mean standing cover of nests was greater than controls in cobble, and nests had less standing cover than controls in limestone, but there were no other significant differences between nests and controls across the habitats over the two years; nests ranged from 20 to 35% standing cover, while controls ranged from 12% to 40% (Table 3.1).

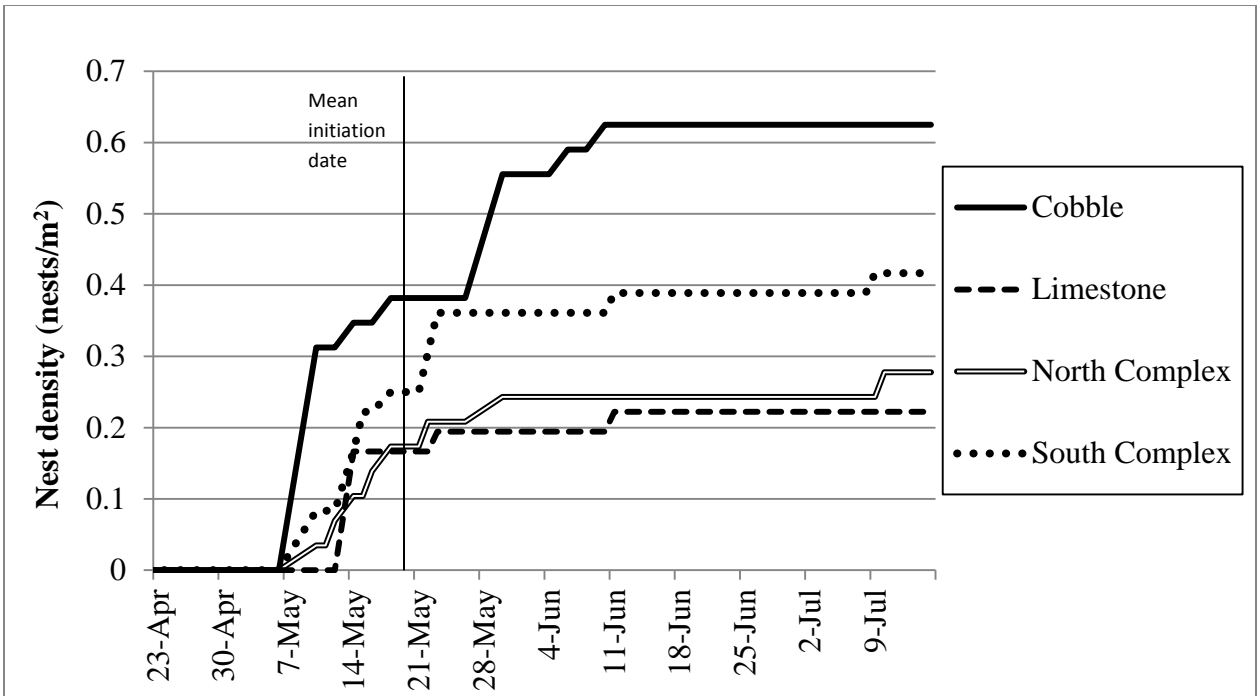


Figure 3.1. Density of common tern nests (excluding re-used nest sites) in each habitat throughout the 2008 season.

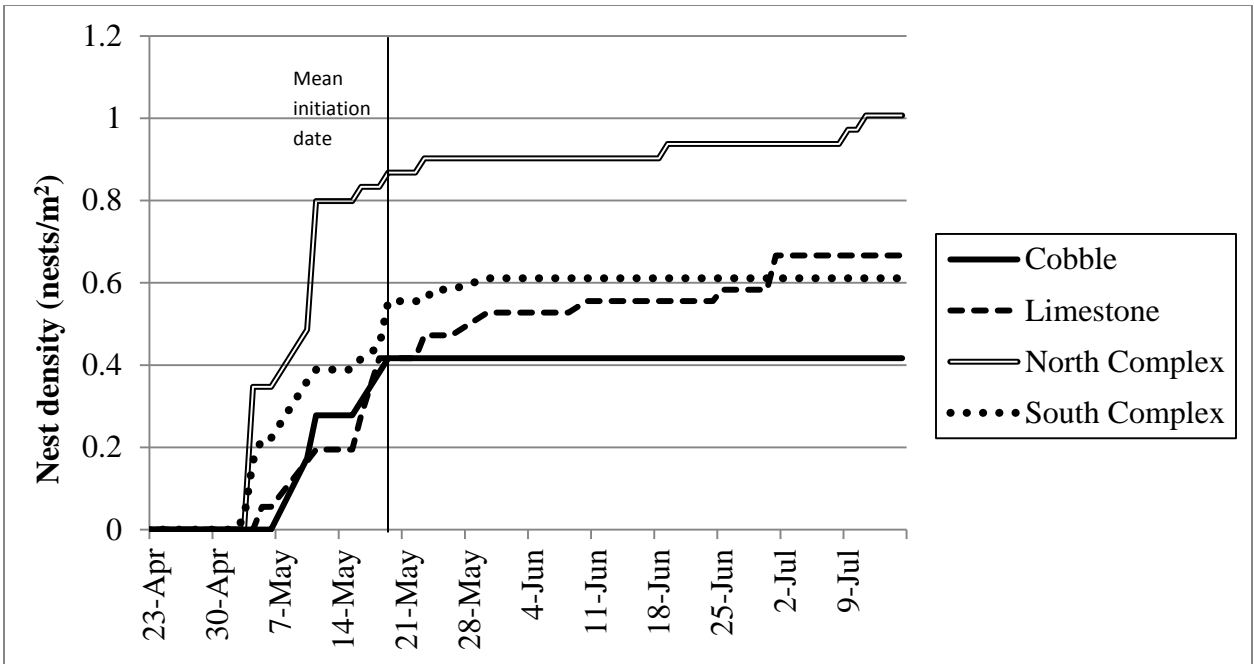


Figure 3.2. Density of common tern nests (excluding re-used nest sites) in each habitat throughout the 2009 season.

