FORAGING ECOLOGY OF BLACK-CROWNED NIGHT-HERONS (*NYCTICORAX NYCTICORAX*) IN THE NEW YORK CITY AREA

by

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Abstract

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Andrew James Bernick

Advisor: Professor Richard R. Veit

Over 1,700 pairs of colonial wading birds (i.e., herons, egrets, and ibis) breed and forage in the industrialized ecosystem of metropolitan New York City (NYC). Wading bird colonies are located on 7 islands that lie between western Staten Island and Long Island Sound. The Black-crowned Night-Heron (BCNH), a mainly nocturnal forager, is the numerically dominant breeding heron in these colonies, and has been undergoing population declines both locally and region-wide since the mid-1990s. My objective was to determine how BCNHs forage in NYC's urban estuarine, freshwater, and terrestrial environments. From March-September 2002-2004, I conducted weekly night surveys on Staten Island, NY to describe BCNH foraging flight patterns from an active breeding colony, abundance and foraging success in 4 habitat types (salt marsh, shoreline, freshwater, terrestrial); and prey availability. I found that: (1) individuals flying from a major breeding colony followed similar flight paths regardless of date or tide; (2) there was a tradeoff between prey size and capture rate, where freshwater foragers captured few large prey while salt marsh and shoreline foragers captured more smaller prey; (3) foraging techniques differed among habitats; (4) activity level was constant through the entire night; and (5) prey composition of nestling diet reflected what was available at foraging sites.

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INTRODUCTION

Background

Most birds are diurnal and conduct life-sustaining activities, such as breeding and foraging, during daylight hours (McNeil et al. 1993). Whereas regular nocturnal activity is less commonly observed in avian species, it is present among many groups of waterbirds, including the Ardeidae. The Black-crowned Night-Heron *Nycticorax nycticorax* is an ardeid present throughout North America, with large concentrations located on the mid-Atlantic and Louisiana coasts (Kushlan and Hafner 2000, Spendelow and Patton 1988).

Black-crowned Night-Herons are flexible both in terms of diet and nesting requirements, and also in diel activity throughout the year (Davis 1993). In the 1970s, increases in nesting populations of Black-crowned Night-Herons and other wading bird species were noted in urban areas of the northeastern U.S., including the New York/New Jersey (NY/NJ) Harbor estuary (Buckley and Buckley 1980, Blanchard et al. 2001) in New York City (NYC). In the NY/NJ Harbor, increases in nesting activity were first noted in island colonies the Arthur Kill and Kill van Kull of northwestern Staten Island (Richmond County, NY). Rather than a novel colonization, this increase represented a resurgence of breeding activity in the Staten Island area, as historical data indicates that Black-crowned Night-Herons were present as a nesting species on mainland Staten Island since at least the mid 19th century, and subsequently disappeared as nesters by the mid 1940s, due largely to pressures of residential and industrial development (Davis 1886, Allen 1938, Peterson et al. 1985), and likely due to the effects of DDT (Anderson and Hickey 1972) and other contaminants obtained from their prey base.

As increased residential and industrial development has brought wading birds in closer contact with humans throughout the world, understanding how wading birds negotiate and survive in urban systems has become critical to waterbird conservation (Kushlan et al. 2002). In several cities in the northeastern U.S., wading bird colonies have arisen within highly industrialized landscapes. Wading birds nesting in these areas are exposed to a range of unique conditions that could influence their health and stability, including artificial light sources, increased food sources due to human behavior, potentially harmful levels of inorganic and organic contaminants present in prey, and human impact on nesting and foraging through direct and indirect practices (i.e., nesting colony disturbance, construction on or near foraging sites).

Objectives

To investigate the nocturnal foraging ecology of Black-crowned Night-Herons, I studied four aspects of Black-crowned Night-Heron nocturnal foraging ecology on Staten Island and the surrounding coastal waters of Upper and Lower NY Bay, Raritan Bay, Arthur Kill, and Kill Van Kull from 2002 to 2004: (1) foraging flight direction from Hoffman Island, a mixed-species breeding colony on the southeastern shore of Staten Island, (2) relative abundance in freshwater, marine, and terrestrial habitats (3) foraging behavior, strike rates, and capture efficiency, and (4) aquatic prey availability at selected foraging sites.

Chapter I provides an overview of the study, including an historical review of Black-crowned Night-Heron breeding activity in the NYC area (with particular attention to Staten Island records), and a description of the study site in Staten Island. Chapter II describes foraging flight of Black-crowned Night-Herons to and from Hoffman Island, and examines the relationship between flight direction and patterns of potential foraging habitat use during the breeding season. I conducted site surveys and focal observations on unmarked Black-crowned Night-Herons in marine, freshwater, and terrestrial habitats to characterize differences in relative abundance, foraging behavior, prey capture efficiency, and prey selection by broad habitat type, and present this information in Chapter III. In Chapter IV, I describe relative prey abundance in marine, freshwater, and terrestrial habitats in the vicinity of Staten Island. I then related these factors to: (1) observations of direct prey capture of Black-crowned Night-Heron, and (2) regurgitant samples collected from nestlings on Hoffman Island. I summarize the implications of this study in Chapter V, and recommend strategies for defining and conserving critical foraging habitat in urban systems in general and the Staten Island area in particular. Appendix A contains aerial images and boundaries of all survey sites on Staten Island, and Appendix B is a list of all common and scientific names of flora and fauna noted in the text.

For the purposes of the historical description in Chapter I, I define the NYC area as the boroughs of Brooklyn, Bronx, Manhattan, Queens, and Staten Island; coastal Westchester County, northeastern NJ, and all surrounding waterways 'Long Island' includes Nassau and Suffolk counties, and 'inland NY' represents counties in NY State outside of NYC.

In Chapters II through V, I assess Black-crowned Night Heron foraging activity on Staten Island, NY and surrounding water bodies.

I selected Black-crowned Night-Herons for this study: 1) Due to their local abundance, as they comprise approximately 50% of the total wading bird population in the NY/NJ Harbor (Kerlinger 2004, Bernick 2005a); 2) Because they have a flexible diet and feed in a broad variety of ecosystems, the relative importance of different ecosystems to their foraging activity could be compared; 3) Being the major nocturnal wading bird species active on Staten Island, they provide a useful comparison to any other wading bird (e.g., Great Blue Heron, Great Egret) that occasionally forages at night, for example near streetlights; 4) Since NYC is heavily contaminated, I sought evidence for differential habitat use that might be influenced by pollutants.

CHAPTER I BLACK-CROWNED NIGHT-HERONS IN THE NEW YORK CITY AREA

New York City (NYC) is a highly urban environment with over 8 million residents. Within this landscape, approximately 1,700 pairs of wading birds (i.e., heron, egret, and ibis) currently breed and forage throughout NY/NJ Harbor and surrounding waterways (Table 1). Nesting species include Great Egret, Snowy Egret, Glossy Ibis, Little Blue Heron, Tricolored Heron, Green Heron, Yellow-crowned Night-Heron, Cattle Egret, and the numerically dominant Black-crowned Night-Heron. These species currently breed in single- and mixed-species assemblages on abandoned or infrequently used islands in the NYC area (Fig 1). Yellow-crowned Night-Herons and Green Herons may nest alone or in small groups on the mainland, separate from other colonies. The Black-crowned Night-Heron, a cosmopolitan species that predominate in most urban colonies along the Atlantic coast of the U.S., is an opportunistic species with a varied diet (Davis 1993).

Over the past 30 years, improvements in night vision optics have allowed direct observation of nocturnal activities in birds, including foraging activity of Black-crowned Night-Herons (Watmough 1978, Black and Collopy 1982, Fasola 1984, Robert et al 1989, Endo and Sawara 2000). Outside of the breeding season, Black-crowned Night-Herons forage mainly at night, and in coastal areas feed more often at low tide (Black and Collopy 1982, Robert et al. 1989, Davis 1993); and (2) during the breeding season, Black-crowned Night-Herons forage, rest, care for nestling, and engage in other activities evenly throughout day and night (Williams 1979, Fasola 1984).

Most previous studies of night-heron activity patterns were conducted in non-urban systems, including agricultural regions with relatively small human populations (Pavia, Italy-Fasola 1984; northeastern Japan-Endo and Sawara 2000), wildlife preserves (Camargue, France-Watmough 1978), and other areas with relatively low-density human presence (Chacopata Lagoon, Venezuela in Robert et al. 1989; Cedar Key, Florida in Black and Collopy 1982). Therefore, I wanted to learn how Black-crowned Night-Heron behavior might differ in an urban setting like NYC.

Over the past twenty years, patterns of wading bird foraging behavior and ecology have been examined in NY/NJ Harbor through focal observation at foraging sites, flight line observations, and repeated site surveys the quantify habitat use and energetics (Bernick 2004, Brzorad et al. 2004, Maccarone and Brzorad 1998, Maccarone and Brzorad 2000, Maccarone and Parsons 1994, Parsons 1994). Here, species differ in habitat use and foraging methods among habitats. For example, Black-crowned Night-Herons use a variety of estuarine, freshwater and terrestrial habitats whereas Snowy Egrets and Glossy Ibis are tied to tidal estuaries. Furthermore, it is possible that local colonies may sort by sub-region. For example, herons nesting in Jamaica Bay, Staten Island, or Long Island Sound may each use unique, non-overlapping foraging areas (Nagy 2005).

Strike rate and capture success of diurnal wading birds in the Staten Island area differ between marine and freshwater habitats (Maccarone and Brzorad 1998, Maccarone and Brzorad 2000, Maccarone and Parsons 1994). Most studies focused on diurnal species, or have been conducted in daylight hours during the breeding season. Observations of nocturnal species, especially Black-crowned Night-Herons, have not previously been carried out. Thus, it is my goal to supplement what is know about wading bird foraging ecology in NY/NJ Harbor through analysis of data collected at night.

Historical review of Black-crowned Night-Heron breeding activity in the NYC area, 1844 to present

Black-crowned Night-Herons have been common as breeders in the NYC area and Long Island since at least the 1840s (Giraud 1844). Evidence of breeding Black-crowned Night-Herons in the NYC area or Long Island prior to that time is scarce. For instance, no Black-crowned Night-Heron bones have been identified at Native American middens to date (A. Cantwell pers. comm.) As summarized below, anecdotal records of food sold in public markets and personal journals of naturalist or biologists of the period also yield little information on historical presence of Black-crowned Night-Herons in the NYC area.

Two common diurnal wading birds in the NYC area, the Great Blue Heron and Green Heron, were commonly encountered in markets of the 19th century, although the former was considered ‘more for the curious than for the table’ (De Voe 1867). Black-crowned Night-Herons were ‘seldom seen in our markets, yet…often shot and eaten’ and that ‘many years ago, they appeared to be more plenty than they are at present’ in the markets of New York, Brooklyn, Philadelphia, and Boston (De Voe 1867). It is unclear whether this indicates a lack of market suitability due to taste, since their flesh has been described variously as ‘rank and fishy’ (Simon 1944) to young birds being ‘quite as good for eating…being tender, juicy, and fat, with very little of the fishy taste of many birds which, like them, feed on fishes and reptiles’ in Audubon’s ‘Birds of America’ (1840).

At any rate, the relative scarcity of Black-crowned Night-Herons in public markets as described in De Voe implies a reduced population size due to over-hunting in the mid 19th century.

By the early 1920s, while Black-crowned Night-Herons were considered common in coastal marshes and as an uncommon, local summer resident inland (Griscom 1923), the location and size of nesting aggregations were not well documented for coastal or inland NY. The only breeding colony identified by name in Griscom (1923) was in Boonton, NJ (~50 pairs). Allen (1938) counted 3,400 pairs in 20 Long Island heronries in 1935, many of which were located inland. By the 1970s, few inland colonies remained (P. Capainolo, pers. comm.), and colonies were restricted to the southern coast, especially the barrier beaches and bay islands (Buckley and Buckley 1980).

Bull (1964, 1974) described Black-crowned Night-Herons as common to abundant residents along the coast, but indicated that large nesting aggregations in the early 1900s such as those at Great Neck, Sandy Hook and Gardiner's Island had declined or disappeared. For example, the Great Neck colony (Great Neck, Nassau Co.) declined from ~1,000 breeding pairs in 1934 to ~600 breeding pairs in 1951. This dramatic decline was likely due to human development in Nassau County, where the human population doubled each decade from ~126,000 residents in 1920 to over 1,300,000 residents in 1960 (U.S. Census data). By 1960, the former Great Neck colony had been almost entirely developed as residential property. The colony at Sandy Hook (Monmouth Co., NJ), estimated at 700 pairs in 1957, disappeared by the early 1970s (P. Kerlinger, pers. comm.). The Gardiner's Island colony (off eastern Long Island) declined from ~1,500 pairs in 1881 to ~250 pairs in 1930, and ~100 pairs in 1970. These declines, particularly those between the mid-1950s and 1970, may well have been due to acute DDT exposure. Other nesting species on Gardiner's Island experienced similar precipitous declines during this period, such as the Osprey. Black-crowned Night-Herons breeding in Long Island decreased from ~3,000 pairs at 18 to 20 colonies in the 1930s (Cruickshank 1942) to 430-760 pairs at 23 colonies in the mid-1970s (Buckley and Buckley 1980).

Though night-herons nested at multiple sites on Long Island between 1950 and 1974, nesting activity in the NYC area was limited to Jamaica Bay (on Ruffle Bar and Canarsie Pol), Lawrence Marsh, and in Kearny, NJ in the Hackensack Meadowlands (Bull 1974, Buckley and Buckley 1980). In the 1970s, Black-crowned Night-Heron colonies relocated to other parts of NYC, first in the waterways surrounding Staten Island (described below), followed by other colonies in western Long Island Sound, Pelham Bay, coastal Westchester County, and Lower NY Harbor (Buckley and Buckley 1980, Parsons 1990, Kerlinger 2002). Colonies found during that period were most likely the result of recolonization events commencing in the mid to late 1970s, though it is possible some colonies had been overlooked. For instance, Buckley and Kane (1975) surmised the existence of an undetected roost or colony in the vicinity of Riker's Island in western Long Island Sound. In 1978, the final year of a 5-year helicopter census of Long Island waterbird colonies, Buckley and Buckley located the predicted colony (dominated by Black-crowned Night-Herons, Snowy Egrets, and Cattle Egrets) on South Brother Island, adjacent to Riker's Island. Based on its size, they described it as 'well established.' More recently, I made shore observations at Mill Rock, a small island located in the Hell Gate at the confluence of the Harlem River, East River, and Long Island Sound. This indicated the presence of a small nesting colony of Black-crowned Night-Herons there in 2003 and 2004 (Bernick unpub. data). A colleague and I visited Mill Rock in October 2004 and found 13 recently constructed Black-crowned Night-Heron nests. The following year, I found 43 active Black-crowned Night-Heron nests at Mill Rock (Bernick 2005a). Therefore, it is possible that sizeable colonies, particularly those of dark wading birds not conspicuous in aerial or shore-based surveys, have been overlooked.

Between 1974 and the early 1990s, Black-crowned Night-Heron numbers in the NYC area were relatively stable compared to other wading bird species such as Cattle Egret and Glossy Ibis (NYS-DEC data). Populations in Long Island grew to 1,187 pairs at 23 colonies in 1993, approximately half of their mid-1900s level (Sommers et al 1994). Since 1995, however, the species has been declining in the NYC area, Long Island, and inland NY (Kerlinger 2004, NYS-DEC data). Today, Black-crowned Night-Herons are the most abundant colonially nesting wading bird in the NYC area and Long Island. In May 2004, approximately 841 active Black-crowned Night-Heron nests were found in 7 NY/NJ Harbor colonies (Kerlinger 2004), comprising approximately 50% of the total wading bird breeding population in NYC; 439 Black-crowned Night-Heron nests were found in Long Island (NYSDEC-LICW, unpub. data).

Black-crowned Night-Herons currently number 50,000 breeders in North and South America, but are declining and are designated “a species of moderate concern” (Kushlan et al. 2002). Regional declines for Black-crowned Night-Herons and other wading bird species have been identified throughout the northeastern U.S. (Parsons et al. 2001). Regional declines are strongly influenced by exposure to environmental contaminants at foraging areas (Matz and Parsons 2004, Parsons et al. 2001). It is also likely that mammalian and avian predation also play an important role in colony abandonment.

The sustained colonization of Black-crowned Night-Herons and other wading birds in the Harbor is often attributed to improved conditions since the enactment of the Clean Water Act in 1972; estuarine fish populations have certainly increased dramatically since this time (Steinberg et al. 2004). NY/NJ Harbor also provides a number of relatively inaccessible, predator-free islands for breeding. However, habitat loss and development elsewhere may have forced wading birds to seek nesting and foraging habitat in NYC’s industrialized harbor, with potential deleterious effects to long-term productivity. It may be that the cumulative effects of contaminants on nesting success are important factors in the observed patterns of colony abandonment in the Staten Island area (i.e., in the Arthur Kill-Kill Van Kull, Ch. I).

For instance, white blood cell counts, an index of immune function, differ statistically among Black-crowned Night-Heron nestlings reared at different colonies, and these nestlings are thought to be fed prey from different locations in NY/NJ Harbor (Newman et al. 2007). If adults feed contaminated prey items to nestling birds, there exists the potential for negative health consequences to nestlings, and poor fledging rates. Nestling exposure to contaminants has been documented in NY/NJ Harbor and other urban areas, and contaminants may act as stressors through compromised immune systems, neurological impairment, and reduced reproductive success (Rattner et al. 2000, Parsons et al. 2001). For instance, organophosphate and carbamate contamination may affect levels of the neural enzyme cholinesterase, and thus make nestlings more susceptible to parasites through reduced nest attendance, ultimately reducing the rate of reproductive success (Parsons et al. 2001).

Nesting habitat and location of breeding aggregations

Prior to their precipitous decline in NYC after 1950, Black-crowned Night-Heron breeding colonies were found in both mainland and coastal areas, particularly in wooded swamps (e.g. Red Maple swamps), mixed deciduous woodlands near water, early successional forests (e.g. Black Cherry, Eastern Red Cedar), and thickets (e.g. Poison Ivy, Cat Briar, Bayberry).

Colonies were subject to a variety of pressures, from hunting and egg poaching (W.T. Davis unpub. data, Bull 1964) to habitat destruction resulting from industrial or residential development (Marcotte 1998) to the prevalence of DDT obtained from prey and producing disastrous effects on reproductive success due to eggshell thinning (Anderson and Hickey 1972). Other top level avian species present in the region, such as Bald Eagles, Ospreys, Peregrine Falcons, and Cooper’s Hawks experienced precipitous declines in or extirpation from NYC and Long Island (Osprey, Cooper’s Hawk), NY State (Bald Eagle), or the eastern United States (Peregrine Falcon), due to increased use of DDT following World War II (Schriver 1969, Bull 1974, Spitzer 1978). Metabolites of DDT collecting in tissues interfere with eggshell production, leading to well-documented effects in the aforementioned species. Since the ban on DDT use in the United States in 1972, most of these species have recovered in the NYC area, through reintroductions, management, or natural recolonizations.

The location of Black-crowned Night-Heron colonies changed substantially with their resurgence around the mid 1970s, with all nesting colonies in NY/NJ Harbor presently located on islands (Table 1, Fig 1). Nest site locations have remained fairly constant. The history and provenance of these islands is rich and varied (see McDonald 2002, Seitz and Miller 1996, and Black 1981). They were either uninhabited (e.g. Goose Island, Canarsie Pol), or formerly used as quarantine islands (e.g. Hoffman, Swinburne, and North Brother Islands), in the ship-building industry (e.g. Shooters Island), or former salt meadows later used as dump sites for shipping channel dredge material (e.g. Prall's Island, Isle of Meadows). Two additional islands are privately owned, one currently unused (e.g. South Brother Island), and the other partially used for recreation throughout the year (e.g. Huckleberry Island).

Black-crowned Night-Herons on Staten Island

Staten Island (Richmond Co., NY) has been populated by humans for approximately 11,000 years, following the subsidence of the Wisconsonian glaciers. Evidence of Paleoindian implements (e.g. Clovis fluted projectile points) has been uncovered at several sites on Staten Island, including Port Mobil (Cantwell and Wall 2001). Further evidence, such as implements and food items from storage and waste pits, confirm Native

American habitation on Staten Island from the Archaic (10,000 years BP) through European contact in the 1600s (Skinner 1909, Cantwell and Wall 2001). To date, no wading bird bones have been identified from NYC area archaeological sites (A. Cantwell, pers comm.), though the diversity of habitats (including woodland swamps and coastal thickets) on Staten Island during this period would have provided suitable nesting and foraging habitat for Black-crowned Night-Herons and other wading birds (Greene 2001). The first permanent European community was established at "Oude Dorp" (currently South Beach) in 1661 by Dutch and French Huguenot settlers. From the surrender of NY to the English in 1664 to the period following the Revolutionary War, the island supported a sparse (3,827 residents in 1790, U.S. Census data), relatively pastoral community engaged in farming, maritime trades, or commercial activities. The island's human population grew more rapidly in the mid 1800s following the industrial revolution (38,991 residents in 1880, U.S. Census data), though its growth lagged in comparison to other parts of NYC due mainly to its isolation. Industry (i.e. tanneries, breweries, brick factories) became more common in the mid 1800s, though farming (particularly of salt hay) and oystering remained the primary industries through the 1900s. Encouraging further commercial and residential development were railways along the north and south shores built between 1851 and 1885, and a commercial rail bridge connecting Howland Hook and Elizabeth, NJ in 1889.

Records of Staten Island's natural history, including those of Black-crowned Night-Heron activity, were first compiled by local naturalist and entomologist William T. Davis (1862-1945), who recorded data on Black-crowned Night-Heron nest location, behavior, and human disturbance between 1886 and 1924 (W.T. Davis, unpub. data). Davis alternately referred to the birds he observed as ‘Night-Herons’, ‘qua birds’, ‘quawks’, ‘bitterns’, or ‘bitt’runs’, which are all common or vernacular terms for Black-crowned Night-Herons. This leads to some confusion, as American Bitterns also nested in small numbers on Staten Island at the time. For instance, one observation he made from the new railroad trestle from Howland Hook to Elizabeth, NJ in northwest Staten Island was described:

> *At dusk the qua birds (bitterns) fly across the meadows in some numbers, occasionally two or three together. As they fly they utter their quaint cries, and in the thickly-wooded lowlands their voices occasionally sound like the barking of a puppy. It is a particularly sharp quck, quck. After dark they fly over the open spaces in the woods and it is then, at late twilight, that those who are near enough to shoot the poor birds as they pass over, for their flight is slow. I heard the report of a gun, often repeated, in the distance, and mentally exclaimed “there dies a bittern and life goes out of those large yellow eyes”. But I believe they are good to eat, so humans have some excuse after all.*
> (W.T. Davis’ personal journal, 20 Aug 1889)

His description of behavior, habitat, and vocalization in this case indicates that he was unquestionably observing Black-crowned Night-Herons. In most instances, regardless of the vernacular term he used, Davis provided enough description to make a positive identification.

In addition to his direct observations, Davis collected many anecdotal records from local residents during his travels around Staten Island; many are vague in terms of location, or species of wading bird involved, but they do indicate that humans made frequent visits into nesting aggregations for hunting, egg collection, and other purposes. An entry made on 10 November 1888 described an interesting account, where an old man from Rossville told him that when he was a boy (presumably in the early 1800s) 'the white herons used to be plentiful on the marshes by the great kill' (possibly Great or Snowy egrets, which were occasional summer and fall visitants to coastal Long Island) and also of a man from Lake Homestead who 'had gone back of Richmond and got some Black-crowned Night-Heron eggs which he placed under a hen and hatched. He reared the birds, which used to sit about his house and on his bed posts. When the old man died his son killed the birds and ate them.'