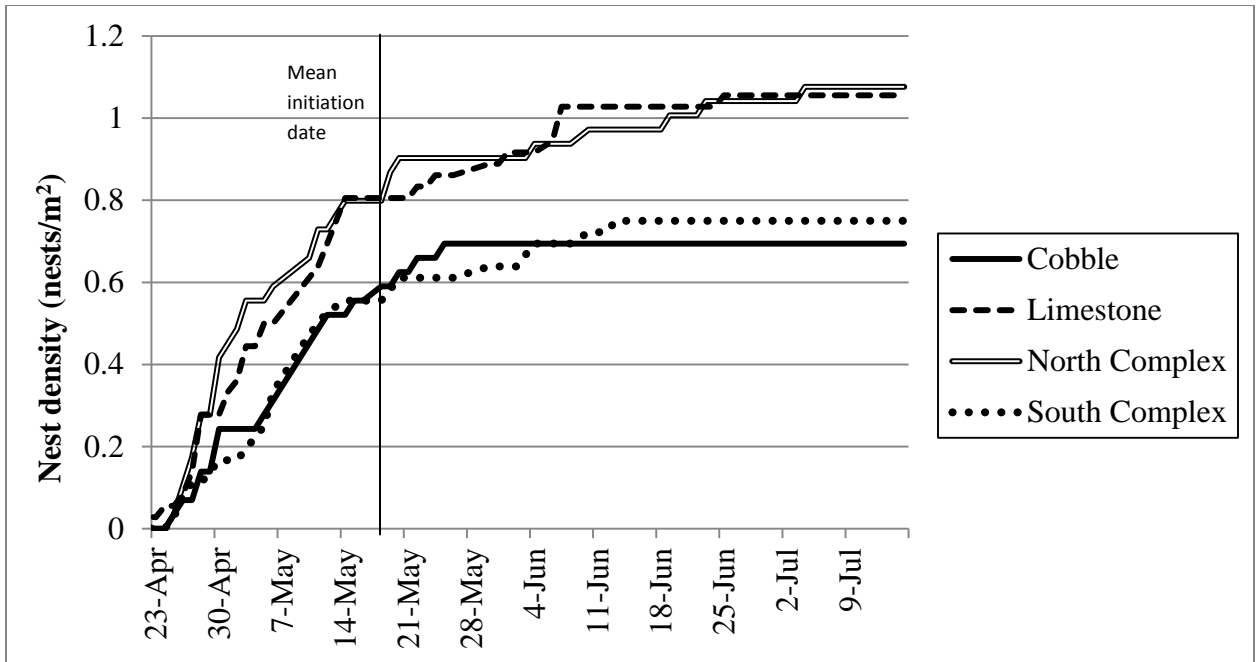


Figure 3.3. Density of common tern nests (excluding re-used nest sites) in each habitat throughout the 2010 season.

Table 3.1. Substrate diversity and standing cover (mean \pm SE) of common tern (*Sterna hirundo*) nests and controls in four habitat types.

Habitat	Year	Substrate Diversity	
		Nests	Controls
Cobble	2009	0.05 (\pm 0.02)	0.02 (\pm 0.02)
	2010	0.09 (\pm 0.03)	0.03 (\pm 0.01)
Limestone	2009	0.35 (\pm 0.05)	0.08 (\pm 0.03)
	2010	0.21 (\pm 0.03)	0.20 (\pm 0.04)
North Complex	2009	0.35 (\pm 0.04)	0.24 (\pm 0.04)
	2010	0.30 (\pm 0.03)	0.21 (\pm 0.04)
South Complex	2009	0.39 (\pm 0.03)	0.29 (\pm 0.05)
	2010	0.40 (\pm 0.03)	0.30 (\pm 0.05)

Habitat	Year	Standing Cover	
		Nests	Controls
Cobble	2009	21.8 (\pm 7.82)	20.4 (\pm 8.19)
	2010	28.41 (\pm 5.72)	12.29 (\pm 3.57)
Limestone	2009	19.79 (\pm 4.66)	21.00 (\pm 3.08)
	2010	19.44 (\pm 2.47)	30.10 (\pm 4.22)
North Complex	2009	36.46 (\pm 2.90)	27.38 (\pm 4.60)
	2010	31.76 (\pm 3.95)	20.93 (\pm 4.48)
South Complex	2009	27.27 (\pm 4.24)	25.36 (\pm 6.27)
	2010	22.16 (\pm 3.94)	17.60 (\pm 4.62)

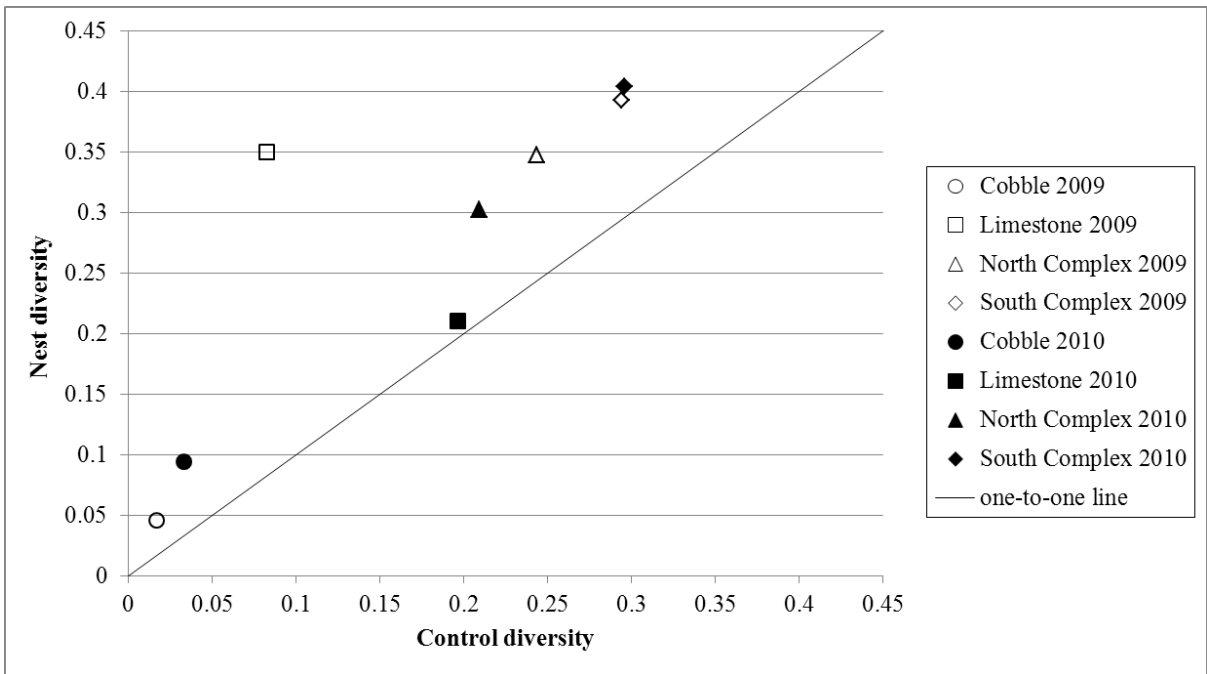


Figure 3.4. Substrate diversity index values for each paired common tern (*Sterna hirundo*) nest and control point in all habitats in 2009 and 2010.