Between 1886 and 1924, Davis described 14 colonies and roost sites on Staten Island (Table 2), most of which were located in undeveloped woodland swamps at both coastal and interior locations. He recorded his first observation of unoccupied Black-crowned Night-Heron nests in January 1886:

> *I went to the New Dorp station for the weather was fine, and from there to the swamps in the interior of the island. There was considerable snow last evening of the moist character, and all day long it has hung on the trees producing a most beautiful effect. We heard a long time*

ago, upon the authority of a negro cook, that a great heron used to breed in one of the swamps on Staten Island, in numbers. Recently I was informed by Matthew Taylor that a friend had told him a story to the same effect, and that afterward he had found the locality and an egg or two, and saw the birds. I was interested, and today I went to find the locality. When I had arrived near the place where I thought the nests ought to be, I inquired of some of the people in the neighboring houses concerning the birds, for I had heard that the Italians who were employed on the Cross Island Railroad [Founded by Cornelius Vanderbilt, with construction beginning in 1851] *used to eat their eggs in large numbers. I was directed to Mr. Austin Dupuy, who did a great deal of hunting, they said, and knew all about the native animals. I knocked at Mr. Dupuy's door and after he had kindly brushed the snow off of me, I told him all about myself and my desires, and he in turn gave me much interesting information. He said that the birds built a little way back in the woods and that the Italians ate a great many of their eggs at the time they were employed on the R.R., and his boy also stated that some of the neighbors used to collect the eggs, break them up and give them to the cows. Mr. Dupuy, who has lived in the vicinity all his life, says that the birds came to the spot only a few years ago and that they make a great noise on occasions he thinks they have been about driven away by the bad treatment which they have received. He called them "quacks" and I see the name in Jordan's* [David Starr

> Jordan's 'A Manual of the Vertebrate Animals of Northern United States' (1876)] *as "Squawk"; Night-Heron. His wife informed me that they were particularly noisy in the mornings…I went out with two of his boys, who were remarkably quick in seeing squirrel tracks in the snow, to look at the nests. They were indeed very plentiful, I counted seventeen without moving from the spot where I stood. They were in oak trees and placed quite high up, and in some trees there were two and three nests.* (W.T. Davis' personal journal, 31 Jan 1886)

Though Davis was observing these nests during the non-breeding season, his entry implies that Black-crowned Night-Herons were breeding in the vicinity of New Dorp on the southern shore of Staten Island as early as the 1850s, but subsequently abandoned the area due to egg predation and disturbance by humans. Davis returned to this site in spring of 1886 and 1887 and found no evidence of breeding activity. Other small colonies of Black-crowned Night-Herons along the west and north shore of Staten Island seemed to persist through 1910.

Between 1888 and 1924, Davis made numerous observations of Black-crowned Night-Heron foraging flight patterns, mainly of those heading towards Newark Meadows (i.e. NJ Meadowlands) from roosts or breeding areas along the north and west shores of Staten Island. He also observed crepuscular foraging behavior, as in:

> *…after daylight was gone, the fish in the creeks kept up a constant splashing and I noticed many dead in the little grooves…no wonder then the Night-Herons, of which I saw one and heard another "qua" after it was too dark to see, when the little fish fairly jump into their mouths.* (W.T. Davis' personal journal, 28 June 1889)

Davis made numerous entries on hunting of Black-crowned Night-Herons, particularly along the north and west shore. At 'the Doons' (western Staten Island), he noted that 'gunners [are] still hunting the Qua birds…two birds flying slowly over the woods when a gunner below discharged his piece and one of the birds turns in the air with a start and flies most rapidly in the other direction….it was interesting to see their behavior, whether or not the gun was aimed at them' (W.T. Davis' personal journal, 6 Sept 1889).

Davis' final spring observation was made on 27 May 1907, of 2 individuals flying northwest over the Kill Van Kull towards the Newark Meadows. Davis wrote that 'these birds add much to the dusk and gloom of evening and I regret that they are killed so often….they are gradually disappearing from the island…they at present bred in some private grounds and so in a measure are protected'. As was occurring elsewhere in the NYC area and Long Island, increased contact between mainland breeding Black-crowned Night-Herons and humans through residential development and hunting caused a discernable decline in the size and number of breeding colonies of Black-crowned Night-Heron on Staten Island. While he did record observations of Black-crowned Night-Herons through 1924, most were fall or winter records.

By the 1920s, the human population on Staten Island reached 116,531 residents (U.S. Census data). Griscom (1923) described a marked deterioration in available habitat for birds noting ‘it is here (Staten Island, NYC, Bronx, Westchester) that the greatest changes for the worst have taken place. In recent years this is particularly true of Staten Island, which 15 years ago was chiefly unspoiled country. It is now almost ruined for birds.’ The last breeding record of Black-crowned Night-Heron before their resurgence in the 1970s was during a breeding bird count in 1948 (Redjives 1948), although the specific location was not noted. From the 1950s through the 1970s, breeding bird activity (including that of wading birds) was regularly monitored on Staten Island by Howard Cleaves, Casimer Redjives, Norma Seibenheller, and Henry ‘Bill’ Flamm, and other dedicated individuals. During that time, there were no active Black-crowned Night-Heron colonies reported on Staten Island or its offshore islands (Seibenheller 1981), although Black-crowned Night-Herons may have bred undetected on islands in the north and west shore of Staten Island in the late 1960s (Scotty Jenkins, pers comm.). For example, Flamm (1986) noted 16 immature Black-crowned Night-Herons flying over South Avenue on 25 June 1967. Black-crowned Night-Heron was confirmed nesting on Shooter’s Island, an uninhabited island in the Kill Van Kull, in 1974 (Buckley and Buckley 1980), and subsequently in the Arthur Kill on Prall’s Island and Isle of Meadows in 1978 and 1981 (Blanchard et al. 2001), respectively.

In the late 1990s, the local breeding range expanded to include Hoffman Island (Table 3), while numbers declined at the 3 Arthur Kill/Kill Van Kull colonies. These declines occurred after a series of oil spills in tidal marshes off western Staten Island in 1990 (Burger 1994).

Following the 1990 spill, wading bird populations in the Arthur Kill continued to increase in size, from ~900-1200 pairs pre-1990 to ~1300 pairs in 1991 in 3 colonies combined (e.g., Prall's and Shooter's islands and Isle of Meadows). In spite of overall increases in abundance, tidal foraging species dropped sharply in abundance in 1991 (e.g., 42% decrease for Glossy Ibis) compared to generalist foragers (e.g., 34% increase for Black-crowned Night-Heron), and colony relocation was also observed (Parsons 1994). Important estuarine prey species, Mummichog and Grass Shrimp, were also influenced by the 1990 spills (Brzorad and Burger 1994). Shrimp abundance decreased sharply post-1990. Mummichog community structure also was influenced; an absence of older age-classes was coupled with an observed increase of young age-classes, which may have increased through reduced predation. Wading birds specializing in tidal habitats (Snowy Egret, Glossy Ibis) experienced reduced reproductive success, while opportunistic species such as Black-crowned Night-Herons showed little negative response (Parsons 1994).

All wading birds abandoned Shooter's Island in 1997, initially discouraged by disturbance created by campers there. Prall's Island was subsequently abandoned in 1998, and Isle of Meadows followed in 2001. There were several proximate causes for these declines, including the presence of mammalian and avian predators and evidence of human disturbance. That breeding activity has not returned to the Arthur Kill, which once supported the majority of NYC's nesting wading birds points to more complicated ultimate factors for these declines, including reproductive failure due to contamination and possible mortality due to West Nile Virus in 1999-2000. The ultimate factors involved in these declines warrant further study. While low density nesting attempts have recently been recorded in the Arthur Kill (~3-20 nests on Prall's Island in 2003-2005, described in Bernick 2006), there continue to be new challenges to a breeding activity on these islands. For instance, an Asian Longhorned Beetle infestation was identified on Prall's Island in March 2007 (A. Sawyer, USDA, pers. comm.). This prompted the removal of 50-60% of the island's tree canopy and the majority of nesting tree species (i.e., Gray Birch, Red Maple) which also serve as the most common host trees for the beetle. This makes it very unlikely that birds will recolonize Prall's in the near future, and threatens nesting habitat on nearby islands in the Arthur Kill. Currently, Black-crowned Night-Herons in the Staten Island area only nest at Hoffman Island.

Study Area

Staten Island

The borough of Staten Island (Richmond County, lat 40° 34' 60" N, long 74° 9' 0" W) is a 151.5 km^2 island located in the southwestern portion of NYC, and is bounded by the Kill Van Kull to the north, Upper NY Bay to the east, Lower NY Bay and Raritan Bay to the south, and the Arthur Kill to the west. The island has the smallest human population of NYC's 5 boroughs (463,314 residents, 2004 U.S. Census Bureau estimate), the highest growth rate of NYC boroughs and one of the fastest growing counties in NY State (4.4%, 2004 U.S. Census Bureau estimate). Approximately 20.4% or 31.2 km^2 of Staten Island's total land area (153 km^2) is defined as open space by the NYC Department of City

Planning, which includes ~12 km² of state regulated freshwater wetlands, ~14 km² of tidal wetlands, and approximately 4 km² of grasslands (NYS-DEC).

I conducted Black-crowned Night-Heron surveys (2002-2004), focal observations (2002-2004), prey sampling (2002-2004), and capture and radiotracking of adults (2004-2005) at 61 sites throughout the inland and coast of Staten Island (Fig. 2-3, Table 4), in a diversity of freshwater, coastal, and terrestrial habitats. I selected sites based on the following rationale. As the distance from the closest breeding colony (Hoffman Island) placed Staten Island within the range of typical foraging flight distances (15-20 km), I identified all potentially suitable estuarine, freshwater and terrestrial foraging habitats on Staten Island based on published information on Black-crowned Night Heron foraging ecology (Davis 1993) and diet (Parsons 1995), National Wetlands Inventory coverages, historical abundance and habitat use data on Staten Island, and personal observations of nocturnal abundance of Black-crowned Night-Herons (1999-2001). I excluded habitat that was currently developed for industrial and residential purposes, which offered no suitable aquatic or terrestrial food resources for foraging birds.

From a list of 150 potential foraging sites of varied patch sizes, I assigned each site a numerical code, and randomly selected sites from the above distribution. The resulting distribution of sampling sites were geographically dispersed throughout Staten Island and included locations that were both known Black-crowned Night-Herons foraging areas, and others not known *a priori* to support this species (Fig. 2a&2b). I categorized sites into broad habitat types: salt marsh, shoreline, freshwater, and terrestrial. I defined salt marsh sites as the surface of *Spartina* marshes with adjacent creeks and ditches. I classified shoreline sites as estuarine habitats marked by natural or man-made sand beaches, jetties, piers in proximity to shore. Freshwater sites included natural or man-made ponds, lakes, streams, and reservoirs. Terrestrial foraging habitats for Black-crowned Night-Herons are limited on Staten Island, and I identified a random sample of grassland, meadow, and manicured sporting fields distributed throughout the area.

Hoffman Island

Hoffman Island (lat 40° 34' 43", long N 74° 3' 15" W) is currently the only substantial nesting colony near Staten Island and the source of the majority of Black-crowned Night-Herons foraging on Staten Island, I conducted flight line observations (2001-2004, Chapter II) and nestling regurgitant sampling on Hoffman Island (2002-2004, Chapter IV) to describe foraging activity of Black-crowned Night-Herons on Staten Island. It is a 4 ha island located in Lower NY Bay, 1.45 km off the southeastern shore of Staten Island (Fig 2a). The island was created from landfill in 1872-3 on Old Orchard Shoals, was one of 2 quarantine islands (the other being Swinburne Island) constructed for immigrants who were suspected to be infected with or were carrying a contagious disease (Seitz and Miller 1996). At one point, there were 17 buildings on Hoffman Island, including multi-story brick dormitories, a delousing plant, and officials’ headquarters. A dock was located on the northwestern corner of the island. All structures were demolished in 1962 after a fire (McDonald 2002). Ownership and plans for the island varied between the 1930s and 1973, when the City of New York (which had acquired it in 1956 for landfill deposit and potential park development) sold the island back to the federal government. The island has since been managed as protected nesting habitat by the National Park Service as part of the Gateway National Recreation Area (McDonald 2002).

The island was first colonized by Herring and Great Black Backed Gulls between 1964 and 1974. Bull (1964) makes no mention of either species nesting on Hoffman or Swinburne Islands, though lists the presence of nesting Herring Gulls on Hoffman in 1974. Buckley and Buckley (1980), who confirmed nesting of both species between 1974-1978, offers an aerial photograph of Hoffman taken in 1979, which shows the island covered with low vegetation not yet suitable structurally to support nesting wading birds (Buckley and Buckley 1980; Bull 1964, 1974). Wading birds were first observed nesting on Hoffman Island in 1989 (Downer and Leibelt 1989). A complete nest count by R.Cook, D. Reipe, and V. Tearce located 3 Black-crowned Night-Heron nests, as well as 42 Great Black-backed and 65 Herring gull nests. Incidentally, the same 3 observers confirmed 1 Double-crested Cormorant nest on the same day at Swinburne Island, the NYC second nesting location for this species following a new colony established near Shooter's Island in 1987 (5 nests, Parsons 1995).

Hoffman Island was added to NYC Audubon's 'Harbor Herons' wading bird survey in 1998, and was conducted annually between 1999 and 2004, and triennially thereafter (Table 3). Kerlinger (1998) noted approximately 100 wading bird nests on a partial island count, including those of Black-crowned Night-Herons, Great Egrets, Snowy Egrets, and Glossy Ibis. The first complete nest count was conducted in 2001, and over 400 nests were located, including those of Cattle Egrets, Little Blue Heron, and possibly a Tricolored Heron (Kerlinger 2001). These numbers increased to 500 nests in 2004 (Kerlinger 2004), and corresponded with the complete abandonment of nearby Shooter's and Prall's islands and Isle of Meadows. The increases on Hoffman likely indicate a shift of nesting activity from the Arthur Kill/Kill Van Kull complex.

Nesting of Herring and Great Black-Backed Gulls on Hoffman Island declined between 1999 and 2004 (Table 3), although estimates based on adults have offered mixed results. In 1998, a 3:1 ratio of Great-black Backed to Herring Gull adults was observed, versus a 1:1 ratio between 1999 and 2002, and a 2:1 ratio in 2003 and 2004. The first Double-crested Cormorants nested on Hoffman Island in the early 1980s (D. Reipe, pers comm.), although Swinburne Island is the main cormorant colony. The most recent and largest expansion of Double-crested Cormorant breeding activity on Hoffman Island began in 2002, and their numbers have doubled each following year (Table 3). While negative impacts on wading bird nesting caused by Double-crested Cormorant activity are prevalent in the Great Lakes region (C. Weseloh pers. comm.), their influence in the NY/NJ Harbor area is not entirely clear. Beginning in 2006, efforts to study, among other things, impact of Double-crested Cormorants upon herons were undertaken by Wildlife Trust, NYC Audubon, and students from Columbia University and Queens College (Bernick 2006).

Wading bird nests have been located throughout the island in a variety of tree and shrub species, including Black Cherry, White Mulberry, Hackberry, Privet, Multiflora Rose, Oriental Bittersweet, and a patch of *Phragmites* spp. on the southern end of the island.

Cormorants mainly nest in Black Locust in the southwest portion of the island, although currently occupy most of the available locust trees and may begin competing with wading birds for nest sites in future years (Bernick 2006, Elbin and Bernick *in prep*). On Hoffman Island, Black-crowned Night-Herons nest in a variety of arrangements; from 1-8 nests per tree, located between 0.5 and 6 meters above the ground, in close proximity to Snowy Egrets, Glossy Ibis, and Great Egrets (Bernick pers. obs.). Gulls nest on the ground throughout the colony.

Of potential interest are 3 immature Brown Pelicans I observed on Hoffman Island; 2 on 3 July 2002 (NYS Avian Records Committee Report# 2002-87-A), and 1 on 5 July 2005. Pelicans roosted on Hoffman and Swinburne islands, and it is likely that breeding will occur here in the future given their recent range expansion into NJ.

CHAPTER II USING FLIGHT OBSERVATIONS TO DESCRIBE PATTERNS OF NOCTURNAL FORAGING HABITAT USE IN THE STATEN ISLAND AREA

Introduction

Waterbird colonies have been broadly defined as locations used predominantly for nesting where nests are closely or contiguously arranged, and where birds interact with each other regularly (Burger 1981). Colonies of wading birds often number from tens of nests to thousands. Resources are usually located at some distance from the colony; both reproductive success and sustained use of a colony require that adequate foraging resources exist in proximity to the nesting area. Reproductive success in Black-crowned Night-Herons has been shown to relate negatively to the distance of the colony from food resources (Frederick and Collopy 1988). I wanted to study Black-crowned Night-Heron foraging flight activity to describe any differences in flight direction of individuals or groups throughout the breeding season. Observation of directed flights to and from a known breeding colony (i.e., "flight-lines") is a relatively simple, non-invasive technique to verify onset, cessation, and sustained activity of breeding over a nesting season.

In breeding birds, female Black-crowned Night-Herons mostly incubate eggs during the daytime in captive birds (Noble et al. 1938), although in the wild, females incubate for about ~30% of day hours (Custer and Davis 1982). Both parents alternately incubate eggs and depart the colony to forage (Davis 1993), although differences by sex in total incubation time in wild populations are not clear. By the time chicks are ~12 days old, both parents may spend most of their time away from the nest foraging (Custer and Davis 1982).

Energetic demands of Black-crowned Night-Herons typically peak after hatching. Egg-laying and hatching is generally asynchronous, with a range of 2-5 day differences in age of siblings within 1 nest (Chapman et al. 1981). Nestlings up to 5 days-old require constant parental care, though have been found to maintain body temperatures above ambient temperatures after this time. Nestlings from 5-10 days old undergo a period of rapid growth (Chapman et al. 1981), and a sharp reduction of nestling care occurs after young reach 12 days. In 3-egg clutches, the most common for Black-crowned Night-Herons, the last chick (or the "C-chick") to hatch tends to have a lower growth rate than the A&B siblings (Custer and Peterson 1991, Erwin et al 1996). In general, early nesters show a greater ability to raise 3-young broods to fledging than late-nesters, although late-nesters may not be limited by food resources, allowing a full brood of chicks to be raised (Parsons and Burger 1981). Interspecific egg dumping has been identified a rare event, perhaps attributable to accidents in egg laying, with Black-crowned Night-Herons laying eggs in Snowy Egret nests (N=2), and a Great Egret laying eggs in a Black-crowned Night-Heron nest (Cannell and Harrison 1984).

Observational data of flights provides a measure of reproduction, with relative presence or absence of observed flights representing the degree of nesting activity over a breeding season. This is at best a coarse measurement; nesting biology and reproductive success are best estimated by direct nest monitoring. However, the degree to which human presence influences nesting activity within a colony should be carefully considered before conducting intensive research on reproductive success for colonial wading birds.

The flight line technique has been used to illustrate species differences in flight patterns or direction (Maccarone and Parsons 1988); describe mean directions and flight speed of wading birds flying to foraging grounds (Custer and Osborne 1978); quantify activity patterns by time of day, tide, and light level; determine location and usage of roost sites in the non-breeding season (Perlmutter 1992); or estimate nesting populations (Erwin 1981). Analysis of flight characteristics has also been used to test assumptions of foraging models and hypotheses relating to central place foraging (Orians and Pearson 1979), social foraging (Pratt 1980, Erwin et al. 1991), and the information centre hypothesis (Ward and Zahavi 1973, Krebs 1974), where departures towards foraging grounds are made in groups, with unsuccessful foragers following more successful individuals to areas of abundant resources.

Evidence supporting the influence of foraging flight distance on reproductive success and colony stability is varied. In the Florida Everglades, colony abandonment seems to be associated with increasing foraging flight distances (Frederick and Collopy 1988, Bancroft et al. 1994). This is due to the reduction in prey provisioning to nestlings rather than to the energetic costs to adults of increased flight distances (Frederick and Spalding 1994). Colonies in proximity to foraging habitats with varied water levels, such as diked lakes and tidal estuaries, offer a number of possible foraging locations available to foraging birds. Smith (1995) found that availability of habitat with varied water levels allowed for some flexibility in foraging effort. In a study of foraging flights and nest productivity at Lake Okeechobee, Florida, Great and Snowy Egrets, Tricolored Herons, and White Ibis flew from nesting colonies to both natural and artificial habitats. The observed flight distances averaged shorter than other such studies in the southeastern U.S., as foraging activity shifted significantly with changing water levels in the diked system. The availability of a variety of habitat patches did not require individuals to increase foraging flight distances significantly.

Tide level, time of day, nesting phase, species, and colony location all may influence the numerical relationship between flight rates (i.e., number of flights per hour) and timing of flights, thus substantial variation in the flight frequency may occur (Erwin 1981). Many species of wading birds require suitable hydrology, due to the importance of water depth in allowing individuals of various body sizes or leg lengths access to prey resources (Kushlan and Hafner 2000). The broad diet, varied foraging strategies, and flexible habitat preferences of Black-crowned Night-Herons indicate that they are not obligated to forage in tidal estuaries (Kushlan 1978, Davis 1993, Ch. III), and thus follow a different pattern of foraging flight activity when compared to species directly influenced by tidal cycles in coastal ecosystems (i.e., Snowy Egret).

I predict that foraging flight patterns should be more similar within than between species based on broad differences in diet (Custer and Osborne 1978). Maccarone and Parsons (1988) found differences in flight patterns of wading birds based on to prey preferences. Flight patterns of those species feeding strictly on insects and benthic invertebrates

(Cattle Egret, Glossy Ibis) were different from those of piscivorous species (Snowy Egret and Great Egret). Snowy and Great Egret flew towards a nearby freshwater pond, while Cattle Egrets and Glossy Ibis largely flew towards an active landfill and large areas of tidally-exposed mudflats.

Black-crowned Night-Herons have not been the ideal subject for foraging flight studies or subjects for investigation of foraging models, due mainly to their cryptic behavior (i.e., nocturnal foraging and peak flight activity to and from nesting colonies in low-light conditions) and plumage coloration. Black-crowned Night-Heron flight activity differs in timing from that of other wading birds. Peak morning arrivals before sunrise (Perlmutter 1992) and departures after sunset (Seibert 1951) have been offered as a possible strategy to avoid foraging competition with other wading bird species (Seibert 1951, Watmough 1978).

There is evidence of social interaction among foraging Black-crowned Night-Herons. For example, Wong et al. (1999) described diurnal group flights for Black-crowned Night-Herons (26% of flights observed) from a colony in Hong Kong. Erwin et al. (1991) found some tendencies for Black-crowned Night-Herons to depart in groups in Baltimore Harbor, an urban estuary similar to the NY/NJ Harbor. Groups of 2 or more Black-crowned Night-Herons departing at the same time showed a strong dependence in flight direction ($p>0.001$), indicating that these group flights were directed towards a similar area. No significant difference was noted in site choice between urbanized areas and less developed areas by Erwin et al. (1991). In fact, Black-crowned Night-Herons were observed more often in urbanized wetlands than in natural wetlands in the Baltimore area. This indicates that they might benefit from urbanized areas through prey aggregations at artificial lighting in industrial and commercial sites, which may have an important role in the formation of Black-crowned Night-Heron colonies in urban areas. In NY/NJ Harbor, the continued presence of a wading bird breeding populations in the Harbor is interpreted by various governmental and non-profit conservation agencies as a positive sign, one indicator that the Harbor has become cleaner since the enactment of the Clean Water Act in 1972 (Steinberg et al. 2004). On the other hand, this recolonization may indicate that habitat loss and development has forced wading birds to seek nesting and foraging habitat in NYC's still industrialized and contaminated harbor, with deleterious effects on long-term productivity. It may be that the cumulative effects or contaminants on nesting success are important factors in the observed patterns of colony abandonment in the Staten Island area (i.e., in the Arthur Kill-Kill Van Kull, Ch. I).

Wong et al. (1999) found that diurnal Black-crowned Night-Heron foraging flights were the shortest observed in a Hong Kong colony that also supported Great, Little, and Cattle Egrets, and that Black-crowned Night-Herons were dominant breeders in the colony. This suggests that lower foraging flight costs due to the availability of close foraging locations may result in greater reproductive success. Foraging habitat availability near nesting areas may also explain the relative dominance of Black-crowned Night-Herons in NY/NJ Harbor area wading bird colonies, where Black-crowned Night-Heron nests generally have generally composed 50% of total wading bird nests in the region since the 1970s (Parsons 1986, Kerlinger 1998, Bernick 2005a).

While foraging flight observations do provide a measure of foraging habitat use, the method has limitations. Flight observations are conducted on non-marked individuals that are not followed to a specific foraging site. If we were able to track the habitat use of known individuals and associate this with reproductive success, we would have a more complete understanding of population stability at local sub-regional colonies. Individual wading birds can be tracked from boat or aircraft following individuals on flights to foraging grounds, by boat (Erwin 1981), airplane (Custer and Osborn 1978), helicopter (Buckley and Buckley 1980), or blimp (Nagy 2005). This provides more detailed habitat selection data, but is expensive and difficult to achieve in urban areas with restricted airspace.

Tracking individuals by telemetry allows a direct connection between habitat use and various aspects of life history, such as nesting and foraging ecology, productivity, and health (Henny and Blus 1986). Radio or satellite tracked individuals are more easily relocated and are accessible over greater distances. In one telemetry study, Endo and Sawara (2000) found that Black-crowned Night-Herons foraged at single sites for days to months, eventually moving to new foraging areas, often along the same flight path as the previous site. Others fed in different habitats during the day and at night. All individuals switched to different foraging sites as more plentiful resources became available. This type of information is not as easily obtained by following unmarked individuals by boat or air.

Hoffman Island supports several avian species that are potential predators of wading birds. Gulls are opportunistic feeders that nest in proximity to other colonial waterbirds, such as seabirds and wading birds. Gulls have been observed preying upon eggs and nestlings (Hothem and Hatch 2004), particularly in colonies where these waterbirds nest close to the ground. Interspecific egg and nestling predation and kleptoparasitism of colonial waterbirds and seabirds by gulls has been observed for a variety of species, including Atlantic Puffin, Common Murre, Cassin's Auklet, Common Tern, Black-legged Kittiwake, Common Eider, Red-breasted Merganser, and Brandt's Cormorant (Braun et al. 1980, Burness and Morris 1992, Hatch 1970, Massaro et al. 2000, Mawhinney and Diamond 1999, Spear 1993).

I was interested in describing gull interactions with wading birds flying to and from Hoffman Island. Great Black-backed Gulls are known to prey upon adult Atlantic Puffins at breeding colonies in Scotland and Newfoundland (Beaman 1978, Russell and Montevecchi 1996), on hatch-year and adult Common Terns during the day (Hatch 1970, Whittam and Leonard 2000) and at night (Nocera and Kress 1996, Hentzel 2004), numerous species of waterfowl (Ryan 1990), and occasionally on other Great Black-backed Gulls, adult Herring Gulls, and Ring-billed Gulls (pers. obs., Great South Bay, Long Island). Additionally, Western Gulls have been reported to attack and prey upon adult Xantus' Murrelets while at sea (Oades 1974). In spite of a thorough literature search, I located no published records of gull predation on adult wading birds.

Investigation of foraging dynamics of Black-crowned Night-Herons in urban ecosystems is important, as relatively little is understood about their activities in these areas. Heron conservation in localized or fragmented areas requires knowledge of habitat requirements on a local scale (Kushlan and Hafner 2000). We need to fully explore habitat selection of more enigmatic wading bird species, such as Black-crowned Night-Herons, in order to create comprehensive management plans for urban wading bird populations.

For Black-crowned Night-Herons departing from Hoffman Island, I expected flight patterns dependent on time (i.e., with flight activity peaking after sunset and predominantly leaving the colony site) and independent of tidal level, with the majority of evening flights directed towards Staten Island. I based these hypotheses on known Black-crowned Night-Heron foraging activity as summarized by Davis (1993). In this study, I observed evening foraging flights by Black-crowned Night-Herons to (1) verify the sustained nesting activity at the Staten Island area's only remaining nesting colony (Hoffman Island), (2) describe seasonal patterns of foraging flight activity for comparison with weekly surveys at site censuses in this area (Ch. III), (3) describe the proportion of Black-crowned Night-Heron flights directed towards foraging sites in the Staten Island area (roughly north and west of Hoffman Island) versus other nearby foraging sites (Sandy Hook to the south, Jamaica Bay to the east), (4) investigate the frequency of individual and group foraging flights, (5) describe any aggressive interactions between gulls and wading birds, and (6) compare the flight activity of radiotracked Black-crowned Night-Herons to observational data.

Methods

Foraging flight observations

I selected a mixed species wading bird colony at Hoffman Island as the site at which to record foraging flight observations, based on a stable to increasing wading bird breeding population there (Kerlinger 2004). I observed flights (N=7 nights) from May-July 2001 (Fig. 4), and verified breeding activity there. I conducted weekly flight observations of Black-crowned Night-Herons traveling to and from Hoffman Island were conducted once per week from mid-March-August 2002-2004. Over these 3 years, Hoffman Island supported approximately 500 pairs of nesting wading birds (Ch I). Black-crowned Night-Herons composed ≈50% of the total wading bird population on this island (Bernick 2005a).

From a single observation point on South Beach (Fig. 5), I recorded foraging flights to and from Hoffman Island from 2.5 hours before to 1 hour after sunset, during both high and low tides (± 1 hour). Direction was estimated by compass to the nearest 10° of actual flight direction. For each flight, I recorded the number of individuals entering or leaving the colony, flight direction, and any major alteration (≥ 45°) in flight direction after initial observation. I also noted group size, and defined a "group" as ≥ 2 individuals flying in the same direction for 200m, within 50m of each other (Erwin 1984, Wong 1999). I also noted any social interactions before, during, or after foraging flights.

I conducted all shore-based observations with a Kowa Spotting scope (TSN-4 w/ 20x wide angle eyepiece), 8x42 binoculars, and a light intensifying night scope (ITT 190

Night Quest w/ 100-300mm lens) during low light conditions. All boat based observations were made with binoculars and night scope only. Data was entered into an HP iPAQ Pocket PC, using a database form designed in abcDB (PocketSOFT, Inc).

I recorded all data when wind speeds were below 20 knots/hr, when visibility was ≥15 km, and when there was no precipitation. Mean temperatures in March and April (early in the nesting season) averaged 20-30ºF lower than during the peak and end of the season (March 42.3 ºF ± 6.3, April 50.3 ºF ± 9.4, May 63.1 ºF ± 10.7, June 71.9 ºF ± 11.3, July 75.7 ºF ± 7.6, August 79.9 ºF ± 5.2). Observation dates and associated tides are listed in Table 5.

As the purpose of this study was to describe nocturnal foraging behavior, only evening flight observations were conducted. From the observation point at South Beach, flights could be reliably viewed towards and returning from areas in Union and Middlesex counties in NJ, Staten Island, and portions of Brooklyn situated northeast of the colony. Those flying to the east and southeast, towards Jamaica Bay and Breezy Point, were obscured by Hoffman Island when viewed from South Beach. In order to view Black-crowned Night-Herons flying in those directions, I made observations from Brooklyn and from a boat in the harbor (Fig. 5). I observed individuals at peak times of flight activity (i.e., May-June, 1 hour before to 1.5 hours after sunset), both by boat (N=18 hours, 2003-2004) and at 2 land-based locations (N=10 hours each, 2002-2004): Sea Gate, Brooklyn (3.5 km east of the colony) and Breezy Point, Queens (10 km SE of the colony). From these locations, I observed no outgoing Black-crowned Night-Heron flights heading in easterly directions. The Harbor Herons Monitoring Program, a citizen science project operated by NYC Audubon, reported a similar lack of flight activity on the E and SE part of the island; volunteers conducted observations by boat in June-July 2005, and observed only 1 incoming Black-crowned Night-Heron from the east in ~14 hours of observation (Nagy 2005).

Radiotracking

I captured, radiomarked and tracked adult Black-crowned Night-Herons from 15 June-20 October 2004-2005 in NY and NJ (Bernick 2005b). I captured individuals at 3 locations within National Park Service-Gateway National Recreation Area: Great Kills National Park (Staten Island, NY), Fort Wadsworth (Staten Island, NY), and Floyd Bennett Field (Brooklyn, NY). These sites were chosen for their large aggregations of foraging Black-crowned Night-Herons, as noted during previous site surveys and foraging observations (Ch. III). Both the Great Kills and Floyd Bennett sites are popular recreational fishing locations, and groups of 10-15 Black-crowned Night-Herons are commonly found both scavenging for bait and foraging along the shoreline on fish and invertebrates throughout the breeding season. The Fort Wadsworth site, a baseball field at the foot of the Verrazano-Narrows Bridge, attracts groups of 10-30 Black-crowned Night-Herons, which forage on earthworms following periods of rain (Ch III).

From June-August 2004-2005, I trapped individuals on foraging grounds, from 2000 and 0400h, using a 15’ X 15’ remotely triggered drop net (Wildlife Capture, Inc., see Bernick and Newman 2007). Segments of Menhaden were placed under the net as an attractant. No captures were made within colonies.

Following capture, I marked them with USFWS aluminum bands, and measurements on bill length (total culmen and nares to tip), wing length, tarsus length, and mass were recorded. If transmitter weight was less than 3% of the individual's body mass, I attached a backpack-style VHF radio transmitter (G3 transmitters w/ position based feature, 16.5 grams in weight, AVM Instruments, Inc.) with a harness of tubular teflon tape (Bally Ribbon Mills, Bally, PA). The transmitters emitted a rapid pulse rate (~85 beats per minute) when in a vertical position and a slow pulse (~45 bpm) when horizontal. The harness was attached over the keel with 2-0 polypropylene suture (Ethicon, Inc.), a weak point to eventually allow detachment of the radiotransmitter. I tracked them using a handheld receiver (R1000, Communication Specialists, Inc.) and 3-way Yagi antenna. I tracked individuals 3-4 days per week from June-October, alternating between those marked in Staten Island and Jamaica Bay. Tracking sessions were randomized by tide, and time of observation (i.e., during both day (0500 to 2000h) and night (2000 to 0500h) periods).

Analysis

Orientation data was compared among years, tides, month, and by group size using Watson's U^2 test (Batschelet 1981), and the selection of non-uniform flight directions between years using Rayleigh's test, both analyses using the program Oriana (Kovach Computing Services). I made the assumption in the above tests that there were no incoming and outgoing flights to the east (i.e., 40-160º). I used an independent samples t-test to compare individual and group outgoing flights by time, which was divided into 5-minute bins over the observation period (N=3.5 hours), with 0 representing sunset. I used

Chi-square contingency tables to determine differences in solitary versus group flight activity, to test whether singular Black-crowned Night-Herons leaving the colony differed from those flying in groups in choice of direction, and flight frequency by tide, month, and year; the null hypotheses being that Black-crowned Night-Heron flights did not differ between individual and group flights. In these analyses, group flights were treated as flight events, not relating to the number of individuals in the group. All tests were conducted in SPSS version 12.0 (SPSS, Inc.).

Results

From March-August 2002-2004 (N= 206.5 hours), I observed a total of 3,374 Black-crowned Night-Heron flights to and from Hoffman Island in the evening. The majority of flights were of individuals or groups departing Hoffman Island (2,979 flights, 88.3%), with 395 (19.7%) incoming flights (Fig. 6). The mean outgoing flight rate (e.g., flights per hour) peaked in June among all years (22.9 ± 7.2 flights per hour), and flight activity was minimal in both March and August (Fig. 7). I observed a mean of 43.2±9.5 Black-crowned Night-Herons per evening departing Hoffman Island in May, and 61.0±23.3 departing individuals in June, with a maximum of 118 departing individuals on 1 evening in June 2003. The number of adults departing Hoffman Island in May differed significantly from those in June (Mann-Whitney U Test; U=33.000, p = 0.024).

I observed more departing Black-crowned Night-Herons in June (i.e., after hatching, when both parents would spend time foraging outside of the colony), than in May (i.e., when the majority of nestlings would still require at least one parent on the nest). The number of outgoing adult flights from Hoffman Island are fewer than what would be expected in relation to colony size (301 nests in 2002, 274 nests in 2003, 204 nests in 2004), which implies that adults are not exclusively foraging at night during the peak of the nesting season.

Few departing flights were subadults (2.6% of total Black-crowned Night-Heron flights, N=44), immatures (second year; 0.5% of total flights, N=9) or juveniles (first year; 2.1% of total flights, N=35). Outgoing juveniles occurred in groups (57.1% of juvenile flights, N=20), all associated with adults. The sample size of juvenile flights was too small to compare in statistical tests of flight orientation or departures by tide, month, or year. However, the earliest juvenile departures were in late June-early July (e.g., 3 July 2002, 7 July 2003, and 27 June 2004).

Of the few arriving flights I observed, the majority (89%) were of solitary individuals. Group size was limited to 2 (9.5% of incoming flights) or 3 (1.5%) individuals. Arriving groups were observed mainly in May-July; and on 2 occasions (17 July 2003 and 25 July 2004) were composed of an adult and juvenile returning to the colony together.

Flight activity - solitary versus group flights

The majority of Black-crowned Night-Herons (58.9%) departed Hoffman Island in solitary flight; group flights (i.e., flights with more than 1 individual) accounted for 41.1% of total outgoing flights (Fig. 8). Group size ranged from 2 to 16 individuals. The peak of outgoing flights coincided closely with the evening, with 26.3% of outgoing flights occurring ± 10 minutes of sunset, and 51.5% occurring ± 20 minutes of sunset (Fig. 9). There was a significant difference in departure time between the number of solitary flights compared with group flights ($t=1.997$, $p=0.045$) over the entire observation period.

Flight direction of individuals departing the colony alone differed from those flying in groups ($\chi^2=35.13$, $p=1.06e^{-5}$, df = 7). There was no difference between the number of flights that solitary or grouped Black-crowned Night-Herons made by tide ($\chi^2=1.25$, $p=0.246$, df = 1) or month within the breeding season ($\chi^2=5.01$, $p=0.415$, df = 5).

Flight orientation

Figures for orientation output are represented as flights departing Hoffman Island (Fig. 10), and all tests are summarized in Tables 6-7. There was significant directionality in Black-crowned Night-Heron flights by tide, month, and year (Rayleigh's Tests; $p<0.00001$). The majority of flights were oriented to the west, with a mean vector of 266.4 ± 10.9º.

Outgoing foraging flight orientation differed significantly (Watson's U^2 tests; $p<0.005$) from a uniform distribution within each year (Fig. 11), tide (Fig. 12), and by group size (Fig. 13) with the majority of flights directed towards the west and southwest. Flight orientation differed significantly from a uniform distribution for the months of April-August (Watson's U^2 tests; $p<0.005$, Fig. 14-15).

Radiotelemetry

I conducted 87.5 hours of trapping at 3 locations in Brooklyn and Jamaica Bay (Fig.16). I trapped and radiomarked 2 individuals in 2004 (17 July and 6 August at Crooke's Point, Great Kills National Park), and 5 individuals in 2005 (20 and 30 June at Crooke's Point, Great Kills National Park; 22 June, 6 July, and 21 July at Floyd Bennett Field).

Black-crowned Night-Herons (N=4) that I radiotracked through the breeding season on Staten Island showed strong roosting and foraging site fidelity, although only 1 individual seemed to be breeding. For all individuals, I noticed a slight variation in foraging habitat use, including (1) long-term use of a single site for both foraging and roosting; (2) a short-term, short distance shift to a new foraging habitat, then a return to a core area; and (3) longer distance movements to new foraging/roosting locations. Further, I observed no overlap in habitat use amongst those marked in Staten Island and Jamaica Bay, indicating that, in spite of being able to fly 20 km to a foraging area, Black-crowned Night-Herons may be more likely to select nearby foraging sites.

Staten Island, NY and Monmouth County, NJ

I captured the first adult female (Transmitter #61075) on 17 July 2004 at Great Kills, and tracked it for 84 days (Fig. 17). It arrived at Crooke's Point (Fig. A-27) between 2030-2045h, spent the majority of night period either scavenging on bait along the beach (63% of observations) or striking at aquatic prey along the shoreline (37% of observations). Between 0130-0330h, it generally returned to Hoffman Island, where it remained throughout the day. I located it perched above a nest in the center of the colony (21 July), where it was likely returning to feed young. The pulse rate received when the individual was on Hoffman Island showed a regular adjustment of body position, perhaps relating to movement while feeding young. This pattern of activity continued through 11 August, when it began daytime roosting at Crooke's Point, and foraging at the same location through the night. The signal was last received at this location on 9 October, and was not located in 2005.

I captured a second adult female (#61070) on 6 August 2004 at Great Kills, and tracked it for 56 days (Fig. 17). The individual remained solely at Crooke's Point. It roosted in the day and foraged at night at the same location, either scavenging on bait along the beach (80% of observations) or striking at aquatic prey along the shoreline (20% of observations). The signal was last received at this location on 1 October 2004, and was not located in 2005.

Captured a third adult female (#61073) on 20 June 2005 at Great Kills, and tracked it for 110 days. It remained closely tied to the Great Kills Harbor area until the signal was lost on 10 October (Fig. 17). Interestingly, this bird was previously banded; although banding information for this individual was lost (USGS - Bird Banding Laboratory data), it was most likely banded as a nestling at a multispecies wading bird colony in Meadowbrook, Long Island in the 1980s (J. Burger, pers. comm.). It remained in the Crooke's Point area, both foraging and roosting in an approximately 3 km^2 area. From 20 June-9 October, foraging activity was largely concentrated on the Crooke's Point beach shoreline, in the area most heavily used by humans (85% of observations); this individual occasionally foraged along the harbor's eastern shore next to a public boat launch (15% of observations). It roosted in mixed woodlands at 2 locations on the north side of Great Kills Harbor, and within thickets on the tip of Crooke's Point. It was often in plain sight, and I received reports on its location from local fishermen (who fed it bait and fish entrails) and the Nature Section of the Staten Island Institute of Arts and Sciences (C. Hagen, pers. comm.). From 1-12 August, it changed location to the bay side of the park, moving 0.5 km east of Great Kills Harbor to the vicinity of a ~1.2 ha. *Spartina* salt marsh (Fig. A-27). During night intervals, she foraged in the salt marsh and surrounding mudflats, (strike rate=0.53 strikes/minute, capture success=36%, average prey size=~30-60mm, prey species = Atlantic silversides *Menidia menidia* and unidentified items). These rates and prey species were within the ranges for salt marsh foraging Black-crowned Night-Herons (Ch. III). Following this period, it returned to its previous roosting and foraging sites around Great Kills Harbor as described above. I lost the signal following a weather system (including a drop in temperature, heavy rain, and northwest winds) that passed through the metropolitan NYC area from 8-12 October (NOAA Weather Service).

I captured another adult female (#61076) on 30 June 2005 at Great Kills, and tracked it for 99 days between Staten Island and Monmouth County, NJ. After marking, it was not relocated until 7 July, when it was found roosting at NYS-DEC's Mount Loretto Unique Area (approximately 6 km southwest of the capture site, Fig. A-36). From 7-27 July, it roosted during the day in 2 locations within Mount Loretto, including woodlands along a *Phragmites*-filled salt pond near the Sharrott Ave. fishing pier (Figure A-47) in the eastern portion of the area, and mixed shrub-woodlands along the bay in the western portion of the site. In the evenings, it generally flew due south towards the Monmouth County, NJ (approximately 8 km south of Mount Loretto), and on 10 July, east towards Great Kills (Fig. 18). No fixes for this individual were obtained in Staten Island from 28 July-10 August, when I relocated it in NJ between Cheesequake and Keansburg, Monmouth County. Signals were received from NJ at both day and night, and it roosted and foraged within a relatively small area along the coast. On 29 August, the female was located (both by signal and visual confirmation) foraging in a salt marsh creek along the Garden State Expressway in Cheesequake State Park. On the morning of 30 August, it roosted in woodlands approximately 1 km south of the salt marsh creek. Though another visual confirmation was not received, this individual was confirmed to be both roosting and foraging in the vicinity of Cheesequake State Park until 9 October, after which the signal was not received again. It likely moved out of the area following the same weather system as described above.

Jamaica Bay, Brooklyn, NY

I captured an adult male (#61079) on 22 June 2005 in Jamaica Bay, and tracked it for 9 days following capture (Fig. 19). Two signal fixes from within the nearby Canarsie Pol colony were obtained in during the day on 24 June and 1 July, and fixes were obtained each night at either the capture site at Floyd Bennett Field, or the shore opposite this location on the Rockaways (23-30 June). After 9 July, no signal was received from this individual until 14 September, when a weak signal was received from thick shrubs and trees on the shore of Dead Horse Bay in the evening, approximately 0.5 km northwest of the capture location. It flew from this roost towards the east at 2040 h, and was not relocated on that night. No signal was received from 15 September-10 October. It was only observed scavenging on shore in the vicinity of fishermen. The lack of signal reception from 2 July-13 September, and its subsequent reappearance on 14 September, is puzzling, as the transmitter was clearly functioning during this period.

I captured 2 adults in Jamaica Bay on 6 July 2005 (#61080, adult male) and 21 July 2005 (#61081, adult female). While both were relocated within 0.5 km of the capture site on the night of capture (Fig. 19), neither bird was relocated (visually or by signal fix) following release, in spite of intensive search efforts throughout Jamaica Bay and the Rockaways.

Possible reasons for the lack of signal reception in the Jamaica Bay area include transmitter/harness failure, or movement of the individual well beyond the tracking area following capture. It is also possible that they were discouraged from returning to the capture site following radio attachment, but the lack of signal reception by ground, boat, and blimp call into question whether the transmitters were properly functioning. Individual 61079 was tracked for 9 days, then lost, and subsequently relocated, on only one day, over 2 months later. This pattern may have been due to signal interference within the area, or eastward movement to Long Island.

Social interactions

With the exception of grouping during flights and vocalizations among Black-crowned Night-Herons in groups, I observed no intraspecific interactions during incoming or outgoing foraging flights at Hoffman Island in any year. I observed no interspecific interactions between Black-crowned Night-Herons and other wading bird species during foraging flights. However, I observed chasing and occasional adult predation by Great Black-backed Gulls (Bernick 2005c).