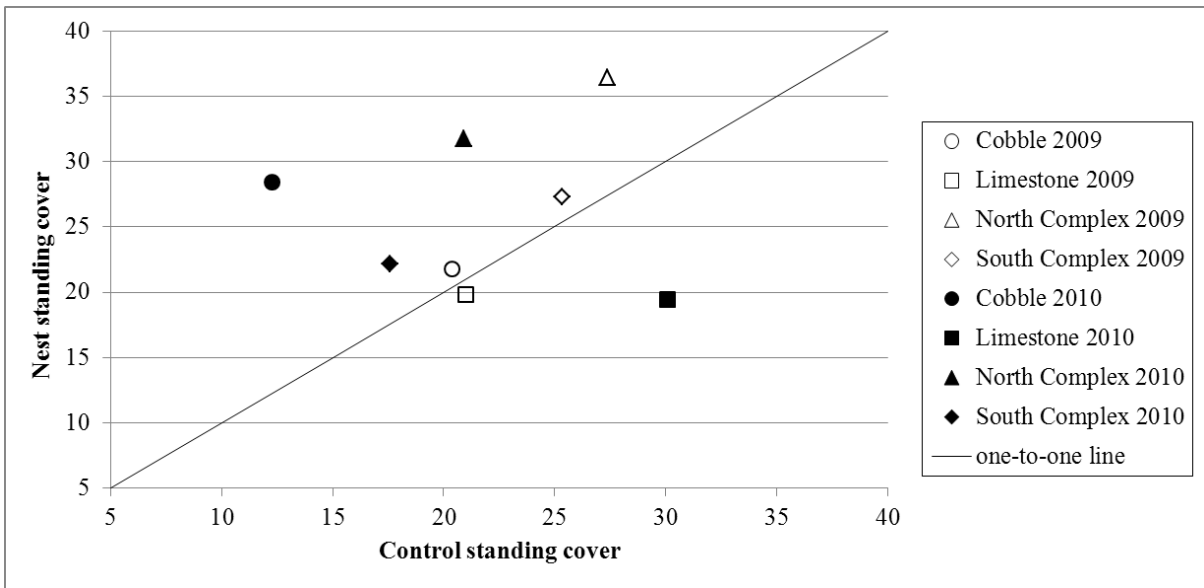


Figure 3.5. Mean standing cover for each paired common tern (*Sterna hirundo*) nest and control point in all habitats in 2009 and 2010.

3.1. Nocturnal nest desertion

3.1.0. Validation of technique

The difference between i-button and camera detection of departing terns ranged from 1.02 to 25.02 minutes (mean = 6.83, SD = 4.00, N= 50). The difference for arriving terns ranged from 0.02 to 28.02 minutes (mean = 8.48, SD = 5.2, N = 75). Terns that were seen on and off their nest before an extended departure or arrival were excluded from analysis. This behavior was seen during four departures with a difference between i-button and cameras of 101.00, 30.98, 1.98, 1.02 minutes. Intermittent incubation was noted on 5 arrivals with a difference of 19.98, 10.98, 14.02, 4.98, and 19.02 minutes between i-buttons and cameras.

3.1.1. Predation and nocturnal desertion

Hatching occurred between 28 May and 22 July and 17 May and 24 July in 2009 and 2010, respectively. No predation was observed during the day. Terns from 11 nests departed for a mean of 5.3 hours (SD= 4.05, N= 123) in 2009 (Fig. 3.6). In 2010, a black-crowned night heron was detected on 33 nights between 30 April and 19 July (Fig. 3.7). There were at least two heron detections on 20 nights and one detection on 13 nights. The frequency of detections was highest between 26 May (9 days after first hatched clutch) and 30 June when a heron was present on 69% of nights. First detection times were between 21:40 EDT to 04:03 EDT with a mean of 1.33 hours (SD = 1.57, N = 20) between the first and last detections.

Terns from 55 nests were monitored from one to 25 consecutive nights (mean = 13) between 2 May and 25 July. An average of 10.28 terns were monitored on 32 nights with a heron detection and 8.58 terns on 52 nights without a heron detection. Incubating terns

temporarily deserted on 86% of nights for a mean of 6.00 hours (SD = 3.38, N = 696). Desertion of at least 25 minutes occurred on 95% of nights when a heron was present and 80% when no heron was detected ($\chi^2 = 31.41$, df = 1, $P < 0.0001$). Terns deserted an average of 5.75 hours (SD = 2.68, N = 415) on nights without a heron and 6.37 hours (SD = 1.25, N = 280) on nights with a heron detected ($t = 2.519$, df = 690, $P < 0.012$). However, after the heron was frequently detected beginning on 26 May, there was no difference in the number of terns that deserted on nights with and without a heron detection ($\chi^2 = 0.528$, df = 1, $P = 0.468$; Fig. 3.8). Furthermore, terns deserted longer (mean = 7.12 hours, SD = 3.32, N = 229) on nights after 26 May without a heron detection than on nights with a detection (mean = 6.30 hours, SD = 2.68; N = 266; $t = 2.957$, df = 438, $P = 0.003$).

Departing terns were less synchronous than arriving terns. There was a mean of 4.17 hours (SD = 2.18, N = 81) difference between the first and last departing tern, and a mean of 1.48 hours (SD = 1.60, N = 80) for arriving terns (Fig. 3.9).