From 2001 to 2004, I observed a total of 110 incidents of gull harassment or predation on incoming (56.4%) and outgoing (43.6%) wading birds at Hoffman Island. Seven species of wading birds (N=162 individuals) were pursued by Great Black-backed Gulls (85%), Herring Gulls (5%), or both (10%). Of these, the species most often chased were Black-crowned Night-Herons (N=70) and Great Egrets (N=20). Black-crowned Night-Herons (3.1% of total flights; 70 individuals), Little Blue Herons (1.9% of total flights), and Snowy Egrets (1% of total flights) were more often chased by gulls. Great Blue Herons, which occasionally used Hoffman Island as a roost site in March and August, were also pursued by gulls (N=3; 7.1% of total observed flights). Pursuits occurred more often in May & June (Fig. 20), thus overlapping with the peak hatching time for both gull and wading bird eggs. Gulls chased wading birds either individually or in groups of up to 16 gulls (Fig. 21), with a mean group size of 3 gulls. There was no effect of wind speed or direction.

The majority of these encounters involved chasing only (i.e., to shore or back to the colony), although 15 Black-crowned Night-Heron adults were grasped by the wing or otherwise struck by Great Black-backed Gulls during a chase. Five individuals were driven to the water between 20 and 500 meters from the colony, and mobbed by either

Great Black-backed Gulls or groups of both Great Black-backed and Herring gulls. While on the water, Black-crowned Night-Herons regurgitated and attempted to escape from the gulls, either by swimming or flying. All 5 Black-crowned Night-Herons were repeatedly driven back into the water by one or several gulls. The chases lasted up to 42 minutes (26 May 2003). Of the 5 individuals, 2 were killed and partially consumed, 2 eventually escaped back to Hoffman Island, and 1 was lost.

I also observed from 12-55 Fish Crows on Hoffman Island in May-August 2002-2004, a species known to eat heron eggs (Meyerreicks 1960). I located a maximum of 6 Fish Crow nests on Hoffman Island in 2004 (unpub. data). I found evidence of egg predation on the island, such as small piles of eggs on the ground opened lengthwise in a manner inconsistent with hatching. It is likely that Fish Crows or other birds were responsible for this predation.

Discussion

Foraging Black-crowned Night-Herons flew towards Staten Island and also towards extensive coastal habitats along Raritan Bay in NJ. This indicated that Black-crowned Night-Herons observed foraging on Staten Island (Ch III) are likely to either be breeding birds from Hoffman Island. Black-crowned Night-Herons have a diverse diet (Davis 1993), incorporating estuarine, freshwater and terrestrial vertebrates and invertebrates. So they likely use a wide variety of habitat types, which may help explain the lack of changes in orientation due to tide. Also, tidal flow in the Staten Island area varies by location, where peak tides average later on the north (up to +2 hrs for high, +1 hr for low) and west (up to +1 hr for high, +30 minutes for low) when compared to the south shore

(Eldridge Tide and Pilot Book data). Estuarine creeks also have delayed emptying rates dependent on sedimentation and other flow restrictions, which further staggers tidal stage at sites around Staten Island, so that at any given time, appropriate tide levels may be found somewhere around Staten Island.

I observed few Black-crowned Night-Herons flying towards Jamaica Bay. Approximately 12 km from Hoffman Island, a large colony of Common (~1,500 pairs) and Least (~170 pairs) terns, Piping Plovers (~10 pairs), and Black Skimmers (~140 pairs) nested at the south shore of Breezy Point, Queens during the study years (U.S. Fish and Wildlife Service data). Black-crowned Night-Herons are known to prey on other colonial species such as terns (Collins 1970, Hunter and Morris 1976), at times causing colony abandonment, and I expected to see some flights directed towards the southeast. While no Black-crowned Night-Heron predation was recorded at this colony (Sue Gilmore, National Park Service, pers. comm.), and I observed no flights in that direction, it is possible that a few individuals may prey on tern chicks at Breezy Point. This would be quite difficult to detect unless the tern colony was monitored, particularly at night, for the presence of Black-crowned Night-Herons. This is a serious concern, as all of the species above are listed as either threatened or endangered by state and federal agencies.

Black-crowned Night-Herons flew as often in groups as they did singly, indicating that social foraging, at least in terms of travel to a foraging location, is important for both adults and fledglings dispersing from the colony. These results support previous research on Black-crowned Night-Herons grouping during outgoing flights in urban (Erwin et al.

1991) and agricultural (Fasola 1982, 1984) areas. An interesting result from this study was that group flights and individual flights differed in mean flight direction.

Flight schedules at Hoffman Island were consistent with reproductive activity recorded there, with peak flight rate occurring in late May-June during the highest period of nestling energetic demands, and the drop in flight activity by late August consistent with the cessation of breeding activity.

Both eggs and nestlings are vulnerable to early season storms. Parsons (1985) found the initiation of breeding for Black-crowned Night-Herons at a colony on Clark's Island in Massachusetts was variable, and that Black-crowned Night-Herons were sensitive to weather a month prior to nesting, with nestlings most vulnerable to poor weather at approximately 12 days old. Adult Black-crowned Night-Herons, however, adapted brooding behavior to during poor weather conditions; they also selected better nest sites and had longer parental care than other wading birds at the same colony, and appeared to nest earlier than other species.

Based on observed flight activity at Hoffman Island, reproductive activity likely commenced from late March-early April 2002-2004. The first juveniles left the colony in late June-early July. These data demonstrate an 80-90 day period between nest initiation and juvenile dispersal. These observations are consistent with previous data on Black-crowned Night-Heron nesting chronology. In the northeastern U.S., incubation generally takes 24-26 days (Gross 1923). In coastal NY, average arrival times at colonies in Long

Island occurs in mid to late March, first occupied nests and egg laying in mid April, and first young flying by late June (Allen 1938, Parsons 1986). At Staten Island, hatching dates for Black-crowned Night-Herons ranged from late April through early May at Prall's and Shooter's islands in the late 1980s, although nesting occurred earlier at Prall's Island (Parsons 1987). At colonies in coastal Virginia, juveniles dispersed from the colony approximately 55-60 days after hatching (Erwin 1996a).

At Hoffman Island, only 1 juvenile was observed returning to the colony, supporting evidence that juvenile Black-crowned Night-Herons, while they tend to remain closer to their natal colony than other wading bird species (e.g., Snowy Egrets), they rarely return to a colony site after dispersing (Erwin et al 1996b). In general, few juveniles were observed departing the colony; this is likely reflective of the short observation periods for this study (i.e., evenings once per week), and not an indication of low productivity.

Radiotracked individuals were clearly influenced by human activity, and all engaged in opportunistic scavenging on bait provided both directly and indirectly by fishermen. The sample was mainly composed of non-breeders heavily using a single site, and though tracking was somewhat hampered by signal interference, these birds did provide important information on site fidelity and foraging patterns in Staten Island. It would be advantageous in the future to mark and track night-herons that use a wider variety of habitats and foraging strategies, as well as known breeders captured within or near active colonies.

Black-crowned Night-Heron adults remained in the NY/NJ Harbor area following the breeding season. Following the first major storm systems in October in both 2004 and 2005, which included heavy rain and northeasterly winds from 10-30 knots, I could not relocate the marked birds, which indicated either dispersal beyond the study area, loss of battery power or transmitter loss.

Observations of foraging flights also provided information on interspecific interactions with gulls, presence of an avian egg predator, and the development of a Double-crested Cormorant population on Hoffman Island. Of the wading birds chased by gulls, the Black-crowned Night-Heron was the only species I observed captured and killed. Thus, gull predation may influence evening departure times for Black-crowned Night-Herons, which is considered a strategy to avoid interspecific foraging competition with other wading birds (Perlmutter 1992, Seibert 1951). While this is the first evidence I have found for gull predation on adult Black-crowned Night-Herons here or elsewhere, their impact on colony size seems minimal. Both Herring and Great Black-backed gulls have nested on Hoffman Island since the mid-1970s. Overall, nesting gulls have declined in the NYC area, most likely due to the closing of the city's large landfills. The closure of the Fresh Kills Landfill in March 2001 removed a large source of food for gulls, where 15,000-20,000 gulls would routinely forage through the 1990s (National Audubon Society Christmas Bird Count data). A lack of suitable nesting sites at former gull colonies may also be important. The peak of gull nesting at islands in the Staten Island area occurred in relatively open areas that were covered with dredge material in the 1950s and 1960s, and where herbaceous or woody vegetation has increased in recent years.

The burgeoning Double-crested Cormorant colony on the southern end of Hoffman Island is of potential concern for the conservation of Black-crowned Night-Herons in NY/NJ Harbor. I observed Double-crested Cormorants building nests and roosting on Hoffman in 2002 (9 and 17 May, pers. obs.), and confirmed nesting activity in 2003 (1 May). Their populations have subsequently doubled each year, with 166 pairs nesting of Hoffman Island in 2006 (Bernick 2006). Population growth for Double-crested Cormorants has reached a near exponential level in the Great Lakes region since recovery from acute DDT contamination (Hatch and Weseloh 1999), and have also expanded in Atlantic coast colonies. However, the cormorant populations along the coast remain much lower than in the Great Lakes, and it is unclear whether the same conservation concerns apply in coastal ecosystems (Elbin and Bernick *in prep*).

The foraging flight observations in this study confirmed that patterns of flight orientation and social foraging of Black-crowned Night-Herons in the Staten Island area was similar to patterns described previously. I identified a unique interspecific interaction, gull predation on adults, and the potential conservation concern of Double-crested Cormorant. It is likely, however, that tracking known individuals to foraging grounds provides more detailed information on habitat selection and how this may influence reproductive success.

CHAPTER III NOCTURNAL FORAGING BEHAVIOR, SUCCESS, AND HABITAT USE BY BLACK-CROWNED NIGHT-HERONS IN STATEN ISLAND

Introduction

Animals that reproduce colonially nest some distance away from foraging locations; locating food requires searching for prey that vary in abundance both in time and spatial location (e.g., Common Murres, Davoren et al. 2003). Energetic demands of raising young include travel time to and from foraging locations, and time foraging at these locations (Orians and Pearson 1979). Wading birds, due to their relatively large body size, require a substantial amount of food for survival and reproduction; daily requirements depend on the time of year, level of activity of foraging birds, efficiency in assimilation of food, and energetic content of resources (Kushlan 1978). For instance, Willard (1977) found that 5 diurnal wading bird species in southeastern NJ were segregated by food source, with larger, longer-legged wading birds (i.e., Great Blue Heron and Great Egret) consuming larger prey at greater depths than smaller, shorter-legged species (i.e., Snowy Egrets, Little Blue Herons). There were also a variety of specialized feeding behaviors used. Snowy Egrets gather in groups and use foot-stirring and rapid striking to capture prey such as small fish and invertebrates. Tricolored Herons, on the other hand, strike at prey horizontally from a stationary position along channels or small ponds.

In coastal systems, tidal cycle is an important regulator of habitat and prey availability (McNeil et al 1993), and the use of habitats when tides are at an appropriate level in terms of a species body size or leg length may encourage nocturnal feeding in species that are otherwise diurnal. Prey taxa, such as estuarine or freshwater vertebrates and invertebrates, tend to increase in abundance and activity near the water surface during crepuscular and night periods for feeding and predator avoidance (Barnes 1991). Further, outgoing tides often concentrate prey into small areas, as in shallow salt marsh creeks (Bernick, pers. obs.). Some mainly diurnal wading bird species, such as Great Blue Herons, are known to forage at night to exploit favorable tide conditions. However, they are not as successful at night as they are in the day (Krebs 1974).

Nocturnality (e.g., activity during darkness) is thought to be characteristic of a relatively small number of species (McNeil et al 1993). Nocturnal foraging is a strategy for avoidance of resource competition at foraging sites dominated by diurnal wading birds (Kushlan 1978, Watmough 1978). Nocturnal Boat-billed Herons depart colonies in groups, and forage approximately 25m from nearby conspecifics. They capture a variety of aquatic vertebrate and invertebrate prey by either striking from a stationary position, or by disturbing and chasing prey (Biderman and Dickerman 1978). They may also use their unique broad bill to scoop prey (Willard 1979). They use similar techniques to those used by nocturnal Black-crowned and Yellow-crowned night-herons feeding at the same locations, and capture similar prey (Biderman and Dickerman 1978).

Foraging activity for Black-crowned Night-Herons is generally described by examining landscape-level activity, and looking for species-specific differences in site preference. In Hong Kong, Black-crowned Night-Herons preferred to forage in mangrove swamps and freshwater fish hatcheries in close proximity to their breeding colony (Wong et al. 1999). Cattle Egrets nesting at the same colony fed in rice paddies and freshwater marshes at a longer distance from the colony (Wong et al. 1999). Endo et al. (2002) found that adult Black-crowned Night-Herons foraged during the day in diverse habitats (e.g., rice paddies, rivers, orchards, and irrigation ditches in 'urban areas') from 2-12 km from a breeding colony, and fed at the same location for a few days to 1 month before moving on. They visited a number of sites over the course of several days before settling into a new foraging location. Generally, all foraging sites were in the same direction from the breeding colony, and previously used sites and new sites were used repeatedly.

Black-crowned Night-Herons expand foraging efforts into daylight hours during reproduction, particularly after hatching (Davis 1993). The distribution of Black-crowned Night-Heron activity has been shown to change from a strong day roosting – night foraging pattern during pre-laying and incubation of eggs (with ~45-47% of time spent outside of the colony), to foraging activity throughout the day (with ~79% of time spent outside of the colony) after nestlings hatch (Fasola 1984). Due to the energetic demands of rearing nestlings, foraging at night only may not provide enough for adults to maintain themselves and provision nestlings with adequate resources for growth.

There has been some debate as to whether Black-crowned Night-Heron foraging activities during breeding season are largely crepuscular (with the majority of foraging activity conducted at dawn and dusk) or active through the nocturnal period. Foraging studies conducted by Watmough (1978) over a 24-hour period in the Camargue, France indicated that night-herons feed similarly in both the day and night, though more individuals were observed feeding at night. Mean strike rates differed significantly between day (27.7 strikes/hour) and night (15.6 strikes/hour) periods, although capture success did not (80% in day, 69.4% at night). Fewer, larger prey items were captured at night, resulting in an overall higher food intake over this period. During daylight, aggressive interactions with diurnal species were frequently observed, with Little Egrets attacking Black-crowned Night-Herons ~5.9 times per hour. This kept Black-crowned Night-Heron densities low in areas with high daytime competition. Black-crowned Night-Herons were, however, observed feeding in these locations at night in the absence of Little Egrets, presumably due to reduced resource competition.

On the other hand, Fasola (1986) found that Black-crowned Night-Herons foraging in agricultural and natural habitats in Pavia, Italy had higher foraging success during daylight hours, due mainly to increased tadpole abundance then. Densities were similar in rice fields throughout the 24-hour period. While this implies equivalent foraging activity regardless of time, the observed pattern may have been due to differences in prey availability. Fish and insect larvae were more abundant at night in the Camargue (Watmough 1978), whereas amphibians were more abundant during daytime in Pavia

(Fasola 1986). Therefore, the timing of foraging activity may depend strongly on seasonal prey availability in a particular habitat.

In this study, I wanted to investigate foraging activity of Black-crowned Night-Herons in urban habitats at night, where artificial lighting may possibly enhance foraging activity. While there may be benefits to enhanced feeding in urban areas, there is also the cost of reduced environmental quality. NY/NJ Harbor has experienced regular inputs of petrochemicals, the most severe occurring in 1990 (5.7 million liters of oil, 684 individual spills; Parsons 1994). The Exxon-Baywat spill in the Arthur Kill, while tragic, afforded researchers the opportunity to compare pre-spill activity with prey availability, foraging, and reproduction following the acute contamination of fish, invertebrates, and wading birds.

Prior to the 1990 spill, Maccarone and Parsons (1988) found that tide level was not as important a factor for Great Egrets as for Snowy Egrets and Glossy Ibis; during high tides, Snowy Egrets and Glossy Ibis were found in higher densities at the freshwater pond, where they also had higher strike success than in the tidal estuary. Great Egrets were able for forage at sites regardless of tides, presumably due to their longer leg length.

Black-crowned Night-Heron diet changed following the oil spill. Because Black-crowned Night-Herons are flexible in their use of a diversity of aquatic and terrestrial habitats and may adapt to feeding on human-influenced food sources (i.e., fish hatcheries, landfills), nesting ecology was less influenced by the spill. Examination of Black-crowned Night-Heron nestling regurgitation indicated that diet composition changed from mostly estuarine fish and invertebrates prior to an oil spill to human refuse available from a nearby landfill after the spill, when estuarine habitats were severely impacted (Parsons 1994). Decreased nesting mortality following the spill was observed in tidal foragers (i.e., Snowy Egret, from 1.5 to 0.7 young fledged per nest before and after the spill), whereas nestling mortality for generalist foragers (i.e., Black-crowned Night-Heron, from 1.7 to 1.6 young fledged per nest before and after the spill) did not significantly increase (Parsons 1994).

By 1997, wading birds were still nesting in Arthur Kill and Kill Van Kill area (1149 pairs, Kerlinger 1997). Tidally foraging wading birds such as Great and Snowy egrets continued to forage at local estuaries and ponds, although their abundance at foraging sites and foraging success significantly lower in 1997 than pre-1990 levels (Maccarone and Brzorad 1998). Since 2002, only small numbers of Black-crowned Night-Herons have attempted to breed on colonies in the Arthur Kill and Kill Van Kull (Bernick 2006), although a similar complement of wading birds continue to forage in this vicinity, presumably flying from the Hoffman Island colony located off the south-eastern shore of Staten Island.

Reproduction and foraging in urban ecosystems may have advantages, such as relatively protected islands with habitat suitable for breeding/roosting sites, increased access to prey through ambient light at foraging sites, and nutrient loads resulting in higher prey abundances in freshwater and estuarine systems. Several disadvantages also exist, including increased exposure to contaminants depending on the foraging site, and increase mammalian predation at colonies close to shore. However, nocturnal foraging behavior and success has not often been studied, for species that either occasionally or routinely forage over the night period. While several studies have quantified strike or capture success for diurnally foraging species in the Staten Island area, and have shown differences in wading bird foraging success in marine and freshwater habitats (Maccarone and Brzorad 1998, Maccarone and Parsons 1994), similar patterns for nocturnally active species have not been described.

I studied Black-crowned Night-Heron nocturnal abundance, foraging rates, and prey selection at salt marsh, shoreline, freshwater, and terrestrial habitats on Staten Island. I asked the following questions: (1) Do Black-crowned Night-Herons show preferences in choice of foraging habitat type, and could this relate to seasonal or tidal differences? (2) Are they active throughout the night? and (3) Does habitat type or tide stage relate to differences in foraging rates, such as strike rate and capture success, or differences in prey selection?

Methods

I collected data and on abundance and focal observations of Black-crowned Night-Herons between March-September 2002-2004. All survey sites were located in Staten Island (Richmond Co.), NY (Table 4, Fig. 2-3). The survey sites were selected using the protocol described in Ch. I (pp. 23-24).

I was assisted by E. Neunteufel and N. Corona (2002), B. Hart (2003), and A. Borker (2004). I located and identified night-herons using a light intensifying night scope (ITT 190 Night Quest w/ 100-300mm lens) and 8x32 binoculars. All data was entered into an HP iPAQ Pocket PC, using a database form designed in abcDB (PocketSOFT, Inc.). I measured light intensity at each site and prior to each foraging observation with a lux meter (Yokogawa Portable Lux Meter, Model 3286A, 0-3.0 lux setting, accuracy ±7%). For site surveys, both observers scanned the site and identified all birds present. For foraging observations, one observer characterized behavior, while the other immediately entered data into the palmtop computer.

Site surveys

Each site was surveyed weekly between 2000 and 0500 EST. Surveys were randomized according to tidal cycle, time, and patch size. At each site, I recorded weather conditions, the number of Black-crowned Night-Herons present at the site, tide stage, age class and behavior, which are defined in Table 8. Length of observation was determined by site area, with total effort (minutes per site survey) constant at all sites.

Focal foraging observations

For each site, I identified actively foraging Black-crowned Night-Herons and, whenever possible, observed focal animals for 20-minute bouts following protocols described in Martin and Bateson (1993). While foraging studies for other diurnal wading bird species have employed shorter or open-length focal observations (e.g., 1-minute observations in Maccarone and Parsons (1988), from first strike to departure from site in Kent (1986,1987) and Brzorad et al (2000)), the potentially slower foraging rates and lower abundance for Black-crowned Night Herons lead me to conduct longer observations, following those used in other nocturnal studies of this species (i.e., 25 minute observations in Watmough (1978), 15 minute observations in Fasola (1986)).

During each observation, I approached within a reasonable distance (between 20 and 100 meters, depending on cover available) to conduct foraging observations without causing the individual to become acutely aware of my presence and moving from the area. For each observation, I recorded tide level, age of individual based on plumage characteristics, and all observed behaviors, including those reflecting movement, foraging, self-maintenance, and any intraspecific or interspecific interactions. I calculated foraging parameters as strike rate and capture success. All variables are summarized in Table 8. To avoid pseudosampling errors, foraging individuals were not included in focal observations more than once on a single night. However, as individuals were unmarked, it was not possible to determine the identity of birds on subsequent nights.

Kushlan (1978) defined 38 standardized feeding behaviors for wading birds, and ascribed 8 of these to Black-crowned Night-Herons, and I used these definitions in this study: standing (i.e., stationary capture of prey), bill vibrating (i.e., open/close bill in water as an attractant to prey), standing flycatching (i.e., stationary capture of airborne prey), walking slowly (i.e., capture while walking at slow speeds), hovering (i.e., hovers over water/ground to capture prey), plunging (i.e., headfirst diving from air), feet-first diving (i.e., landing on water with feet extended), and swimming feeding (i.e., capture while swimming or floating).

When a Black-crowned Night-Heron captured prey, I measured prey size relative to bill length during capture and handling of the prey item. This is a commonly used method of estimation in diet studies of seabirds (Hall et al. 2000) and wading birds (Krebs 1974, Kushlan 1978). Incorrect identification and size estimation can occur, particularly with small prey (<50mm) or during short handling times (Bayer 1985, Cezilly and Wallace 1988, Larson and Craig 2006). I identified prey item to general taxonomic level and ranked size relative to bill length (Table 8).

I also sampled prey directly at foraging sites, often shortly after conducting focal observations. I collected nestling regurgitant samples from nestlings at Hoffman Island during the peak of breeding (May-June 2002-2004), to compare prey items provisioned to young in this area (Ch IV).

Analysis

Each site was grouped into 1 of 4 broad habitat categories: (1) salt marsh (i.e., the surface of *Spartina* marshes, with associated creeks, ditches, and tidally exposed mudflats), (2) shoreline (i.e., sand and rock beaches; jetties, piers, and rock bulkheads), (3) fresh water (i.e., natural or man-made ponds, lakes, streams, and reservoirs), and (4) terrestrial (i.e., playing fields with cultivated grass, uncultivated grasslands with native and non-native herbaceous vegetation). Grouping sites by broad habitat characteristics is a method that has been used previously in wading foraging studies (Smith 1995), and is useful in describing general differences in habitat use that is central to this study.

For each site, I measured the total area and perimeter length of all possible foraging habitat at the site. I calculated abundance as the number of individuals per unit area or length. I compared Black-crowned Night-Heron abundance in each habitat type between months, years, and tides using two-way ANOVA (Zar 1998). To assess relative activity over the night, I measured activity in evening, midnight, and pre-dawn interval and compared time of Black-crowned Night-Heron activity by month, year, tide and habitat type using two-way ANOVA (Zar 1998).

To test for behavioral differences among habitats, I apportioned time spent in each of 4 categories: active foraging, movement within foraging site, maintenance, and interaction with conspecifics or other species (Table 8). I calculated two primary measures of foraging activity: strike rate (number of strikes per minute) and capture success (number of successful strikes per total strike attempts). Whenever possible, I identified prey captured by focal individuals and estimated prey size relative to bill length. Normality was verified using Kolmogorov-Smirnoff tests ($p \geq 0.05$), and data sets were transformed ($\log_{10}$ for strike rate data, arcsin for capture success data). All statistical analyses were performed using the software SPSS version 12.0 (SPSS, Inc.).

Results

From 15 March-15 September 2002-2004, I surveyed 61 potential Black-crowned Night-Heron foraging sites (i.e., 20 salt marsh, 22 shoreline, 13 freshwater and 6 terrestrial sites; Appendix A) once per week (N= 279 nights, 2,466 hours). A total of 3,081 Black-crowned Night-Herons were observed throughout the period of the study (mean number/week = 54.1 individuals, density per site = 1-18 individuals). Individuals were observed at least once at 50 sites (82% of total sites surveyed), including 20 salt marsh, 21 shoreline, 8 freshwater and 2 terrestrial sites (Table 9).

Site surveys

I observed no difference among or between years in density of Black-crowned Night-Herons per hectare within each habitat type (F=2.432, p=0.088; Fig 24). There was, however, a difference in activity by month (F=3.735, p=0.001; Fig 25). Overall abundance was highest from April-August among all sites (Bonferroni multiple comparisons; $p \leq 0.001$). I first noted Black-crowned Night-Herons at salt marsh sites in March (mean=4.46 BCNH/hectare). Black-crowned Night-Heron abundance did not differ by time of night or among habitat types (F=1.930, p=0.145; Fig 26). In terrestrial habitats, they were more abundant from 2300-0500h (mean=5.25 BCNH/hectare) than from 2000-2300h (mean=1.82 BCNH/hectare). Coastal areas with regular sport fishing activity supported some of the highest densities of Black-crowned Night-Herons onStaten Island. For instance, Crooke's Point in Great Kills National Park (Fig A-28) supported a mean of 9-15 individuals during and after breeding season.

Mean abundance per survey differed significantly among habitat types (F=16.070, $p<0.001$). More individuals per survey were present at terrestrial foraging sites than all other sites (Bonferroni multiple comparisons; $p<0.001$). I observed the majority of terrestrial activity at a playing field at Fort Wadsworth (FTWA3, Fig. A-25), and one in Willowbrook Park (1 night, WILL, Fig. A-51). Abundance was lowest in freshwater habitats in all years (mean=0.23 to 0.57 BCNH/hectare; Bonferroni multiple comparisons, p<0.001), though there was no significant difference in abundance between shoreline and salt marsh habitats (p<0.001).

I mainly observed adults (90.8%), and relatively few juveniles (5.6%) at foraging sites. Mean abundance differed significantly by habitat type (F=5.107, p=0.02; Fig. 27). After young fledged from Hoffman Island and were observed at sites on Staten Island, mean abundance of adult and juvenile pairs was highest at shoreline sites (mean=3.68 BCNH/hectare). Mean abundance of Black-crowned Night-Herons varied with tide at salt marsh and shoreline sites (F=3.200, p= 0.041; Fig 28), with highest abundances during low tide (mean=0.9 BCNH/hectare) versus a mean of 0.6 BCNH/hectare at other times.

I found no effect of light levels on feeding behavior among or between years or habitat (F=1.895, p=0.288). All ambient light measurements, including those at urbanized sites with artificial lighting, were between 0 and 0.05 lux. I did not qualitative differences in the amount of ambient light present among sites (i.e., large light arrays in industrial areas along the east and west shores of Staten Island versus darker inland and south shore sites. Further examination of potential interactions between artificial lighting and foraging rates deserve further attention.

Focal foraging observations – strike rate and capture success

I watched 515 individuals for a total of 171.6 hours at 45 survey sites from 2002-2004 (Table 9), including 127 salt marsh foragers, 173 shoreline, 113 freshwater, and 102 terrestrial. I could not follow every night-heron located because some were either too distant from a reasonable observation point, or flushed before an observation could be started or completed. Observations fewer than twenty minutes in length were excluded from the following analyses.

Strike rate differed by habitat type (F=5.786, p=0.017). Freshwater foragers struck less frequently (0.11 to 0.23 strikes per minute, 2002-2004) than in all other habitat types (Bonferroni multiple comparisons; p<0.02). Foragers in terrestrial habitats had the highest strike rates (0.11 to 0.23 strikes per minute, 2002-2004) of all those observed (Bonferroni multiple comparisons; p<0.001). I noted no difference between strike rate for those foraging at salt marsh or shoreline habitats (Bonferroni multiple comparisons; p>0.05). Strike rates did not vary significantly by year among habitat types (F=0.184, p=0.832; Fig. 29), although there were seasonal differences among years (F=3.483, p=0.009; Fig. 30), with lower rates in August than in June (Bonferroni multiple comparisons; p=0.026). There were no differences in strike rate by tide at coastal sites (F=1.586, p=0.212; Fig. 31), time interval (F=0.106, p=0.822; Fig. 32) or age class (F=1.599, p=0.206; Fig. 33). Terrestrial foragers, however, did not strike at prey at all between 0200-0500h, and only adults were observed foraging in this habitat type.

Capture success differed by habitat type (F=27.657, p<0.001), with freshwater foragers capturing prey less often (14-26% of strikes, 2002-2004) than in all other habitat types (Bonferroni multiple comparisons; p<0.03). Terrestrial foragers had the highest capture success (47-66% of strikes, 2002-2004) than in all other habitat types (Bonferroni multiple comparisons; p<0.001). No difference was noted between capture success for those foraging at salt marsh or shoreline habitats (Bonferroni multiple comparisons; p>0.05)

Capture success also differed by time of night among years (F=3.546, p=0.03; Fig. 32), with individuals capturing fewer prey items at salt marsh, shoreline, and freshwater sites in pre-dawn hours (0200-0500h) than earlier in the night. As reflected by strike rates, terrestrial foragers did not feed at all in pre-dawn hours. Capture success did not vary significantly by year among habitat types (F=0.253, p=0.777; Fig. 29), nor were there seasonal differences among years (F=2.312, p=0.057; Fig. 30).There were no differences in capture success by tide at coastal sites (F=1.586, p=0.212; Fig. 31) or age class (F=1.599, p=0.206; Fig. 33).

During nocturnal surveys, I observed several other species of wading birds foraging in freshwater and coastal habitats, either frequently (Great Blue Heron, Green Heron), occasionally (Great Egret) or rarely (Snowy Egret, Little Blue Heron). The presence of these species indicates that nocturnal foraging is a seasonally important aspect of their foraging ecology in urban areas, at least during the breeding season. Further study on nocturnal activity for these species is important to understand the significance of night-time feeding for typically diurnal species.

Prey species

I was able to identify captured prey during focal observations using behavioral cues such as throat pulsing, swallowing and handling. I was able to assign broad prey categories for 54% of Black-crowned Night-Herons observed (N=280 individuals). The image achieved through the light intensifier made it possible to distinguish certain prey, such as estuarine fishes from shrimps when larger than 25% of bill length, but not others. I did not assign a category to prey items I could not identify with certainty.

There were no significant differences in prey species captured by habitat type ($p>0.05$). Prey items captured during focal observations included fish, shrimp, and crabs at salt marsh and shoreline sites; scavenged fish at shoreline sites; fish and rodents at freshwater sites (Fig. 34). Black-crowned Night-Herons only foraged at a single terrestrial site, a playing field at Fort Wadsworth (FTWA3, Fig. A-25). They fed solely on annelid worms pulled from the surface of the field (Fig. 34)

Prey size

I recorded prey size in units of bill length. The average bill length of Black-crowned Night-Herons is approximately 80mm, and thus prey size can be estimated easily from proportions (Table 8). I excluded terrestrial foragers from this analysis, as it was difficult to accurately assess the length of earthworms. When pulled from the substrate, these prey items had a tendency to either stretch or break. Of the 3 remaining habitats, there were significant differences in mean prey size by year ($F=11.106$, $p<0.001$) and among habitat types ($F=37.726$, $p<0.001$), and a significant interaction by year and habitat type ($F=2.910$, $p=0.009$). At freshwater sites, prey captures were larger in 2002 (mean=0.84, ~67mm) than 2003 and 2004, and larger in 2003 at shoreline sites (mean=0.46, ~37mm) than in other years. Among habitat types (Fig. 35), prey captured by freshwater foragers was significantly larger than prey captured by shoreline or freshwater foragers

(Bonferroni multiple comparisons; $p<0.001$), although prey size did not differ between salt marsh and shoreline sites (Bonferroni multiple comparisons; $p=0.928$).

Discussion

Abundance and foraging habitat use of Black-crowned Night-Herons differed substantially on Staten Island. The probability of capturing prey, the relative sizes of prey available in different habitat types, and intensity of competition all likely influence foraging decisions (Maccarone and Parsons 1994). I have shown a tradeoff between prey abundance and prey size. Habitats supporting smaller, more abundant prey populations supported night-herons that fed rapidly with median foraging rates, whereas those habitats with larger prey were used by night-herons that employed less active foraging techniques. In terrestrial areas, seasonally abundant prey that was easily captured were used by birds with both high foraging rates and high success.

Black-crowned Night-Herons foraged at sites throughout Staten Island, up to 19 kilometers from the nearest colony (Conference House Park, Fig A-12). They fed in relatively low abundances at most sites surveyed on Staten Island (<1 BCNH/hectare). Higher abundances were found at sites within 8 kilometers of the nearest colony (e.g., Clove Lakes Park, Great Kills Park, Fort Wadsworth), and also within salt marsh complexes along the west shore (e.g., Fresh Kills). While there is some indication that not all night-herons foraging on Staten Island were nesting (radiotelemetry data, Ch. II), peak abundance and foraging activity corresponds with the months that energetic demands of rearing young are highest (e.g., May-July), suggesting that many were nesting.

Freshwater foragers had the lowest strike rate and capture success, compared to those in the other habitat, but they captured larger prey. At freshwater sites, Black-crowned Night-Herons tended to be more stationary (e.g., standing at a single location and scanning for prey), and either foraged along shore at the perimeter of a water body either from land, low-hanging branches, or perches on slightly elevated structures. Water clarity was reduced by algal blooms occurring in freshwater ponds from June-August, which may also hamper their ability to see and capture prey.

Individuals in estuarine habitats had higher foraging success than freshwater sites, but captured smaller prey. Interactions between Black-crowned Night-Herons and humans were most frequently observed at shoreline habitats. Black-crowned Night-Herons abundance along open beach was generally low, with the exception of sites frequently used by humans (e.g., fishermen). In these places, most observed foraging activity involved birds scavenging fragments of bait (e.g., Menhaden and American Eel) and entrails of Striped Bass, Bluefish, Weakfish, and other game species. Interestingly, these sites supported some of the largest concentrations of foraging Black-crowned Night-Herons observed in the Staten Island area. Their scavenging behavior was useful for capturing Black-crowned Night-Herons with a remotely-triggered drop net for application of radio-transmitters (Ch II), but also is an indication of flexible behavioral traits for this species, and a possible reason why they are able to breed in higher numbers in the NYC area.

Black-crowned Night-Herons were most abundant in a single terrestrial site in close proximity (~2.5 km) to the nesting colony at Hoffman Island, and highly successful in capturing and consuming seasonally abundant earthworms. This corresponds to typical Black-crowned Night-Heron opportunistic foraging behavior, as they frequently observed exploiting a seasonally abundant prey sources in a variety of habitat types (Davis 1993).

Foraging behaviors used by Black-crowned Night-Herons in Staten Island's urban ecosystem were similar to those reported previously; 5 of the 8 feeding behaviors described by Kushlan (1978) were observed in the Staten Island area (i.e., standing, bill vibrating, walking slowly, plunging, and swimming feeding). Some of these behaviors have been described as rare. Bill vibrating is characterized as an individual rapidly opening and closing the bill tip while submerged in water, presumably as a prey attractant. This is observed when vision is obscured by reduced water quality or darkness, has been infrequently reported (Drinkwater 1958, Davis 2004). In this study, I observed 9% of individuals (N=21) using this technique, at 2 freshwater ponds, one of which (Clove Lakes Park, Fig. A-11) typically experienced dense algal blooms during the breeding season, but also in habitats characterized as shoreline (N=3 sites) and salt marsh (N=9 sites). It is possible, however, that the same individual was observed using this technique on different occasions. Black-crowned Night-Herons in the Staten Island area also used other techniques not attributed to this species by Kushlan (1978), including pecking (i.e., picking up prey from substrate), walking quickly (i.e., feeding on aquatic prey while walking quickly in shallow water), running (i.e., capturing aquatic and terrestrial prey while running), and diving (i.e., diving headfirst from a perch to capture aquatic prey). Swimming, as described by Hoffman (1941), was not a foraging method used by Black-crowned Night-Herons I observed in this study. Competition or agonistic interactions among individuals was not frequently observed, although low abundances at most sites implies spacing among individuals, reinforced by the defense of foraging territories (Noble et al 1938).

Black-crowned Night-Heron abundance and foraging rates in this study fell within previously reported ranges for nocturnal activity patterns, with foraging activity occurring throughout the night, and not concentrated at dusk and dawn (Watmough 1978), and an increase in foraging activity in months that correspond to high energetic demands (Fasola 1986).

Black-crowned Night-Heron foraging has been reportedly influenced by tide, with those flying farther to forage during high tides than low tides (Custer and Osborne 1977). Abundance was higher at coastal sites during low tide than during tidal shifts, although I observed no effect of tide on strike rate or capture success.

Black-crowned Night-Herons have been recommended as potential indicator species for ecosystem health in urban ecosystems. Erwin et al. (1996) states that other wading bird species more directly dependent on estuarine wetlands may be more appropriate for such evaluations, as stronger relationships occur when examining growth rates, reproductive success, and nesting population dynamics. But they are also much more common and accessible, and less prone to dramatic population fluctuations. The variability of habitat use by Black-crowned Night-Herons described in this study means that care should be taken in identifying appropriate parameters to measure from Black-crowned Night-Herons.

CHAPTER IV PREY AVAILABILITY IN THE STATEN ISLAND AREA

Introduction

Prey resources are required to support wading birds in an area, during both the breeding and non-breeding seasons. It is useful to monitor prey populations when evaluating how organisms in higher trophic levels, such as fish-eating wading birds, may be influenced by changes in estuarine productivity and quality (Erwin et al 1996). Comparison of the seasonal abundance of available prey species in different habitat types to actual prey choice and provisioning by individuals is important to identify patterns of prey selection.

Sampling near-shore aquatic vertebrates and invertebrates, even at precise locations using a repeated method, is unlikely to result in an accurate estimate in total prey abundance over time. Abundance of aquatic vertebrates and invertebrates in coastal wetland habitats fluctuates by time of season, tide, lunar cycle, substrate type, and other factors. Methods used in this study represent a coarse, relative measure of prey abundance in each of 3 broad habitat types.

I conducted prey surveys at sites Black-crowned Night-Herons foraged, often shortly after focal observations were conducted on site. I also collected samples from nestlings at Hoffman Island during the peak of breeding (May-June 2002-2004), to compare prey availability with common prey items provisioned to young. The goal of this study was to determine prey abundance and differences in length and weight of fishes at known Black-crowned Night-Heron foraging sites, to compare with both observed prey capture (Ch III), and diet composition of provisioned to nestlings on Hoffman Island.

Methods

From May to September 2002-2004, I sampled aquatic organisms at sites in Staten Island, NY frequented by foraging Black-crowned Night-Herons. Sampling sites corresponded to the following broad habitat categories (as discussed in Ch III). Salt marsh sites included a ~1.2 ha *Spartina* marsh at Great Kills National Park (Fig. A-26) on the south shore of Staten Island; a 5.8 ha *Spartina* marsh at Arlington Marsh (Fig. A-7) on the northwestern shore of Staten Island; and a site on the northeastern branch of Main Creek (Fig. A-33), which is associated with the ~120 ha *Spartina* marsh complex within Fresh Kills Landfill. Shoreline sites included a ~4 ha sand beach and mudflat area along the Arthur Kill at Kreischer's Cove (Fig. A-4), and a ~12 ha sand beach within the harbor at Great Kills National Park. Freshwater sites were located at 2 parks managed by NYC Department of Parks and Recreation: a 4.1 ha pond at Clove Lakes Park (Fig. A-11) and a 1.9 ha pond at Willowbrook Park (Fig. A-51),

I collected one biweekly sample from each estuarine and freshwater site between 2200 and 0400h. For salt marsh and shoreline sites around the island, I timed samples to occur at the same water level (mid-tide) during both incoming (flood) and outgoing (ebb) tides, and sampled freshwater sites at times when coastal site tides were not at the appropriate level. I used a 20 foot bag seine net (1/8 inch mesh) to capture near-shore aquatic fauna. At each site, 2 researchers pulled the seine in 3 passes along a 50 meter transect.

In each year, I also set 2 minnow traps baited with 0.1 liters of dry cat food at both freshwater and coastal sites. I set traps at freshwater sites for the night period (i.e. 8 hours), and through a tidal cycle (from mid-tide to mid-tide) at coastal locations. Samples collected from killifish traps were negligible (N=0 to 4 organisms), and as the timing of tides occasionally resulted in traps remaining in the water during daylight hours, I did not include them in this analysis. Kneib and Craig (2001) discussed the effects of soak time on capture and escape rates, suggesting that shorter soak times resulted in larger samples; unfortunately, available time for setting and collecting traps at 6 sites in a 150 km^2 area in addition to seining was limited.

For each sample, I identified prey species to the lowest possible taxonomic level, counted the number of individuals per species, recorded body length and weight, and released individuals whenever possible. A portion of prey samples were stored in a -80°C freezer for future contaminant analysis.

I collected regurgitant samples from randomly selected 3-4 week old Black-crowned Night-Heron nestlings at Hoffman Island to determine diet composition in June 2002 (N=9), 2003 (N=11), 2004 (N=10 samples) and 2005 (N=11 samples). I collected samples passively, from nestlings weighing more than 400 grams that regurgitated during handling, and stored the entire bolus at either -80ºF (2002-2003) or 20ºF (2004-2005). In a laboratory, I sorted and weighed each bolus, and identified prey items to lowest taxonomic order using field guides and dichotomous keys freshwater and marine fauna (Gosner 1978, Haynes and Frisch 1993, Page and Burr 1991, Pollock 1998, Robbins and

Ray 1986, Werner 1980). Voucher specimens of prey items sampled in the field and nestling regurgitant are stored at CUNY-College of Staten Island in a -80ºF freezer for future toxicological analysis.

Results

Abundance

A total of 6,189 individuals representing 24 species were captured between May-September 2002-2004 (Tables 10-13). The majority were fishes, 13 estuarine and 6 freshwater species. In addition, 2 species of marine shrimp and 3 species of marine crab were present in the prey samples. The most prevalent species at shoreline and salt marsh sites were Mummichog, Grass Shrimp, Striped Killifish, and Atlantic Silverside. Estuarine fish and invertebrate abundance differed among salt marsh and shoreline sites, with the highest abundance of Mummichogs sampled at Main Creek, of Atlantic Silversides at Great Kills Harbor and of Grass Shrimp at Kreischer's Cove (Figs 36 and 37).

At freshwater sites, the prevalent species were Bluegill, Pumpkinseed and Largemouth Bass (Fig. 38). Although relatively small samples were captured at freshwater sites, this does not indicate that the sites were unproductive. Fish were occasionally able to evade the seine net due to the irregular and debris-strewn pond substrate. None of these species are native to Staten Island and were clearly stocked at some point, although I found no evidence of annual stocking by the NYSDEC or other agencies.

Fish length and weight

In salt marshes, there was a significant difference in length of fishes captured among years (F= 7.851, p<0.001), with longer fish captured in 2003 than in 2002 or 2004. Significant differences also were present among all sampling sites (F=12.358, p<0.001). There were also species differences in terms of weight (F= 14.536, p<0.001) among all years and all sites (Bonferroni multiple comparisons; p<0.001). Mummichogs averaged longer (mean length=62.5mm) and heavier (mean weight=4.9g) at Arlington Marsh than at Main Creek or Great Kills Marsh (Table 14, Figs. 39 & 40). Weights differed among all 3 species (Bonferroni multiple comparison; p<0.001).

In shoreline habitats, there was a significant difference in length of fishes captured among years (F=10.333, p<0.001), though not between sampling sites (F= 0.686, p= 0.408). There were species differences in terms of weight among years (F=43.001, p<0.001; heavier fish captured in 2004 than other years) and between sites (F=43.232, p<0.001). Mean Mummichog and Atlantic Silverside lengths and weights were greater at Great Kills Harbor than at Kreischer's Cove (Bonferroni multiple comparison; p<0.001, Table 14).

In freshwater habitats, there was no significant difference in length of fishes captured among years (F=2.202, p=0.112) or between sampling sites (F=3.558, p=0.06). There were species differences in terms of length (F=146.491, p<0.001) and weight (F=50.364, p<0.001). Largemouth Bass individuals averaged longer (mean length=108mm) than Bluegill or Pumpkinseed (Figs. 39 & 40), and weights differing among all 3 species

(Bonferroni multiple comparison; p<0.001; Table 15). However, this is most likely due to the variation in age classes captured, with larger individuals evading capture in seine nets.

Nesting regurgitant analysis

Mean bolus weight was 20.5g ± 13.2 SD (range: 0.2 - 58.9g). Eestuarine fish and invertebrate species comprised a majority of the average bolus from Black-crowned Night-Heron nestlings (N=41 samples, Fig. 43). The proportion of prey items identified in regurgitated boluses did not differ significantly among years (F=2.699, p=0.053), nor was there a significant interaction between prey and year (F=1.430, p=0.169). There was a significant difference in prey type; in boluses containing estuarine fish (31%; Fig. 43), this prey type formed a large proportion (mean = 68%; Fig. 44).

Main fish species identified in regurgitant included Mummichog, Atlantic Silverside, Winter Flounder, and Pumpkinseed. Other items present in average boluses included unidentified marine shrimp (12%), unidentified crabs (9%), unidentified rodents (8%) and unidentified arthropods (1%).

Prey that could be identified in regurgitated boluses included several of the most abundant species present in estuarine and freshwater habitats in the Staten Island area, including Grass Shrimp (present in 44% of boluses), Mummichog (32%), Atlantic Silverside (27%), and Bluegill (10%). Additional species identified include estuarine crabs (Blue Crab, Green Crab), amphibians and reptiles (American Bullfrog, juvenile Snapping Turtle), rodents (Meadow Vole), and terrestrial insects (Earwig). Precisely cut segments and entrails of marine fish (Striped Bass, Menhaden) were found in 3 samples, which showed that some adults scavenged in areas where fishermen leave remnants of filleted fish and bait (i.e., Great Kills Park).

Discussion

Three estuarine fishes (i.e., Mummichog, Atlantic Silverside, and Striped Killifish), 1 species of estuarine shrimp (i.e., Grass Shrimp) and 3 species of freshwater fish (i.e., Bluegill, Pumpkinseed, and Largemouth Bass) were well represented in coastal and freshwater sites in the Staten Island area, were observed as major prey species captured during focal foraging observations of foraging Black-crowned Night-Herons (Ch III), and composing significant proportions of regurgitated boluses from Black-crowned Night-Heron nestlings at the Hoffman Island nesting colony. This indicates a link between the most abundant aquatic organisms available to foraging individuals, and the prey species selected.