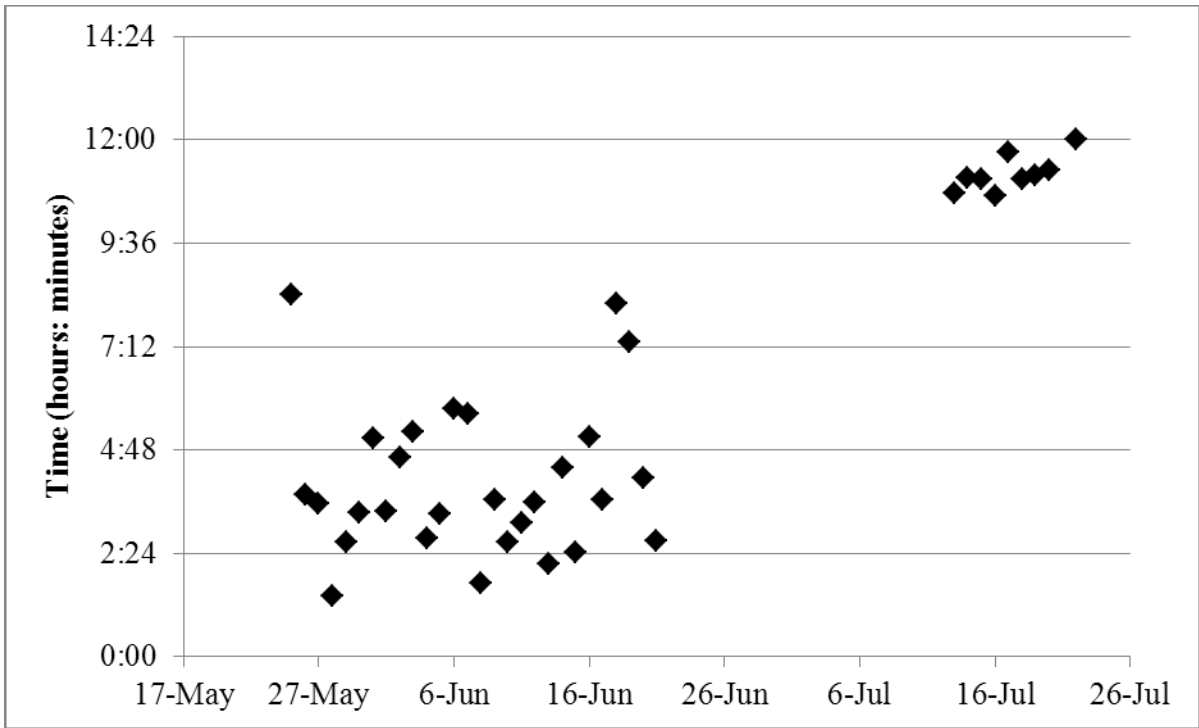


Figure 3.6. Mean hours of nocturnal nest desertion of common terns (*Sterna hirundo*) during the 2009 season on nights with at least two nests monitored.

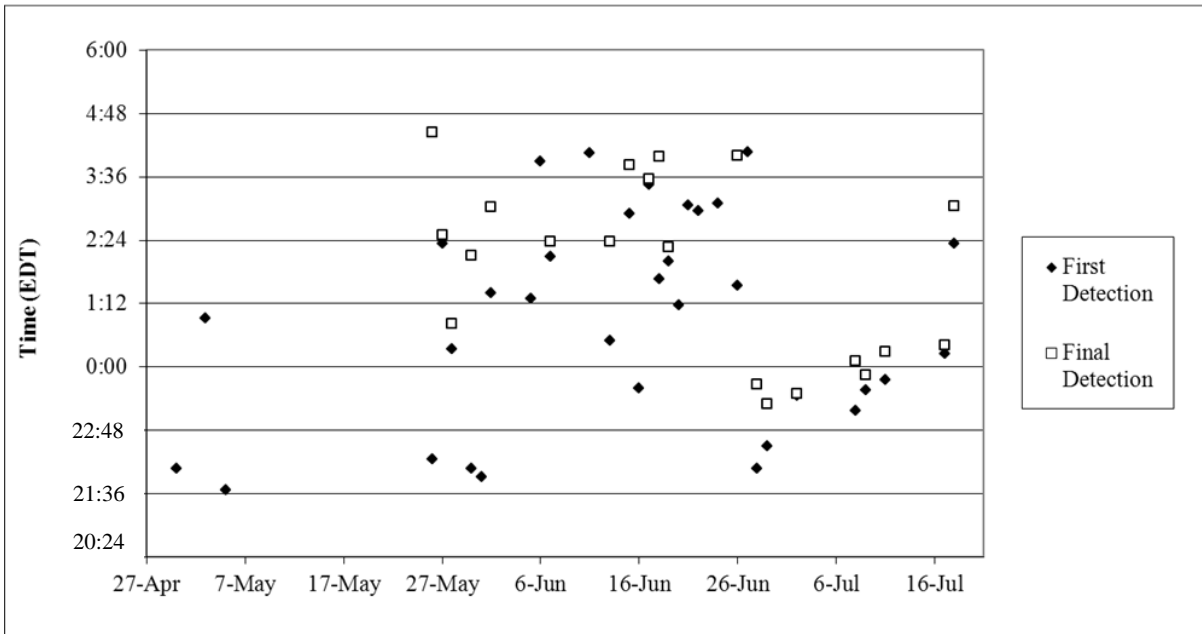


Figure 3.7. Time of first and last black-crowned night heron (*Nycticorax nycticorax*) detection for each night in a common tern (*Sterna hirundo*) colony.

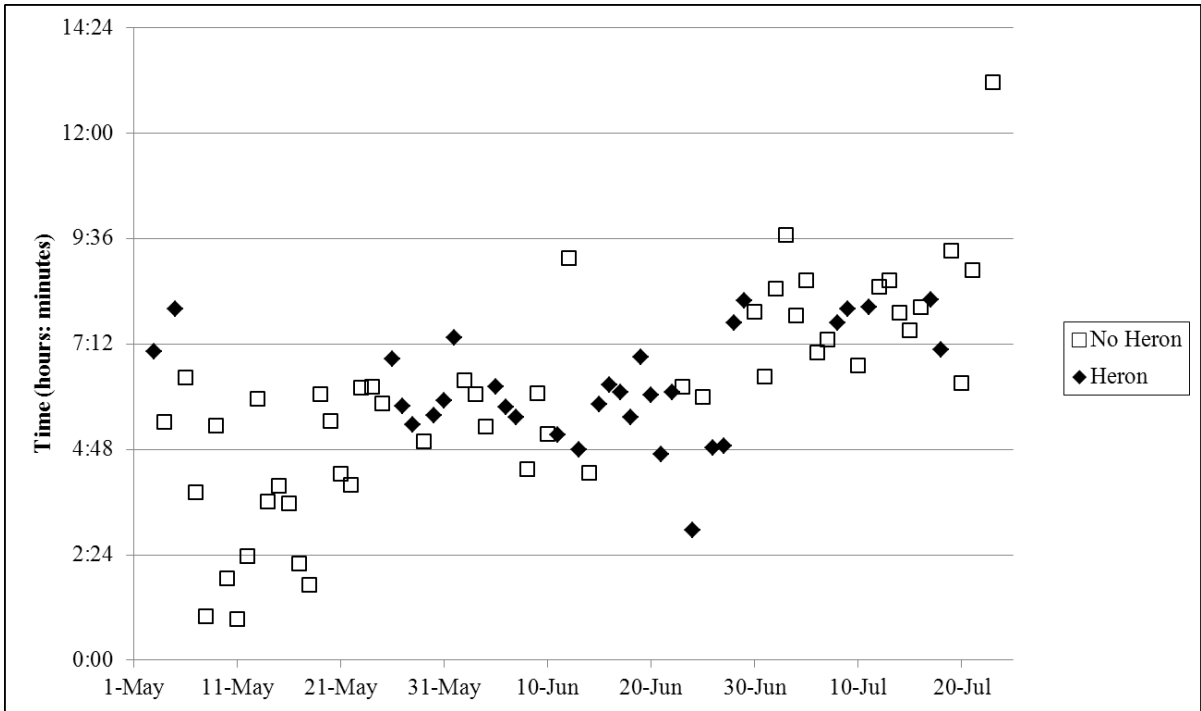


Figure 3.8. Mean hours of nocturnal nest desertion of common terns (*Sterna hirundo*) on nights with and without a black-crowned night heron (*Nycticorax nycticorax*) detected throughout the 2010 season.