It has been proffered that sublethal levels of contamination may have a considerable influence over behavior in estuarine invertebrates. Wallace and Estephan (2004) examined the impact of cadmium (Cd) exposure on horizontal and vertical swimming activity of captive amphipods. Amphipods were exposed to sediments of various Cd concentrations, and found that both horizontal and vertical swimming decreased significantly with Cd exposure. Thus, behavioral changes due to contaminant loads may influence the ability to avoid predators, and may be one pathway for such contaminants to cascade through a community (Weis et al. 2001).

Amphipods are key prey species of Grass Shrimp, a common shrimp in near-shore tidal estuaries in Staten Island. Several studies have described the mechanism by which trophically available metals (TAM), such as cadmium, may be passed through higher trophic levels in metal-contaminated estuarine communities (Perez and Wallace 2004, Seebaugh et al. 2005, 2006).

Mummichogs and Grass Shrimp, two common species used in laboratory and natural ecotoxicological experiments, are known to be a readily available and important prey resource for Black-crowned Night-Herons, as indicated in this study. Contaminants, such as mercury or cadmium, could potentially be more easily passed to higher trophic levels if prey species have high enough loads to reduce mobility and avoid predators. In this scenario, Black-crowned Night-Herons or other organisms feeding in tidal estuaries might achieve greater foraging success at a contaminated site feeding on abnormal prey. The consequences of consuming contaminated prey would then include deleterious effects relating to provisioning young with such sources. Further study of this process, particularly the mechanisms of contaminant uptake in birds with high versus low foraging rates, could be one effective way to associate prey choice or habitat selection with wading bird reproductive success and population stability in urban systems.

Regurgitated boluses collected from Black-crowned Night-Heron nestlings at Hoffman Island corresponded to known diet composition for this species, with estuarine and freshwater fishes and invertebrates composing the majority of average samples, as well as a variety of terrestrial vertebrates (rodents, amphibians, reptiles) and invertebrates (insects). No birds were identified in Black-crowned Night-Heron nestling regurgitant in this study, although they are known to prey upon nestlings and young of other ground nesting waterbird taxa, including those of Common Terns (Collins 1970, Hunter and Morris 1976). While no tern colonies are currently located on Staten Island, there is a large colony of Common Terns and Black Skimmers in Breezy Point, Queens (~12 km from Hoffman Island) and it is possible that Black-crowned Night-Herons may forage in this vicinity. In addition, 2 ground-nesting shorebird species reproduced on Staten Island during the course of this study (Killdeer and Spotted Sandpiper, NYSDEC Breeding Bird Atlas data). A third species, American Oystercatcher, attempted to breed in 2003 and 2004 at 2 locations (Great Kills National Park and Prince's Bay) where Black-crowned Night-Herons were frequently present. No information exists on the prevalence of such species in Black-crowned Night-Heron diet in the NYC area.

Nutritional and energetic requirements of Black-crowned Night-Herons have not been established to date, particularly for adults rearing young during the breeding season, although Fasola (1986) estimates that adults require ~70 grams dry weight of prey per day for self-maintenance (assuming an average daily energy expenditure of 3.5 times BMR, a weight of 636 grams, and a metabolizable energy content of tadpoles at 4.1 kcal/g and 0.8 assimilation efficiency), and also observed an actual daily food intake of ~150 grams during the nestling period.

Brzorad et al. (2003) used a non-invasive, observational technique to estimate energy budgets of Great and Snowy Egrets in the Arthur Kill and Rahway River; they found a seasonal increase of prey density, a seasonal decrease in foraging success, and higher net gains of energy in early than late season foraging activity (May, 227 watts vs. August, 52.5 watts). The authors show that estimates of foraging energetics (i.e., intake and expenditure at foraging sites) help explain how far wading birds are able to travel for foraging resources, and perhaps describe the distribution and abundance of wading bird nesting populations in a region.

CHAPTER V SUMMARY

In the present study of Black-crowned Night-Heron foraging ecology, I found that: (1) individuals flying from a major breeding colony followed similar flight paths regardless of date or tide; (2) there was a tradeoff between prey size and capture rate, where freshwater foragers captured few large prey while salt marsh and shoreline foragers captured more smaller prey; (3) foraging techniques differed among habitats; (4) activity level was constant through the entire night; and (5) prey composition of nestling diet reflected what was available at foraging sites. The novel aspect of this study was that I studied Black-crowned Night-Heron foraging behavior at night in an urban system. This research supports current knowledge of Black-crowned Night-Heron foraging rates and habitat use, and offers key insights into why this species is numerically dominant in urban ecosystems.

My results support simple models of optimal diet choice (Futuyma 1998), which explore which prey items a predator may be expected to choose, and the relationship between profitability and strategy among patches. In these models, generalists may be expected to spend time searching for profitable prey but also pursue prey of lower profitability; specialists would spend greater amounts of time and energy searching for the most profitable prey (MacArthur and Pianka 1966, Begon et al. 1996).

Black-crowned Night-Herons used moderate strike rates in habitats with superabundant, moderately sized prey, such as estuarine creeks or shorelines. In comparison, those foraging in freshwater habitats infrequently captured prey, although the prey items tended to be larger, containing a higher energetic value. Seasonally abundant, easily captured prey was available in a terrestrial habitat closest to the breeding colony, where both the highest densities and highest foraging rates were also observed. Black-crowned Night-Herons, however, were not observed feeding at this site through the night, suggesting that they switch to different foraging locations following an initial pulse of activity when the prey was most available. Endo and Sawara (2000) indicated that Black-crowned Night-Herons switch foraging sites over short time scales when prey is abundant, which effectively explains this behavior.

The mean size of prey captured by foragers (Ch. III) tracked closely with the mean size of prey available in estuarine and freshwater habitats (Ch. IV). Night-herons were likely attempting to select the largest prey within a particular habitat type. Strike rate differed substantially among habitats as did capture success. Night-herons choosing larger prey were less successful in terms of foraging rate, but captured larger prey. Night-herons feeding in salt marsh and shoreline habitats struck at and captured prey more often. Interestingly, in terms of energy content both of these outcomes may meet energetic requirements of rearing young. In this study, differences in searching were not reflected in varied Black-crowned Night-Heron densities among habitat types.

It is a complex and interesting question why Black-crowned Night-Herons and other wading birds persist in seriously polluted urban ecosystems. In this chapter, I will offer future research that will address this question.

Contaminants, trophic transfer and health

Environmental contaminants and pollution threaten reproductive success and population stability of wading birds that breed and forage in urban ecosystems. We need to know how organic and inorganic contaminants impact these birds. Black-crowned Night-Herons vary in their response to contaminants. Mercury in its methylated form (MeHg), is highly toxic to organisms, as it is easily absorbed along the alimentary canal. Direct exposure to inorganic mercury (IoHg) is less toxic due to its poor absorption (Clarkson 1972). In a study of acute mercury contamination in Nevada (Henny et al. 2002), high concentrations of total mercury (THg) were found in Black-crowned Night-Heron livers (mean 43.7μg/g wet weight) and kidneys (mean=11.1 μg/g wet weight). Analysis of stomach contents in night-herons with high proportions of fish (>40%) showed a mean of 0.69 μg of methylmercury, whereas those with predominantly insect or mammalian prey in stomachs had lower levels of MeHg. Livers with high levels of MeHg also had much more IoMg, and Henny et. al (2002) ascribed this to demethylation processes and sequestration occurring in the liver; kidneys and spleen. Concentrations of THg greater than 0.8 μg/g in eggs did not seem to influence overall productivity in Black-crowned Night-Herons; however, these concentrations did have adverse effects on Snowy Egrets and Double-crested Cormorant productivity. Young Black-crowned Night-herons showed similar mercury concentrations in organ tissues as adults, although young also showed more evidence of histological damage and significant biochemical changes related to oxidative stress. Ultimately, wading birds and cormorants in this region were able to tolerate elevated levels of mercury in the prey base through demethylation, after which IoMg is either excreted or sequestered in organ tissues (Henny et al. 2002).

Young birds, however, had neurological and histological damage associated with mercury in the diet, which may have profound effects on post-fledging survival.

In the eastern U.S., hatching success and nestling production of Black-crowned Night-Herons were higher in urban estuaries including Boston and NY/NJ Harbors than in mixed urban-agricultural estuaries such as Delaware Bay in the 1990s (Parsons et al. 2001). Potential sources of reduced productivity included egg and nestling predation by mammals and birds (Raccoon, Barn Owl, American and Fish crows, Common Grackle), egg inviability caused by polycyclic aromatic hydrocarbons and chlorinated hydrocarbons, reduced productivity due to metals contamination and organochlorines, and sub-lethal neurotoxicological impairments due to cholinesterase-inhibiting contaminants present in agricultural pesticides (i.e., carbamates, organophosphates). However, Black-crowned Night-Herons in eastern U.S. estuaries tend to have higher nestling productivity than do Glossy Ibis or Snowy Egrets (Parsons et al. 2001). Rattner et al (2000) concluded that low-level exposure to chlorinated hydrocarbons and heavy metals may combine with other stressors to affect population stability. In San Francisco Bay, Hothem and Hatch (2004) found that contaminants did not affect hatch rates or survival of Black-crowned Night-Herons. Whether night-herons deal with contaminants by avoiding ingesting them or metabolizing them requires further study.

Trophic transfer of several contaminants and pollutants from zooplankton through mid-level consumers has been extensively investigated at biochemical, cell, and organism levels (Weis et al. 2001). Contaminants and pollutants have been linked to negative impacts on behavior, such as predator avoidance and prey capture in fishes (Brown et al. 1987) and invertebrates (Wallace and Estephan 2004, Perez and Wallace 2004). For instance, Mummichogs and Grass Shrimp are important prey species for wading birds in the NY/NJ Harbor (Brzorad and Maccarone 2004, Brzorad and Burger 1994). Mummichogs are important components of tidal marshes, and are able to tolerate extreme variations in tidal cycle, water temperature, salinity and contamination (Halpin 1997). They exhibit strong site fidelity across their range (Skinner et al. 2005, Sweeney et al. 1998). Mummichogs feed on Grass Shrimp; in the Arthur Kill, Mummichogs experience reduced prey capture and growth patterns when compared to a cleaner site in Tuckerton, NJ (Weis and Weis 1989, Toppin et al. 1987).

Grass Shrimp are less mobile in areas with high levels of lead, copper, and other contaminants (Perez and Wallace 2004). Furthermore, Mummichogs capture fewer shrimp in contaminated estuaries (Smith et al. 1995, Smith and Weis 1997) and may act as potential vectors for metals to higher trophic levels (Seebaugh et al. 2005). Since higher than expected capture rates may occur, Mummichogs may tolerate contaminants (Weis et al 2001). Densities and body size of Grass Shrimp are higher at a contaminated site (i.e., Piles Creek) than at a cleaner site (i.e., Tuckerton). Densities of Grass Shrimp are influenced by densities of older age classes of Mummichogs (Kneib 1986). This suggests that both reduced populations of Mummichogs and reduced prey capture by the fewer Mummichogs present (Santiago 1997) are plausible examples of shifts in community composition due to pollutants.

Reduced mobility and higher concentrations of trophically available contaminants present within important prey species for wading bird may play an important role in the transfer of metals and organic contaminants. Some of the sites with highest densities of Black-crowned Night-Herons included a landfill (Fresh Kills), and freshwater ponds (Clove Lakes Park) known to have high levels of copper in sediments. If the most abundant prey species in these areas are made more available through behavioral impairment to foraging wading birds, examining the transfer of contaminants between lower and higher trophic levels would be illustrative, particularly in light of studies that indicate Black-crowned Night-Herons do not have substantially lower reproductive rates in urban estuaries (Parsons et al. 2001).

Health assessments for wading bird nestlings and adults are also a necessary component in examining wading bird population stability in urban and non-urban systems. Wildlife Trust conducted a 2-year study to establish baseline health data for nestling wading birds in NY/NJ Harbor to describe any intercolony differences in health parameters (Newman et al. *in prep*). They found that nestlings reared on Hoffman Island in 2004 had significantly more compromised immune systems than nestlings from North Brother Island and Goose Island, although these patterns were not exhibited in 2005. A proportion of Black-crowned Night-Herons from both Hoffman and North Brother islands tested positive for West Nile virus antibodies (~10% of individuals tested) and Aspergillosis antibodies (9-50%) and antigens (29-57%) both in 2004 and 2005, indicating that disease could also play an important role (Newman et al. *in prep*). We need to understand typical ranges and interannual variation in individual nestling health to attribute these differences to specific factors, such as contaminants, parasites, and disease. Further monitoring and analysis of health parameters are an important aspect of understanding wading bird population stability in NY/NJ Harbor. Ultimately, collaborative studies of trophic transfer of contaminants from prey populations to wading birds would greatly enhance our knowledge of the effects of contaminants on wading bird reproductive success, health and population stability. Chemical risk and health assessments of wading birds would be most effectively approached by a diverse team, including avian and marine biologists, ecotoxicologists, wildlife veterinarians, analytical chemists, statisticians, and risk assessors (Rattner 2000).

Telemetry, foraging ecology and metapopulation dynamics

In this study, a small number of Black-crowned Night-Heron adults (N=7 individuals) were captured and applied with VHF radiotransmitters (Ch II); marked individuals showed strong patterns of foraging site fidelity, returning to a single foraging site throughout the season. As the majority of marked individuals did not regularly return to a breeding colony, not all of those observed foraging were breeding.

How individual reproductive success is influenced by foraging patterns could reveal the link between habitat use and population stability. One limitation of the present study was the reliance on unmarked birds; no data on the consequences of feeding at sites of varying quality could be collected. The use of telemetry to track movements of known individuals to an array of foraging sites, coupled with nest monitoring to assess productivity and toxicological effects, would greatly enhance our understanding on foraging decisions on health and population stability.

It would be useful to track Black-crowned Night-Herons with transmitters to study dispersal (Henny and Blus 1986, Koenig et al 1998, Erwin et al. 1996); foraging activity (Priede and French 1991, Endo and Sawara 2000); remote measurements of physiology or energetic status (Cooke et al. 2004); and estimates of survival, movement, or capture rates (Powell et al. 2000). A promising alternative to radiotelemetry is the use of satellite technology, which would result in a greater likelihood of success in consistently and reliably tracking Black-crowned Night-Herons. The cost of satellite transmitters (approximately $3,000 per unit) and ARGOS tracking time (approximately $1,500 per unit for this type of study) is significantly higher than the cost of VHF radio transmitters ($200 per unit) and receivers ($1,000 per unit). Using satellite telemetry, however, allows researchers to avoid logistical problems associated with VHF radio telemetry, such as signal interference, the extensive time necessary to search for marked birds both within and beyond the transmission range of the VHF radios, and the cost of physically tracking from the air, water, and ground.

Along with telemetry, other marking techniques (color bands, wing tags, dyeing) would be key in investigating the metapopulation dynamics of wading bird colonies. The metapopulation approach to studying populations involves two crucial premises: populations are structured into assemblages of local breeding populations, and migration among these local populations influences local dynamics, including the possibility of population reestablishment following local extinction (Hanski and Gilpin 1997). If a metapopulation of a species can be defined, its long-term persistence may involve individuals using a group of small patches (i.e., nesting islands, foraging “patches’) that change in suitability over time (Pickett and Thompson 1978, Buckley and Downer 1992), and are required for a sustained breeding population (Erwin et al. 1981). As human populations expand and push colonial waterbird populations to coastal estuaries, and climate change causes inundation of coastal nesting and foraging patches, these areas become far more important for overall population stability (Erwin et al. 1995), and require special conservation measures.

Between-patch movement is notoriously difficult to estimate, requiring both simultaneous study of marked individuals in numerous local populations, and development of a statistical model to estimate rates or probabilities of movement. These methods were approached in a study of a metapopulation of Roseate Terns in NY, Connecticut, and Massachusetts to investigate hypotheses about geographic and temporal variability in survival and movement (Spendelow et al. 1995). They found that, consistent with observed habitat selection prior to the breeding season for this species, movement rates varied with the identity of a destination colony rather than the colony of origin.

Russell (2006) proposes that a mechanistic understanding of population trends may be of equal or greater importance than precise abundance or trend data, as fluctuations may be explained largely by an intrinsic tendency towards coloniality rather than the result of external factors (i.e., disturbance by predators, short-term changes in nesting habitat).

Following this framework, increases or abandonments on individual islands may be attributed to colonial behavior of wading birds throughout the system, with the number of available nest sites as the main limiting factor in the global system. As colonies increase in size, there is a point at which a theoretical limit is reached where colony 'attractiveness' to immigrating individuals decreases. We need to understand rates of exchange (i.e. frequency of movement within the system and among nearby systems, whether prey resources or exposure to contaminants are as limiting to system-wide abundance as available nest sites, how they select nest sites, and how intraspecific and intraspecific interactions regulate nesting activity on islands). These factors are not well understood for wading bird colonies, and telemetry and other marking techniques are critical to understanding these processes.

Conservation

On the regional scale, the northeastern coast has the largest human population densities in the U.S. (Southworth 1989), as well as substantial nesting and wintering populations of wading birds (Butler et al. 2000). Urban ecosystems, particularly the industrialized Atlantic coast of the United States, are important breeding areas for wading birds. Prior to the 1970s, only colonial nesters such as the Black-crowned Night-Heron were known to regularly nest in the NYC area (Bull 1974). Breeding activity for several species of wading birds has expanded in NY/NJ Harbor over the past 30+ years. Wading birds nesting in the northeastern U.S. typically migrate along the Atlantic coast, coastal plain and Appalachian Mountains to winter in the southeastern U.S., West Indies, Mexico, and Central America (Hancock and Kushlan 1984, Mikuska et al. 1998). Recoveries of nestling Black-crowned Night-Herons banded in NY indicate wintering in Florida, Cuba, and Nicaragua (Bull 1974).

It is difficult to estimate numbers of Black-crowned Night-Herons in the Americas (Butler et al. 2000). Their cryptic coloration, nocturnal behavior, and tendency to nest underneath vegetation confound aerial surveys; their tendency to establish small colonies across coastal and inland landscapes makes detectability difficult. Estimates from the 1970s vary from 9,009 pairs between Maine and Virginia (Erwin 1979) to ~48,000 nesting pairs along the Atlantic Coast, with largest concentrations along the mid-Atlantic and Gulf Coast (Spendelow and Patton 1998). Kushlan et al. (2002) found >50,000 pairs Black-crowned Night-Heron abundance in the Americas, excluding Central America. Overall declines in the number of nesting pairs has been intimated (Davis 1993, Sauer et al. 2004), although variability in nesting survey methodology and the lack of systematic survey data from Mexico and Central/South America create some difficulty in assigning a reliable number, but the decline is undeniable. Regional differences, particularly declines in the mid-Atlantic and increases in the northeastern U.S., have been well-described (Erwin and Spendelow 1991).

Globally, Black-crowned Night-Herons are listed as a species of "lowest concern" (BirdLife International 2004), with and estimated global population of 430,000 to 3,600,000 individuals (Wetlands International 2002). In the Americas, Black-crowned Night-Herons are listed in the North American Waterbird Conservation Plan (2002) as a species of moderate concern with a widespread breeding distribution, undergoing an apparent population decline between 1970 and the present, although without significant threats during breeding or non-breeding seasons. They are not federally listed as threatened or endangered, although are protected as a non-game, migratory species by the Migratory Bird Treaty Act.

Along the U.S. Atlantic coast, their status varies from no special protective status other than federally defined (VA, CT, NH), species of special concern (NY, RI, MA), proposed threatened (ME), threatened (NJ), to proposed endangered (PA). This variation in regional status is confusing, particularly for areas where populations nest and forage in two state jurisdictions, such as NY/NJ Harbor. Both regional and international cooperation is crucial to wading bird conservation, and several legislative measures and treaties have contributed to habitat- and species-level protection in recent decades (e.g., North American Waterfowl Management Plan between Canada, U.S., and Mexico; Ramsar Convention between North and Central American nations). Habitat quality is as important as maintaining adequate areas of habitat for wading birds, particularly the maintenance of vegetation at colony sites, prey populations to support activity during breeding and non-breeding seasons, and hydrological management. Loss of wetland habitat in North and Central America is one of the principal conservation concerns for wading birds (Butler et al. 2000).

Additionally, the concentration of wading bird nesting activity in urban ecosystems along the U.S. Atlantic coast is a serious conservation concern. One perspective on recent expansion of wading bird nesting in urban ecosystems postulates that human activities have played a significant role in concentrating wading birds nesting in industrialized landscapes (Parsons 2006). Residential and agricultural development in rural areas exposed wading birds to agricultural pesticides (i.e., cholinesterase-inhibiting pesticides such as carbamates and organophosphates), as well as increased predation and loss of nesting and foraging habitat. Shifting to available nesting and foraging areas urban habitats, wading birds were then exposed to industrial contaminants (i.e., polycyclic aromatic hydrocarbons, chlorinated hydrocarbons, metals and organochlorines), as well as mammalian and avian predation. This movement of breeding activity may explain the perceived overall declines for several species of wading birds in the northeastern U.S., including Black crowned Night-Herons, Glossy Ibis, and Snowy Egret (Parsons et al 2001).

Ultimately, investigating foraging behavior for all breeding wading bird species is imperative to heron conservation in urban ecosystems. Heron conservation in localized or fragmented areas, requires knowledge of habitat requirements on a local scale (Kushlan and Hafner 2000). We need to fully explore habitat requirements of enigmatic wading bird species, such as Black-crowned Night Herons, to succeed in designing a comprehensive management plan for wading bird populations.