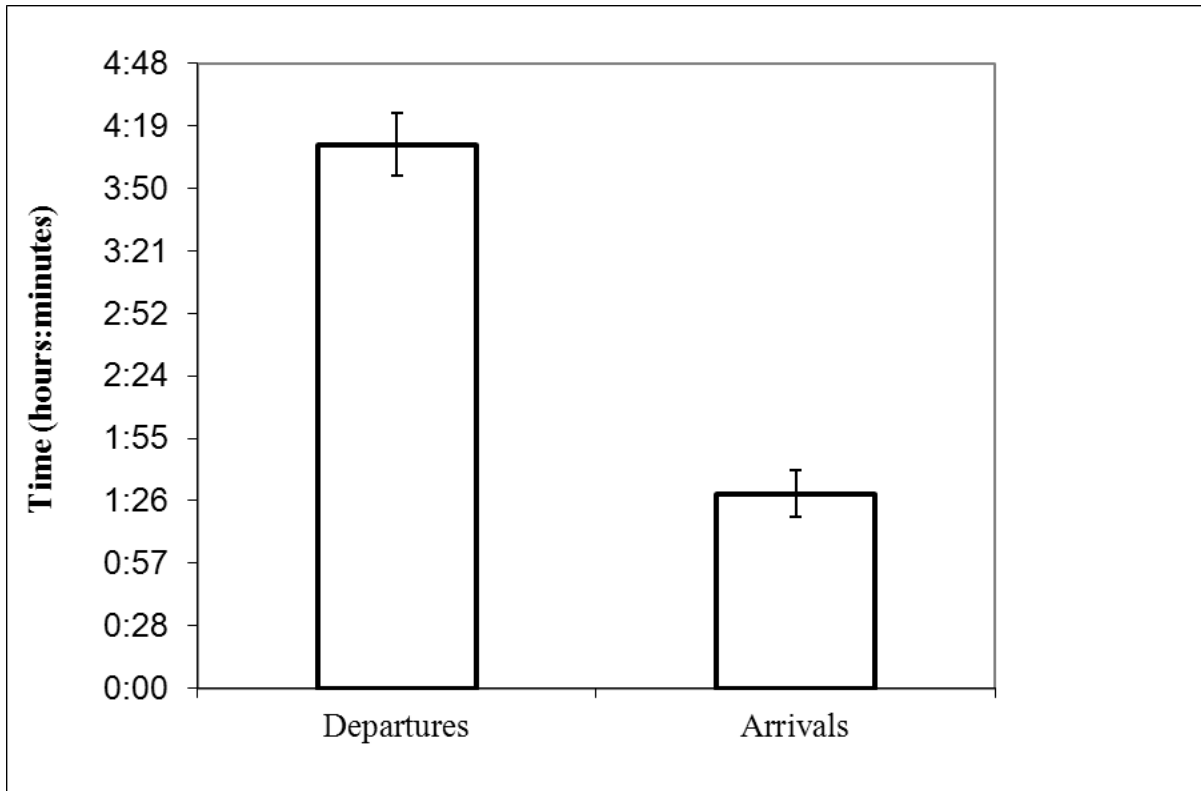


Figure 3.9. Mean (\pm SE) hours between first and last departure and arrival of common terns (*Sterna hirundo*) from nocturnal nest desertion between 2 May and 24 July 2010.

3.2. The effects of nest-site selection and nocturnal nest desertion on productivity

3.2.0. Habitat

The entire colony consisted of 37, 73, and 78 pairs of common terns between 2008 and 2010. Predation caused re-nesting to occur across the three breeding seasons resulting in 53, 99, and 156 initiated nests. Clutch sizes were 2.54, 2.58, and 2.72. Mean incubation length was 28.4 days (SD = 2.64, N = 80) in 2010.

Hatching and fledging success varied across the three breeding seasons and habitats. Terns hatched fewer chicks per nest in cobble (mean = 0.58, SD = 0.95, N = 62) than limestone (mean = 1.88, SD = 1.22, N = 76), north complex (mean = 1.16, SD = 1.27, N = 73) and south complex (mean = 1.82, SD = 1.28, N = 78) over the three breeding seasons ($\chi^2 = 31.41$, df = 3, $P < 0.0001$; Table 3.2 and Fig. 3.10). In 2008, north complex and south complex had the highest hatching success per nest versus cobble and limestone. In 2009 and 2010, south complex and limestone had the highest hatching success per nest versus cobble and north complex.

More chicks were fledged per nest in the north complex (mean = 0.92, SD = 0.98, N = 37) and south complex (mean = 0.69, SD = 1.04, N = 52) versus the cobble (mean = 0.33, SD = 0.69, N = 18) and limestone (mean = 0.35, SD = 0.93, N = 51) over the three breeding seasons ($\chi^2 = 14.03$, df = 3, $P < 0.003$; Table 3.2 and Fig. 3.11). In 2008 and 2010, terns had higher fledging success per nest in north complex and south complex than cobble and limestone habitats. In 2009, terns had lowest fledging success in cobble and similar fledging success per nest in limestone, north complex, and south complex habitats.

3.2.1. Nest-site

Condition indices ranged from 3.57 to 14.40 and variance inflation factors ranged from 1.01 to 1.77. Upon examining the linear combinations of variables, no two variables had large proportions of variance (.50 or more) that corresponded to large condition indices (>10); therefore the models were not affected by multicollinearity (Belsley et al. 1980). Furthermore, variance inflation factors were sufficiently low (<2.5); this measured the inflation in the variances of the parameter estimates due to collinearities that exist among the independent variables (SAS Institute Inc. 2009). Hatching success was not affected by year, standing cover, substrate diversity, and initiation date (Table 3.3.). Fledging success was not affected by substrate diversity and initiation date, but years differed and standing cover had a positive effect (N = 115; df = 1; P = 0.021).

The second set of models suggested a correlation of the duration of nocturnal desertion on hatching success (N = 38; df = 4; P = 0.161; Fig. 3.5) but not fledging success (Table 3.4). Like the first model, standing cover had a positive effect on fledging success (N = 30; df = 4; P = 0.038) and was correlated with nest initiation date (N = 30; df = 4; P = 0.149). However, standing cover had no effect on hatching success (Table 3.5). The duration of nocturnal nest desertion and substrate diversity did not affect fledging success.

Table 3.2. Productivity related variables of common terns (*Sterna hirundo*) in four habitat types in 2008–2010.