TABLES

Islands (Date confirmed)	**Waterbird families present**	**BCNH nesting 2002-2004**	**Ownership**
Long Island Sound			
Goose Island (1989)[3]	A, L, T	Yes	NYC Parks & Recreation
Huckleberry Island (1975)[1]	A, L, P	Yes	Huckleberry Indians, Inc.
East River			
North Brother (1978) [1]	A, L	Yes	NYC Parks & Recreation
South Brother (1978) [1]	A, L, P, T	Yes	Hampton Scows
Mill Rock (2003)[4]	A, L	Yes	NYC Parks & Recreation
U Thant Island	L, P	No	NYC Parks & Recreation
Arthur Kill-Kill van Kull			
Shooter's Island (1974)[2]	L, P	No	NYC Parks & Recreation
Pralls Island (1978)[2]	A	Yes*	NYC Parks & Recreation
Isle of Meadows (1988)[2]	--	No	NYC Parks & Recreation
Lower NY Harbor			
Hoffman Island (1989)[3]	A, L, P, T	Yes	National Park Service
Swinburne Island (2006)[4]	A, L, P	No	National Park Service
Jamaica Bay			
Canarsie Pol (1985)[1]	A, L, T	Yes	National Park Service
Ruffle Bar (1977) [1]	A, L, T	No	National Park Service
Ruler's Bar Hassock (1955) [5]	A,T	No	National Park Service

Table 1: Wading bird and cormorant colonies in the vicinity of the NY/NJ Harbor, 2002 to 2004. Families abbreviated as A = Ardeidae, L = Laridae, P = Phalacrocoracidae, T = Threskiornithidae. Asterisk denotes attempted breeding on Prall's Island, see Bernick 2006 for discussion. Dates following colony names refer to confirmation of wading bird nesting activity, as described in [1] Buckley and Buckley 1980, [2] Parsons 1990, [3] Downer and Leibelt 1990, [4] Bernick 2006, and [5] Meyerriecks 1957

Date	Location	# Nests	Active site?	Comments
Summer 1885	Greenridge	40+	Yes	Nests in swamp oaks
31 January 1886	New Dorp @ Garretson's Road	17+	No	17+ nests observed from one spot in oaks, 2-3 nests to a tree
23 May 1886	Greenridge	40+	No	"Someone had climbed most of the trees and disturbed the birds"
20 May 1887	New Dorp @ Garretson's Road	17+	No	No nesting occurred in 1886 or 1887, Great-horned owl nesting in the vicinity
29 May 1887	Old Place meadows along Arthur Kill	0	Possible	Seven adults flushed, no nests found
4 June 1887	New Dorp @ Garretson's Road	1	No	In a grove of shell bark hickory & other species, nest @12 ft
7 July 1893	Old Place, in northern meadows	N/A	Possible	Adults flying to and from site towards Newark Meadows
13 July 1893	Pond Meadow	"Large roost"	Yes	Adults flying to and from Newark Meadows
25 June 1895	Peggy's Point	10	No	Nest in thick oak-maple woods. Active 'in previous years'
23 May 1896	Richmond @ Gifford's Lane	"Many"	Yes	Egg collected by Captain Wainwright, saw many nesting therein 1896 and past years
16 April 1897	Richmond @ Gifford's Lane	20+	Yes	
14 April 1906	Great Kills woods	1	Possible	"Noisy" adult flushed
14 April 1907	Great Kills woods	2	Yes	Nest in a white pine at Rose Swamp
27 May 1907	Snug Harbor vicinity	"Several"	Yes	"At present bred in some private grounds and so in a measure are protected"
17 July 1909	Mariners Harbor	4	Yes	Nests in woods along South Avenue
24 August 1919	Richmond, near St. Andrews Church	N/A	Possible	"A man who resides there said they flew over every evening on their way to the meadows"
24 August 1920	Kreischerville @ Mill Creek	"A Number"	Yes	Saw a number of nests in the woods
13 September 1924	Watchogue	"A Number"	Yes	A number breeding on Mr. Hughes' farm property

Table 2: Historic Black-crowned Night-Heron nesting sites on Staten Island from William T. Davis' personal journals (1885-1924)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Black-crowned Night-Heron	130	130	208	301	274	204	n/a	n/a
Snowy Egret	11	11	70	44	45	100	n/a	n/a
Great Egret	21	21	54	81	71	97	n/a	n/a
Glossy Ibis	2	0	51	81	75	65	n/a	n/a
Cattle Egret	0	0	3	3	1	0	n/a	n/a
Little Blue Heron	0	0	1	1	3	6	n/a	n/a
Yellow-crowned Night-Heron	0	0	0	2	2	0	n/a	n/a
Green Heron	0	0	0	0	0	0	n/a	n/a
Tricolored Heron	0	0	1	0	0	0	n/a	n/a
Double-crested Cormorant	0	0	0	18	25	34	64	166
Great Black-backed Gull	220	n/a	70	185	135	112	n/a	n/a
Herring Gull	265	n/a	115	75	80	47	n/a	n/a

Table 3**:** Wading bird, cormorant, and gull nest estimates at Hoffman Island, 1999-2006. The survey in 2000 was a partial count. The next survey of wading birds on Hoffman Island is scheduled for May 2007. Data courtesy of NYC Audubon (1998-2004) and Wildlife Trust (2005-2006).

SITE NAME	**Description**	**Habitat type**	**Area (hectares)**	**Perimeter length (meters)**	**Latitude**	**Longitude**
AKRD1	Saltmarsh/mudflats and man-made structures	Salt marsh	5.94	1013.89	40.557222°	74.212639°
AKRD2	Freshwater - pond and ditch	Freshwater	0.13	225.31	40.547639°	74.232083°
AKRD3	Freshwater marsh & culvert	Freshwater	0.02	96.56	40.541167°	74.237389°
AKRD5	Shoreline/mudflats with localized salt marsh fragments (<0.01 ha)	Shoreline	4.03	1641.53	40.536944°	74.245139°
AKRD6	Saltmarsh	Salt marsh	2.46	949.51	40.520000°	74.239722°
APGO	Freshwater ponds & stream	Freshwater	0.77	1271.38	40.638056°	74.102222°
ARMA	Saltmarsh/mudflats	Salt marsh	5.82	2092.15	40.642778°	74.177500°
AUST	Shoreline (beach & rocks)	Shoreline	0.91	1094.35	40.615278°	74.062500°
BRCK	Saltmarsh/creeks	Salt marsh	0.15	386.24	40.632500°	74.183889°
BRTN	Shoreline (beach)	Shoreline	0.23	547.18	40.497639°	74.240972°
CLOV	Freshwater ponds & streams	Freshwater	15.02	4136.01	40.621111°	74.115278°
CONF	Shoreline (beach)	Shoreline	3.48	4152.11	40.500000°	74.253194°
CRES	Shoreline (beach and jetty)	Shoreline	0.66	498.90	40.535833°	74.145556°
CSIF	Playing fields, lawn	Terrestrial	5.95	880.5	40.604377°	74.152503°
EIBS	Freshwater ponds	Freshwater	2.55	1440.7	40.611359°	74.081084°
FKLA1	Landfill - shoreline / mudflats (Main Creek)	Salt marsh	30.57	3798.05	40.587917°	74.180000°
FKLA2	Landfill - runoff retention ponds	Freshwater	5.16	2510.58	40.578333°	74.170833°
FKLA3	Landfill - Richmond Creek	Salt marsh	19.13	3717.59	40.574722°	74.184444°

Table 4: Sampling sites in Staten Island, NY (Richmond Co.), 2002-2004. Site names in bold represent location of prey sampling activity (Ch. IV). See figures in Appendix A for corresponding aerial images. Part I.

SITE NAME	Description	Habitat type	Area (hectares)	Perimeter length (meters)	Latitude	Longitude
FKLA4	Landfill - shoreline, mudflats and skim booms at Main Creek	Shoreline	6.13	1271.38	40.577917°	74.180833°
FKLA5	Landfill - salt marsh fragments, mudflat with artificial structures	Salt marsh	1.43	1625.44	40.578750°	74.193333°
FKLA6	Landfill - salt marsh and mudflats	Salt marsh	3.99	3299.16	40.566667°	74.210139°
FRNT1	Shoreline (jetties, pilings, and rocky shore, concrete debris)	Shoreline	0.51	289.68	40.635833°	74.072861°
FRNT2	Shoreline (rocky shore, concrete debris)	Shoreline	1.15	1062.17	40.623333°	74.071389°
FTWA1	Shoreline (sand beach, mudflats, rock breakwaters)	Shoreline	2.87	2977.29	40.599444°	74.053056°
FTWA2	Shoreline (rocky beach, granite structures)	Shoreline	0.58	933.42	40.605556°	40.605556°
FTWA3	Playing fields, cultivated grass	Terrestrial	2.54	708.11	40.602222°	74.055556°
GBPO	Fresh/brackish pond, interrupted tidal flow	Freshwater	6.86	1319.66	40.629167°	74.178333°
GRKI1	Salt marsh (~1.2 ha), mudflats and sand beach	Salt marsh	2.94	1705.90	40.544722°	74.120139°
GRKI2	Shoreline (sand beach, rocky and wood bulkheads)	Shoreline	12.08	5600.52	40.543611°	74.127500°
HIRO	Freshwater ponds, forested wetlands	Freshwater	1.69	1199.67	40.580520°	74.122438°
KVKF	Playing field, cultivated grass	Terrestrial	3.05	740.5	40.638228°	74.118728°
KVKS1	Shoreline (man-made structures and debris)	Shoreline	0.55	1335.76	40.645278°	74.101667°
KVKS2	Shoreline (mudflats and man-made structures	Shoreline	2.46	627.64	40.637083°	74.152778°
LEMC3	Shoreline (sand beach and tidal pond)	Shoreline	1.70	1158.73	40.512778°	74.199444°
LEMC4	Salt marsh & Lemon Creek	Salt marsh	6.44	1512.78	40.517778°	74.201250°
LEWO	Shoreline (sand beach & mudflats)	Shoreline	5.33	2510.58	40.511389°	74.193333°

Table 4: Study areas in Staten Island, New York (Richmond Co.). Site names in bold represent location of prey sampling activity (Ch. IV). See figures in Appendix A for corresponding aerial images. Part II.

SITE NAME	Description	Habitat type	Area (hectares)	Perimeter length (meters)	Latitude	Longitude
MAHA	Playing field, cultivated grass	Terrestrial	1.89	611.55		
MAIN1	Salt marsh at Main Creek, Travis Ave. bridge	Salt marsh	0.53	756.39	40.598333°	74.175556°
MAIN2	Salt marsh at Main Creek, Signs Ave. culvert	Salt marsh	0.12	209.21	40.602500°	74.171540°
MILL	Shoreline (sand beach & jetty)	Shoreline	5.70	1979.49	40.563333°	74.094722°
MTLT	Terrestrial (uncultivated grasslands)	Terrestrial	39.46	2687.60	40.507873°	74.221612°
MTLO	Freshwater ponds	Freshwater	1.57	756.39	40.507873°	74.221612°
NECK 1	Salt marsh at Neck Creek, west of Route 440	Salt marsh	4.93	1786.37	40.596667°	74.194167°
NECK 2	Salt marsh at Neck Creek, east of Route 440	Salt marsh	3.80	933.42	40.597222°	74.188333°
OAKW	Shoreline (sand beach, canals, and wet meadow)	Shoreline	3.26	3655.21	40.552778°	74.109306°
OLDP2	Salt marsh, creek, tidal mudflats	Salt marsh	1.06	1142.63	40.629444°	74.186667°
OLDP3	Salt marsh, creek, tidal mudflats	Salt marsh	1.11	595.46	40.626111°	74.180278°
OLDP4	Salt marsh, creek, tidal mudflats	Salt marsh	0.29	354.06	40.621806°	74.177361°
RVRD	Salt marsh, creek and tidal mudflats	Salt marsh	6.75	1786.37	40.616667°	74.194722°
SAWM	Salt marsh, creek, tidal mudflats	Salt marsh	1.69	1029.98	40.608194°	74.188611°
SBEA	Shoreline (sand beach and jetty)	Shoreline	7.07	2269.18	40.591667°	74.062778°
SGEO1	Shoreline (rocky, man-made structures and debris)	Shoreline	5.60	2912.91	40.648194°	74.080000°
SGEO2	Shoreline (rocky, man-made structures and debris)	Shoreline	14.70	1802.47	40.641667°	74.071667°
SHAR	Shoreline (sand beach and pier)	Shoreline	0.70	1609.34	40.510575°	74.210194°
SILV	Freshwater reservoir with rock/forested shore)	Freshwater	19.38	2124.33	40.627778°	74.095417°
SNUG	Freshwater ponds	Freshwater	1.26	804.67	40.641538°	74.10527°
TOTT	Shoreline and barge remnants	Shoreline	0.26	965.61	40.513333°	74.251306°
VICT	Salt marsh and debris	Salt marsh	0.29	514.99	40.585278°	74.204444°
WILT	Playing fields, cultivated grass	Terrestrial	3.75	772.49	40.605556°	74.158333°
WILL	Freshwater pond	Freshwater	1.88	740.30	40.605556°	74.158333°
WOLF	Freshwater pond and culverts	Freshwater	6.88	1609.34	40.514722°	74.192222°

Table 4: Study areas in Staten Island, New York (Richmond Co.). Site names in bold represent location of prey sampling activity (Ch. IV). See figures in Appendix A for corresponding aerial images. Part III.

2001 (N = 7 observations): 5/2 H, 5/4 H, 5/7 L, 6/3 H, 7/5 H, 7/7 L, 7/23 L
2002 (N = 22 observations): 3/21 L, 3/29 H, 3/31 H, 4/3 L, 4/7 H, 4/11 H, 4/17 L, 5/1 L, 5/7 H, 5/9 H, 5/17 L, 5/24 H, 6/8 H, 6/15 L. 6/24 L, 7/3 L, 7/12 H, 7/17 L, 7/25 H, 7/31 L, 8/13 L, 8/21 H
2003 (N = 19 observations): 3/24 L, 3/28 H, 4/6 L, 4/13 H, 4/20 L, 4/24 L, 5/1 H, 5/6 L, 5/13 H, 5/26 H, 6/6 L, 6/17 L, 7/10 H, 7/17 L, 7/24 H, 7/31 L, 8/15 L, 8/23 H, 8/29 L
2004 (N = 18 observations): 3/28 L, 4/5 H, 4/10 L, 4/18 H, 4/25 L, 5/5 H, 5/12 L, 5/18 H, 5/25 H, 6/1 H, 6/9 L, 6/18H, 6/27 L, 7/6 L, 7/15 H, 7/25 L, 8/8 H, 8/19 L

Table 5: Dates of flight line observations of Hoffman Island, 2001 -2004. H and L represent high and low tide counts, respectively.

Year	**2002**	**2003**	**2004**
Number of Observations	506	572	611
Mean Vector (μ)	262.098°	262.919°	282.274°
Length of Mean Vector (r)	0.556	0.605	0.621
Circular Standard Deviation	62.106°	57.439°	55.891°
Rayleigh Test (Z)	156.268	209.377	235.932
Rayleigh Test (p)	p<0.00001	p<0.00001	p<0.00001
Watson's U^2 Test (Uniform, U^2)	9.359	12.317	13.602
Watson's U^2 Test (p)	< 0.005	< 0.005	< 0.005

Tide	**High Tide (± 1 hour)**	**Low Tide (± 1 hour)**
Number of Observations	714	975
Mean Vector (μ)	271.022°	269.2°
Length of Mean Vector (r)	0.584	0.591
Circular Standard Deviation	59.445°	58.761°
Rayleigh Test (Z)	243.339	340.578
Rayleigh Test (p)	p<0.00001	p<0.00001
Watson's U^2 Test (Uniform, U^2)	14.036	19.887
Watson's U^2 Test (p)	< 0.005	< 0.005

Table 6: Flight orientation analyses by year and tide for Black-crowned Night-Herons departing Hoffman Island, using Watson’s U2 and Rayleigh’s Test.

Month	**March**	**April**	**May**	**June**	**July**	**August**
Number of Observations	4	224	492	617	335	17
Mean Vector (μ)	240°	269.044°	272.479°	274.444°	258.904°	268.255°
Length of Mean Vector (r)	0.72	0.6	0.6	0.585	0.579	0.646
Circular Standard Deviation	46.457°	57.899°	57.931°	59.322°	59.9°	53.602°
Rayleigh Test (Z)	2.073	80.678	177.006	211.22	112.297	7.085
Rayleigh Test (p)	0.125	p<0.00001	p<0.00001	p<0.00001	p<0.00001	p=0.000415
Watson's U^2 Test (Uniform, U^2)	**N/A**	4.771	10.091	12.161	6.918	0.487
Watson's U^2 Test (p)	**N/A**	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

N/A: Minimum necessary sample size for Watson's U^2 Test (N=10)

Table 7: Flight orientation analyses by month for Black-crowned Night-Herons departing Hoffman Island, using Watson's U2 and Rayleigh's Test.

Tidal cycle = *Low, Rise/Fall, High* (for salt marsh and shoreline sites only)

Patch size = *Small* (1-3 hectares), *Medium* (3-20 ha), *Large* (>20 ha)

Age class = *Juvenile* (in basic plumage, birds <1 year-old), *Immature* (in intermediate plumage, birds 1 to 2 years-old), *Adult* (birds 3+ years-old), and *Adult-Juvenile groups (*adults and juveniles flying into a site in unison or feeding within 5 meters)

Time intervals = evening (2000-2300 h), midnight (2300-0200 h), and pre-dawn (0200-0500 h)

Strike rate = number of strikes per minute

Capture success = percent of successful captures per number of observed strikes

Prey species = fish, crab, shrimp, rodent, annelid worm/earthworm

Prey size = Ranked size relative to bill length (25% of bill length = ~20mm; 50%= ~40mm; 75%= ~60mm, 100%= ~80mm)

Bill length (total culmen) of Black-crowned Night-Herons = 76.6±4.9mm (Gross 1923), 80.1±3.0mm (Bernick unpub. data)

Foraging behaviors:

Foraging	**Movement**	**Maintenance**	**Intraspecific interactions**
Scan	Step	Rest	Vocalize
Bill bait	Walk	Drink	Chase
Crouch	Run	Wing flap	
Extend neck	Fly	Head shake	
Handle	Hop	Preen	
Feed	Flush	Stand	
Pick	Swim	Shake	
Plunge	Fall	Defecate	
Strike		Stretch	
		Open bill	

Table 8: Parameters measured in site surveys and observations of Black-crowned Night-Herons (Ch III)

Habitat type	**Site**	**# Birds**	**# Obs periods**	**Site**	**# Birds**	**# Obs periods**
Salt marsh	**AKRD1**	56	35	**MAIN1**	61	38
	AKRD6	32	23	MAIN2	1	1
	ARMA	93	59	NECK1	12	10
	BRCK	10	10	**NECK2**	7	7
	FKLA1	27	21	**OLDP2**	18	17
	FKLA3	144	86	**OLDP3**	11	9
	FKLA5	17	15	**OLDP4**	6	6
	FKLA6	79	50	**RVRD**	22	19
	GRKI1	72	54	**SAWM**	35	33
	LEMC4	54	44	**VICT**	4	4
Shoreline	**AKRD5**	56	40	**KVKS1**	30	26
	AUST	26	21	**KVKS2**	13	12
	BRTN	11	6	**LEMC3**	76	55
	CONF	50	40	**LEWO**	105	60
	CRES	4	4	**MILL**	45	29
	FKLA4	110	55	**OAKW**	34	26
	FRNT1	4	4	**SGEO1**	41	33
	FRNT2	11	10	**SGEO2**	27	21
	FTWA1	138	82	**SHAR**	21	15
	FTWA2	17	15	**TOTT**	36	27
	GRKI2	463	188			
Freshwater	**APGO**	38	26			
	CLOV	243	206			
	FKLA2	52	42			
	GBPO	52	37			
	MTLO	14	8			
	SILV	68	53			
	WILL	77	59			
	WOLF	58	44			
Terrestrial	**FTWA3**	399	66			
	WILL	1	1			

Table 9: Observed Black-crowned Night-Herons at foraging sites on Staten Island, 2002-2004. For each foraging site, total number of individuals and number of survey nights when individuals were observed are provided. Sites in bold text represent those where focal foraging observations were taken. See Table 5 for foraging site codes descriptions.

	Arlington Marsh			**Great Kills Park**			**Main Creek**			
	2002 (8)	2003 (7)	2004 (7)	2002 (8)	2003 (7)	2004 (7)	2002 (8)	2003 (7)	2004 (7)	**Total**
Mummichog *Fundulus heteroclitus*	19	15	16	89	108	76	1955	1385	2455	6118
Atlantic Silverside *Menidia menidia*	495	789	122	87	73	116	0	1	0	1683
Grass Shrimp *Palaemonetes pugio*	19	21	27	188	171	405	53	88	29	1001
Striped Killifish *Fundulus majalis*	19	24	24	130	39	547	1	4	2	781
Alewife *Alosa pseudoharengus*	0	0	0	144	335	231	0	0	0	710
Sand Shrimp *Crangon septimspinosa*	24	21	40	3	1	0	0	0	29	118
Blue Crab *Callinectes sapidus*	7	12	17	0	1	2	0	0	2	41
Japanese Shore Crab *Hemigrapsus sanguineus*	0	1	1	0	0	4	4	3	13	26
Green Crab *Carcinus maenas*	0	0	0	4	3	10	0	0	2	19
Bluefish *Callinectes sapidus*	0	0	0	0	0	3	0	0	0	3
American Eel *Anguilla rostrata*	0	0	1	0	0	0	0	1	0	2

Table 10: Aquatic vertebrate and invertebrate abundance at salt marsh sites, 2002-2004

	Kreischer's Cove			**Great Kills Harbor**			
	2002 (8)	2003 (7)	2004 (7)	2002 (8)	2003 (7)	2004 (7)	**Total**
Grass Shrimp *Palaemonetes pugio*	601	659	844	144	95	159	2502
Atlantic Silverside *Menidia menidia*	334	141	192	285	301	335	1548
Sand Shrimp *Crangon septimspinosa*	223	145	385	0	0	12	765
Striped Killifish *Fundulus majalis*	97	144	148	7	14	30	440
Mummichog *Fundulus heteroclitus*	62	82	51	16	27	15	253
Blue Crab *Callinectes sapidus*	15	16	13	5	2	7	58
Green Crab *Carcinus maenas*	0	0	0	8	1	5	14
Herring spp *Alosa spp*	0	3	0	0	2	1	6
Northern Pipefish *Syngnathus fuscus*	0	0	0	0	2	4	6
Atlantic Needlefish *Strongylura marina*	0	0	0	1	1	2	4
American Eel *Anguilla rostrata*	0	1	1	0	0	1	3
Marsh Killifish *Fundulus confluentus*	0	0	0	0	3	0	3
Winter Flounder *Pseudopleuronectes americanus*	0	1	0	0	0	2	3

Table 11 Aquatic vertebrate and invertebrate abundance at shoreline sites, 2002-2004. Part I

	Kreischer's Cove			**Great Kills Harbor**			
	2002 (8)	2003 (7)	2004 (7)	2002 (8)	2003 (7)	2004 (7)	**Total**
Northern Searobin *Prionotus carolinus*	0	0	0	0	1	1	2
Atlantic Bluefish *Callinectes sapidus*	0	0	0	0	1	0	1
Goby spp	0	1	0	0	0	0	1
Japanese Shore Crab *Hemigrapsus sanguineus*	0	0	0	0	0	1	1
Drum spp. *Sciaenid spp*	0	0	0	0	0	1	1
Atlantic Tomcod *Microgadus tomcod*	0	0	0	0	0	1	1
Jack spp	0	0	0	0	1	0	1
Weakfish *Cynoscion regalis*	0	0	0	0	0	1	1

Table 12: Aquatic vertebrate and invertebrate abundance at shoreline sites, 2002-2004. Part II.

	Willowbrook Pond			**Little Clove Lake**			
	2002 (8)	2003 (7)	2004 (7)	2002 (8)	2003 (7)	2004 (7)	**Total**
Bluegill *Lepomis macrochirus*	47	26	54	28	25	25	205
Pumpkinseed *Lepomis gibbosus*	6	11	13	17	13	12	72
Largemouth Bass *Micropterus salmoides*	7	5	14	8	2	7	43
Killifish spp *Fundulus spp*	0	4	0	0	0	0	4
Minnow spp *Cyprinid spp*	0	0	0	1	0	2	3
American Eel *Anguilla rostrata*	0	0	0	1	0	1	2
Golden Shiner *Notemigonus crysoleucas*	1	0	1	0	0	0	2

Table 13: Aquatic vertebrate abundance at freshwater sites, 2002-2004

Site	SPECIES	N	**Mean Length (mm)**	Std. Deviation	**Mean weight (g)**	Std. Deviation
Kreischer Cove (Shoreline)	Grass Shrimp	2,090	37.52	4.95	0.63	0.26
	Mummichog	195	49.98	11.40	2.10	1.95
	Atlantic Silverside	667	72.31	14.04	2.81	1.61
	Striped Killifish	370	59.52	15.09	3.15	3.07
Arlington Marsh (Salt marsh)	Grass Shrimp	67	39.90	9.53	0.41	0.19
	Mummichog	50	62.47	17.38	4.94	4.92
	Atlantic Silverside	1,333	70.56	15.79	2.98	3.53
	Striped Killifish	64	57.73	12.43	2.59	2.38
Great Kills Marsh (Salt marsh)	Grass Shrimp	729	34.64	6.33	0.43	0.29
	Mummichog	272	57.58	17.16	3.59	2.98
	Atlantic Silverside	254	62.33	16.39	2.02	2.00
	Striped Killifish	620	60.63	17.82	3.65	3.36
Great Kills Harbor (Shoreline)	Grass Shrimp	396	37.52	5.90	0.62	0.35
	Mummichog	59	64.60	17.31	5.56	3.55
	Atlantic Silverside	865	65.81	15.55	2.40	2.47
	Striped Killifish	51	55.64	16.26	3.20	2.94
Main Creek (Salt marsh)	Grass Shrimp	170	25.16	8.52	0.21	0.16
	Mummichog	5,714	57.26	16.85	3.59	2.40
	Atlantic Silverside	1	110.00	.	11.00	.
	Striped Killifish	7	54.14	20.34	3.06	3.08
Total	Grass Shrimp	3,452	36.35	6.37	0.56	0.30
	Mummichog	6,290	57.16	16.79	3.58	2.48
	Atlantic Silverside	3,120	68.96	15.74	2.71	2.83
	Striped Killifish	1,112	59.82	16.65	3.40	3.21

Table 14: Mean length and weight of 4 common estuarine fishes sampled in Staten Island, NY, 2002-2004.