2008

Habitat Type	Nests	Eggs	Hatched Young	Fledged Young
Cobble	19	46	8	2–4
Limestone	7	9	4	0-1
North Complex	8	19–21	8	3
South Complex	19	43–44	21	8–9

2009

Habitat Type	Nests	Eggs	Hatched Young	Fledged Young
Cobble	14	31.74*	14	3
Limestone	24	64.58*	41	13–15
North Complex	31	80.32*	40–41	22–24
South Complex	26	69	51	18

2010

Habitat Type	Nests	Eggs	Hatched Young	Fledged Young
Cobble	29	65	14	1
Limestone	45	126	98–100	5–6
North Complex	34	80	37–40	9–10
South Complex	33	83	70	10–13

*There were seven nests of the 98 initiated in 2009 in which clutch size was unknown. The mean clutch size was used for these nests in the analyses.

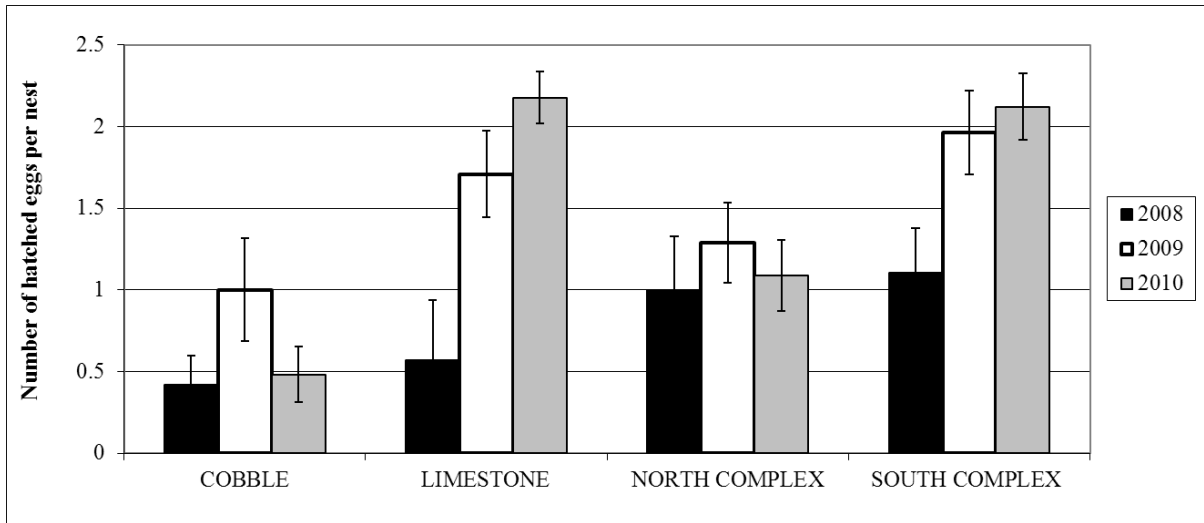


Figure 3.10. Mean (\pm SE) number of common tern (*Sterna hirundo*) eggs that hatched per nest from 2008 to 2010 in four habitat types.

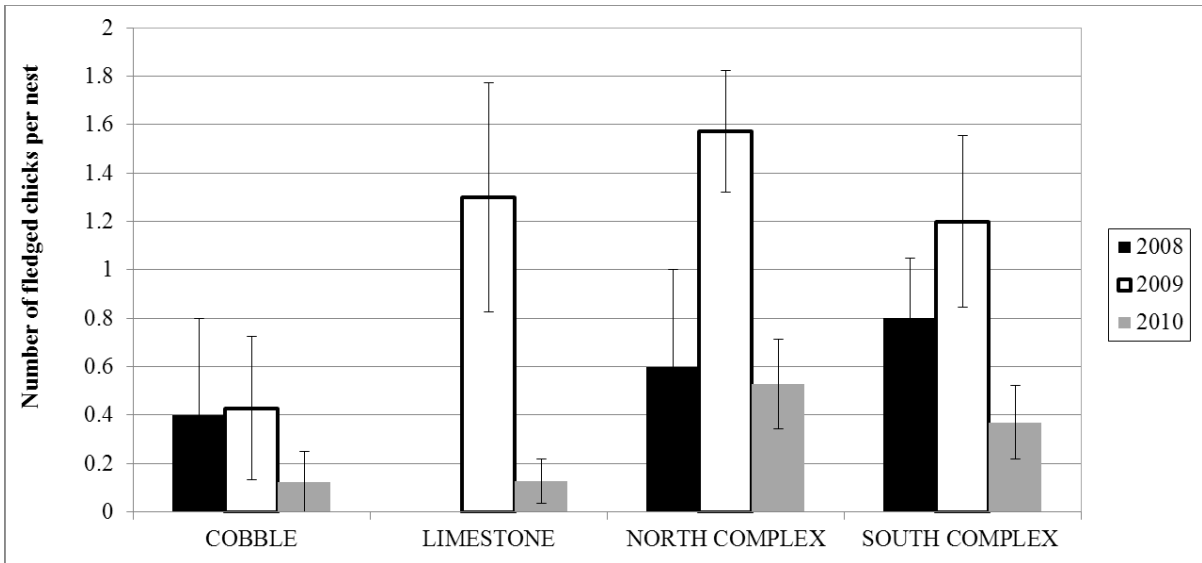


Figure 3.11. Mean (\pm SE) number of fledged common tern (*Sterna hirundo*) chicks per nest from 2008 to 2010 in four habitat types.

Table 3.3. Multiple logistic regression analysis on effect of year, standing cover, substrate diversity, and nest initiation date on hatching and fledging success of common terns (*Sterna hirundo*).

Hatching Success (N = 201)

Parameter	Wald's χ^2	df	P
Year	0.313	1	0.576
Standing Cover	0.251	1	0.617
Substrate Diversity	2.80	1	0.094
Initiation Date	0.628	1	0.428

Fledging Success (N = 115)

Parameter	Wald's χ^2	df	P
Year	11.96	1	0.0005
Standing Cover	5.34	1	0.021
Substrate Diversity	0.983	1	0.322
Initiation Date	0.185	1	0.667

Table 3.4. Multiple logistic regression analysis on effect of duration of nocturnal nest desertion, standing cover, substrate diversity, and nest initiation date on hatching and fledging success of common terns (*Sterna hirundo*) in 2010.

Hatching Success (N = 38)

Parameter	Wald's χ^2	df	P
Nocturnal nest desertion	1.97	1	0.161
Standing Cover	1.52	1	0.218
Substrate Diversity	0.879	1	0.349
Initiation Date	0.007	1	0.935

Fledging Success (N = 30)

Parameter	Wald's χ^2	df	P
Nocturnal nest desertion	0.112	1	0.737
Standing Cover	4.32	1	0.038
Substrate Diversity	0.475	1	0.491
Initiation Date	2.08	1	0.149

CHAPTER 4: DISCUSSION

4.0 Nest-site selection

This study showed that removal of the previous year's vegetation increases the number of common terns that use a habitat. This supports recommendations from Kress and Hall (2004) and Cuthbert et al. (2003), suggesting intensive weed control is necessary at most sites. At the Detroit River colonies, vegetation growth can reach 100% standing cover. This is due to the lack of natural disturbance from waves or ice, as well as the fertile growing conditions, in part from existing soil and thatch, but also guano (Kress and Hall 2004). In New York, terns preferred nest sites that were less concealed than random sites at an interdune area of a barrier beach (i.e., they had less cover above the nest and within 1 and 5 m, were farther from shorter vegetation, had less grass cover, and had greater visibility from above and from 1 and 2 m; Burger and Gochfeld 1988). This may derive from their defense strategy of early alarm calls when a threat is detected, followed by physical defense (Burger and Gochfeld 1991). Presumably, failing to remove the previous year's vegetation at Detroit River inhibits visual detection of threats and obstructs colony defense.

Despite the large difference in substrate between the limestone, cobble, and complex habitats, this study failed to show a consistent chronology in the order of nest establishment between 2009 and 2010 in all but cobble, which was the least preferred because nests were established there the latest, and saturation occurred first. Cobble generally had low standing cover in 2010 (12.3%), and diversity was the lowest of the four habitats in 2009 and 2010. Hatching success in 2008 was lowest in cobble, despite most early nests and the majority of total nests over the season being initiated there. Considering these habitat variables and predation may be linked (Lamp et al. 2003), this study suggests substrate and low

reproductive success during previous years to be the reason this habitat was least preferred in 2009 and 2010.

The principal measure used in this study to determine habitat preference was the order of nest initiation across the four habitat types and nest saturation. The most preferred locations would be used first. Severinghaus (1982) and Richards and Morris (1984) used this measure, concluding that terns sometime aggregate nests around a central point, rather than regularly spaced throughout the available habitat. This study showed that numerous aggregations form across the habitats, with cobble the last to be colonized in 2009 and 2010. Severinghaus (1982) suggests terns place later nests between early nests and do not move out from the aggregation. This may be one reason that there was no consistent chronological order of nest initiation between the four habitats. Cobble seemed to provide fewer preferred places than the other habitats to place nests.

This study was the first to describe intra-habitat variation in substrate preference on a nest-site scale (50 cm X 50 cm). Terns preferred sites within a habitat that were more complex in rock sizes, bare soil, and miscellaneous debris. Limestone and cobble were naturally less diverse than the two complex habitats, and nest preference for diverse sites in limestone was only significant in 2009 when there were fewer overall initiated nests. This study showed nest preference occurred based on characteristics directly at the nest site (50 cm x 50cm), rather than at the general habitat scale (71.4 and 89 square meters). This is perhaps because chick territories are restricted to where their nests are located during the first two or three days (Burger and Gochfeld 1990), so it would be advantageous to place nests directly where chicks have higher survival early during the chick-rearing stage.

Tern preference for more complex nest sites within these four habitats reflects that each habitat is not contiguous in substrate type, but is interspersed with areas of more homogenous cobble. Terns avoid these small areas; furthermore, these data support enriching the existing habitat by adding soil and different size rocks where needed to increase preferred habitat by common terns in this Detroit River colony.

4.1. Nocturnal nest desertion

I predicted that terns would abandon their nests for longer on nights when a heron was detected as found by Arnold et al. (2006). Despite early detections on 30 April and 5 May, the heron was not detected again until 26 May when it began regularly visiting the colony at night. The terns did desert significantly more after the heron was found regularly visiting the colony on 26 May, but I cannot determine if the absence of a predating heron or lower temperatures early in the season caused terns to have less desertion. After this date, terns actually departed longer on nights without a heron detected, suggesting the change in duration of nocturnal desertion was a seasonal shift. Considering desertion was still prolonged to over four hours for terns on nights without a heron prior to 26 May, I conclude that the duration of nocturnal nest desertion is not caused by the presence of a heron on a single night. Instead, temperature and past frequency of disturbance from a predator may have a stronger influence on the duration of desertion. Birds deserted their nests more starting in late May, which suggests night-time temperature may be a more important factor in nest desertion patterns. Terns may desert less when temperatures are consistently low early in the season. Furthermore, data from both years suggest decreased nest attentiveness as the season progressed, possibly reflecting the lower probability of fledging young at the periphery of the season in July.

Nocturnal nest desertion varied widely in frequency and duration. All terns deserted their nests to some degree, but ranged from a mean of 22 minutes to 10.8 hours. Oftentimes, terns were incubating while the heron was in the colony, while other terns were absent.

Other studies have found regular nocturnal nest desertion even on nights when evidence of a predator is lacking (Nisbet 1975; Nisbet and Welton 1984; Holt 1994; and Wendeln and Becker 1999). It appears that once a predator is regularly visiting, the typical response is abandonment of most adults for the majority of the night, whereas most do not depart if a threat is not regular in occurrence. For instance, in a large Massachusetts colony, terns were more likely to depart on nights when a great horned owl was present (Arnold et al. 2006). That study found a mean departure time of 54 minutes, in comparison with terns at Detroit River deserting for a mean of 360 minutes. Furthermore, Arnold et al. (2006) had incubation times of approximately 22 days, while I showed 28.4 days, indicating much longer desertions at Detroit River. I suggest this is because the Detroit River colonies have been heavily predated since they established in the 1990s and have not been productive most years (D. Best personal communication; Norwood 2009; Szczechowski and Bull 2007) as opposed to larger, long-established colonies (Burger and Gochfeld 1991) or where predators are controlled. Furthermore, weather events may be less extreme at the Detroit River. In contrast to other studies (Holt 1994; Morris and Hunter 1976; Nisbet and Welton 1984), I did not find weather events to be a problem for deserted Detroit River tern eggs. However, nest desertion did promote the destruction of eggs from Canada geese (*Branta canadensis*) that would normally not be a threat if an incubating adult were present.

This was the first study to monitor individual nest desertion from a large proportion (35%) of nests in a common tern colony (see Zimmerman 2008 for a similar study of least

terns). Like Arnold et al. (2006), nocturnal desertion was more variable than previously reported (Marshall 1942; Nisbet 1975; Holt 1975; Southern and Southern 1979). In addition, terns did not all depart and arrive at the same time. The behavior at the Detroit River was characterized by more irregular departure where the mean time between the first and last departure was 4.17 hours, while difference in arrivals was 1.48 hours. This suggests that some terns wait for an actual disturbance, as suggested by Arnold et al. (2006), but not all since departure times often matched. I suggest arrival times were more constricted because they were dependent upon sunrise, which is relatively consistent and allows resumption of physical defense of the colony (Southern and Southern 1979).

4.2. The effects of nest-site selection and nocturnal nest desertion on productivity

Habitat influenced hatching and fledging success differently, depending on what destroyed eggs and chicks each year. Overall, cobble had the lowest hatching and fledging success. These results can be explained by considering the types of pressures on eggs and chicks across the three breeding seasons. In 2008, most of the failed eggs were due to nest desertion from a mink (*Neovison vison*), which was seen in the colony provisioning tern chicks to its young in a den found along the water's edge. That year, hatching success was low in general, with the two complex habitats having the highest hatching success. In 2009, hatching success was limited mostly by a raccoon (*Procyon lotor*) as indicated by the type of egg breakage (Kress and Hall 2004; but see Holt 1994) and successful trapping of one individual, after which no egg predation and high fledging success occurred. The raccoon egg predation was highest on the north side of the pier, where the north complex and cobble are located, and conceivably offers easier access to a swimming raccoon. Tern nests are close to each other, so eggs from multiple nests are readily eaten by a predator once one is present

(Moore et al. 2000). Likewise, in 2010, tern nests had lowest success on the same two north pier habitats because cameras showed Canada geese (*Branta canadensis*) consumed and stepped on eggs at night from nests where adult terns temporarily abandoned. Roosting geese were rarely detected on the two south habitats (south complex and limestone), presumably only because it served as a less accessible night-time roosting area, because it was more elevated from the water's edge and surrounded by a fence and rope-lattice structure.

Fledging success was low in cobble all years. In 2008, most chicks were known to be killed by a single mink, which took chicks from all habitats, but most notably from the limestone habitat. (The mink den was found near the water's edge in brush beside the limestone habitat). Predators of chicks in 2009 were not identified, but I suspect the raccoon took most of them, considering chick survival increased once a raccoon was removed. Predation from it was highest in the cobble, which was also where I suspect the raccoon was entering the colony. In 2010, all predation on chicks was attributed to one black-crowned night heron (*Nycticorax nycticorax*) as shown by continuously-running cameras and visually monitoring some nights from an observation blind. The heron appeared to have the least success in capturing chicks in the two complex sites. I suggest that the diversity of hiding spots available within the two complex habitats, in combination with contiguously dense vegetation, may have made chicks less accessible by hiding between or behind larger rocks and low, dense cover. No such opportunity existed in the more uniform topography of the limestone habitat where standing cover was high, but clumps of low, dense vegetation were more sporadic. Furthermore, standing cover at the nest site had a positive impact on fledging success. This likely occurred because chicks remain near the nest-site for the first two to

three days (Burger and Gochfeld 1990) and most stay relatively close throughout the chick stage (personal observation).

The availability of high standing cover exceeding what terns prefer to nest within may increase chick survival during stochastic predator events, but these areas do not offer preferred nesting habitat because of the excess of vegetation. Therefore, one management strategy may be to allow highly vegetated areas to exist as refugia for chicks from nearby nests, even though tern nests will not be placed in the high vegetation. Such a strategy would not completely mitigate the effects of mammalian predators with a keen sense of smell.

Cook-Haley and Millenbah (2002) suggest that sites where there may be too much vegetation (about 40% standing cover) to support a high density of tern nests may still be more successful where there is frequent exposure to predators. However, on natural sites where the frequency of predation may be less, terns have higher success in lower amounts of vegetation (10–30% standing cover) than higher amounts. This suggests that too much vegetation may be detrimental at natural sites. The authors attributed most egg loss at an artificial site to a long-tailed weasel (*Mustela frenata*) in areas where nests were the most dense, but had the least vegetation. My study suggests that high nest density in areas where the predator happens to frequent may lead to the lowest egg survival after a predator gets into an area of the colony as in Moore (2000). Long-tailed weasels and mink employ an erratic hunting pattern (Powell 1973, 1982) with a highly developed sense of smell, with sound as an important tool in hunting (King and Powell 2007). This study suggests that more hiding places provided by topography, in concert with contiguous vegetation density, not strictly percent cover as measured at a human-height, may promote the highest hatching and fledging success where some predation will regularly occur.

CHAPTER 5: SUMMARY AND CONCLUSIONS

In conclusion, this study showed that common terns (*Sterna hirundo*) prefer habitats that have had dead standing cover from the previous year removed. Terns had the least preference for nesting in homogenous cobble (13 to 25-cm diameter) areas when given a choice of small limestone chips (2.5-5.0 cm) or a substrate that was more diverse in rock size, soil, and non-vegetative debris. Cobble had fewer preferred nesting locations as evidenced by nest saturation occurring earlier. In addition, within a habitat type, terns choose nest-sites (as measured in this study by a 50 cm X 50 cm area) that are more diverse in stone size, soil, and non-vegetative debris than what is available. Hatching and fledging success was highly variable between years was influenced by habitat differently, and depended on the type of predator. Mink (*Neovison vison*), raccoon (*Procyon lotor*), and black-crowned night heron (*Nycticorax nycticorax*) reduced reproductive success over three years independently. Cobble was the least productive for hatching and fledging success across the three years. Raccoon predation was highest on the north complex and cobble, presumably because that was where the raccoon was entering the colony, not necessarily because of habitat features. Heron predation was highest in limestone and cobble, suggesting terns have a greater ability to hide in the two complex habitats where there may be more variable topography, higher camouflaging opportunities, and more contiguous low vegetation. Standing cover at the nest site had a positive effect on fledging success but not hatching success. Last, this study showed nocturnal nest desertion of common terns to be prolonged (mean of 6.00 hours) and widely variable between pairs of terns and even within tern pairs, but it was not any longer on nights when a heron was detected versus nights when

one was not detected once the heron began regularly visiting the colony in late May. Terns deserted their nests less synchronously than when they arrived before dawn, suggesting some birds may wait for disturbance to occur, then return shortly before dawn when they can more safely resume physical defense of the colony.

Managers of common terns should invest in annual vegetation control at artificial sites in the Detroit River. There would be higher preference, hatching, and fledging success by enhancing areas of cobble (13 to 25-cm diameter) to more diverse substrate; fledging success may increase by adding locations for chicks to hide and promote approximately 30-40% standing cover during the latter stages of incubation. Despite enhanced areas offering some additional safety for chicks, predation can still be excessively high when predators that effectively use sound and/or scent are impacting the colony. Nocturnal nest desertion at the Detroit River exposes eggs to threats that would otherwise not lead to egg destruction, such as Canada geese (*Branta canadensis*). The data provide support for the use of continuously-running night cameras to monitor predation and to employ proactive predator control if common terns are to have higher reproductive success in the future at the Detroit River.

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