Site	SPECIES	N	**Mean length (mm)**	Std. Deviation	**Mean weight (g)**	Std. Deviation
Little Clove Lake	Bluegill	71	40.54	15.34	1.96	4.89
	Largemouth Bass	18	108.56	47.91	31.40	38.59
	Pumpkinseed	42	87.94	22.89	16.51	13.46
Willowbrook Pond	Bluegill	129	40.02	20.23	2.60	6.89
	Largemouth Bass	26	107.98	46.94	24.33	30.39
	Pumpkinseed	31	80.95	24.56	14.13	15.21
Total	Bluegill	200	40.21	18.60	2.37	6.25
	Largemouth Bass	44	108.22	46.78	27.23	33.74
	Pumpkinseed	73	84.97	23.70	15.50	14.18

Table 15: Mean length and weight of 3 common freshwater fishes sampled in Staten Island, NY, 2002-2004.

FIGURES

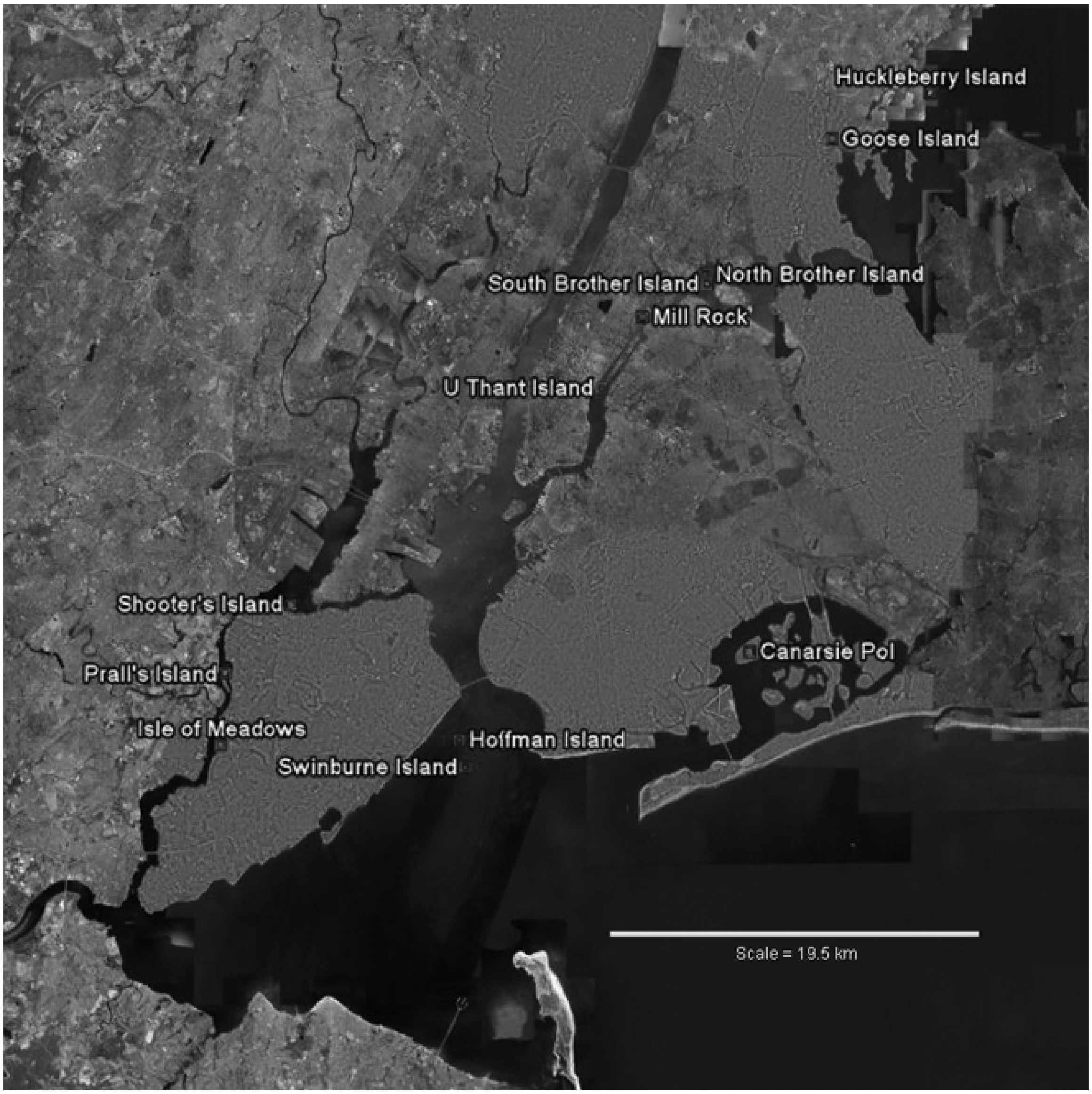

Figure 1: Wading bird and cormorant nesting colonies in the NY/NJ Harbor (2000-2006). At present, no colonial waterbirds are nesting on Isle of Meadows, Shooter's Island, or Prall's Island (Ch. I)

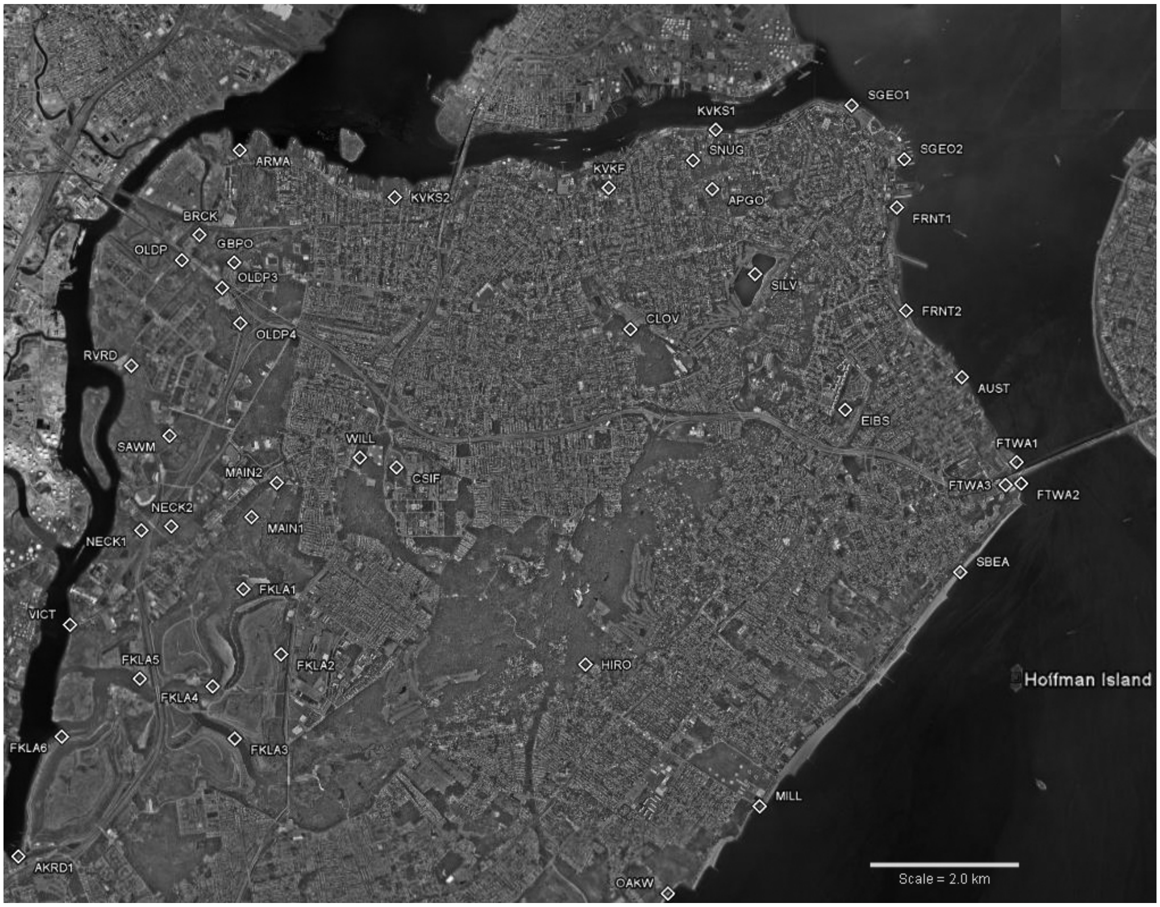

Figure 2: North end of Staten Island (Richmond Co.), NY. Diamonds denote Black-crowned Night-Heron sampling sites as referenced in Chapters II-IV. See Appendix A for individual site maps.

Figure 3: South end of Staten Island (Richmond Co.), NY. Diamonds denote Black-crowned Night-Heron sampling sites as referenced in Chapters II-IV. See Appendix A for individual site maps.

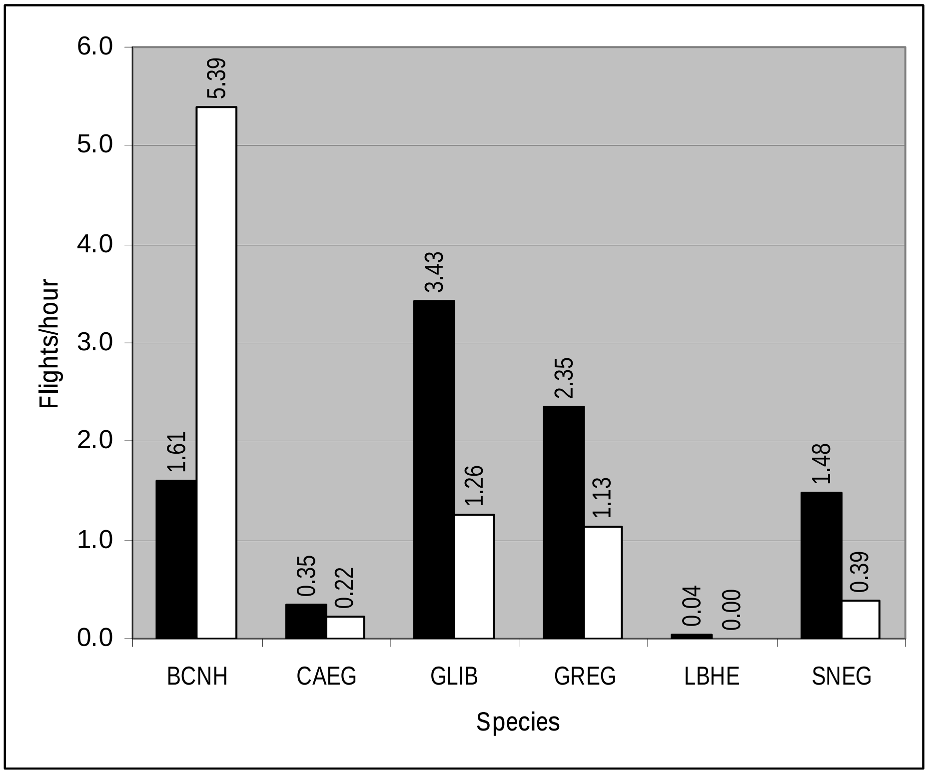

Figure 4: Evening flight rates (flights per hour) of wading bird species at Hoffman Island, May-July 2001: Black-crowned Night-Herons (BCNH), Cattle Egrets (CAEG), Glossy Ibis (GLIB), Great Egret (GREG), Snowy Egret (SNEG), and Little Blue Herons (LBHE). Black bars represent mean incoming flight rate, white bars represent mean outgoing flight rates.

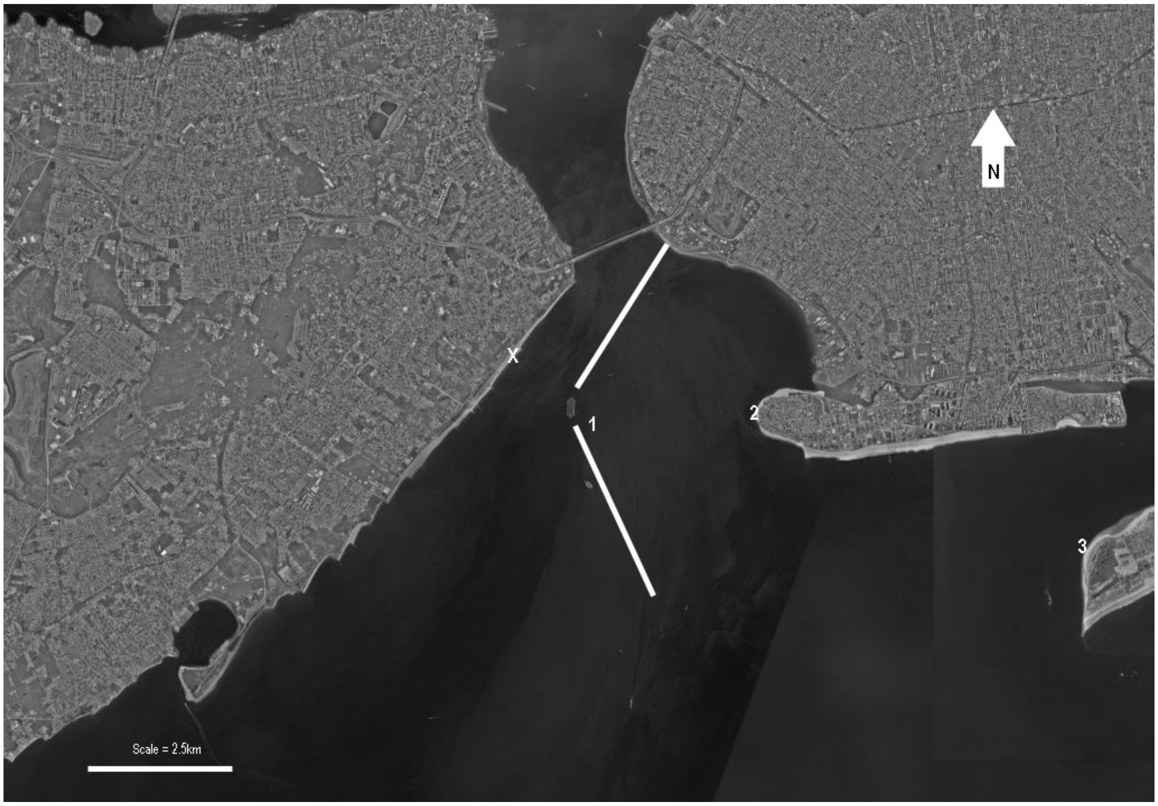

Figure 5: Map overview of foraging flight observations. X represents the main shore-based location where flight observations were conducted (South Beach, Staten Island), where flights west of the white lines could be seen. Flights to the east of the lines were observed from (1) a boat anchored southeast of Hoffman Island, (2) Sea Gate, Brooklyn, and (3) Breezy Point, Queens.

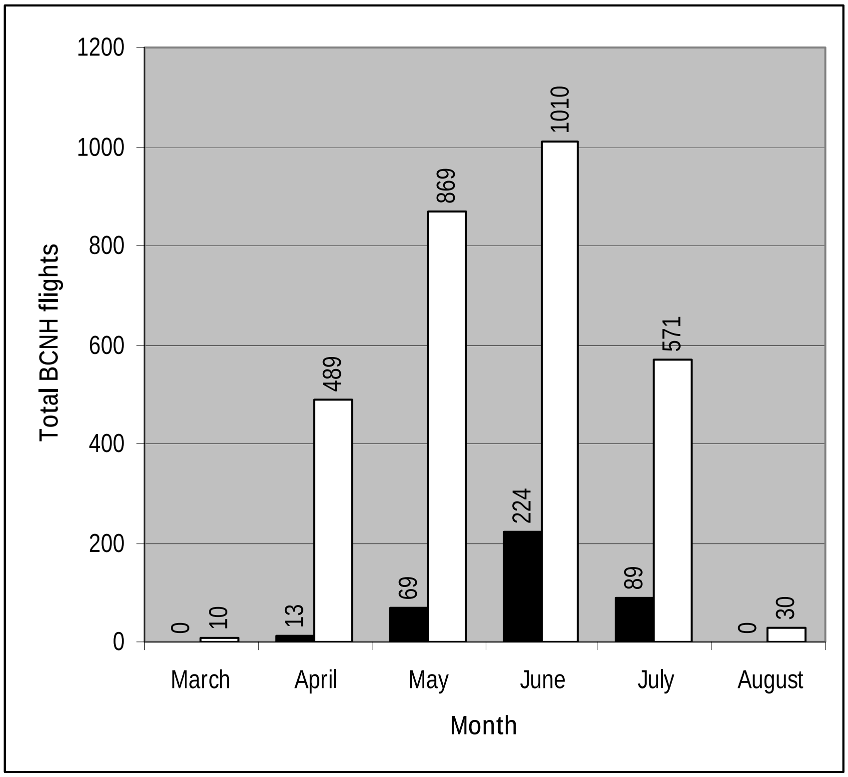

Figure 6: Black-crowned Night-Heron flights by month at Hoffman Island, 2002-2004. For 2002-2004 inclusive, black bars represent total number of incoming flights, white bars represent total outgoing flights.

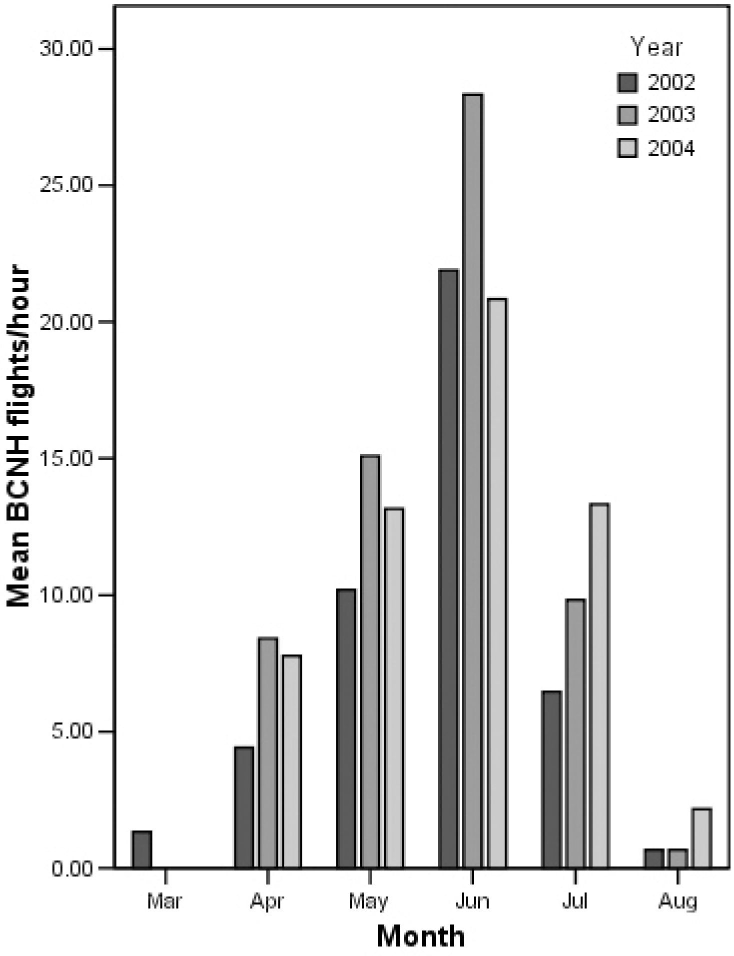

Figure 7: Mean flights per hour for Black-crowned Night-Herons by month, 2002-2004. Peak flight activity occurs in June, the month of highest reproductive demands.

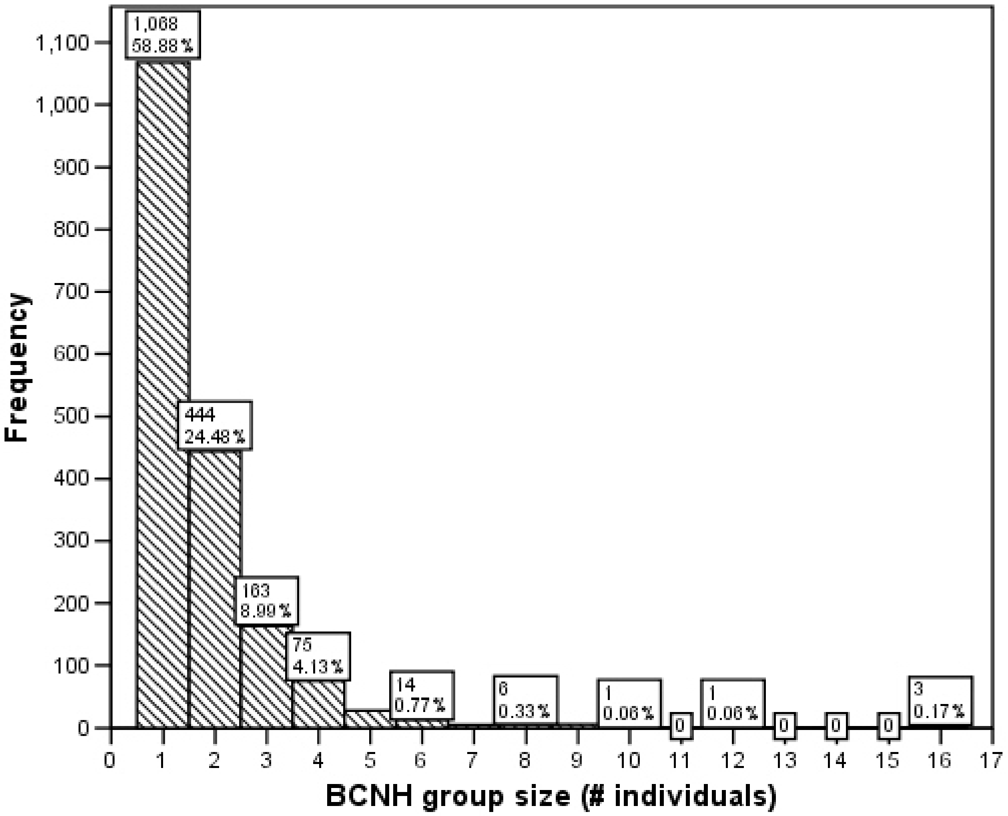

Figure 8: Group size histogram, incoming and outgoing Black-crowned Night-Heron flights, 2002-2004.

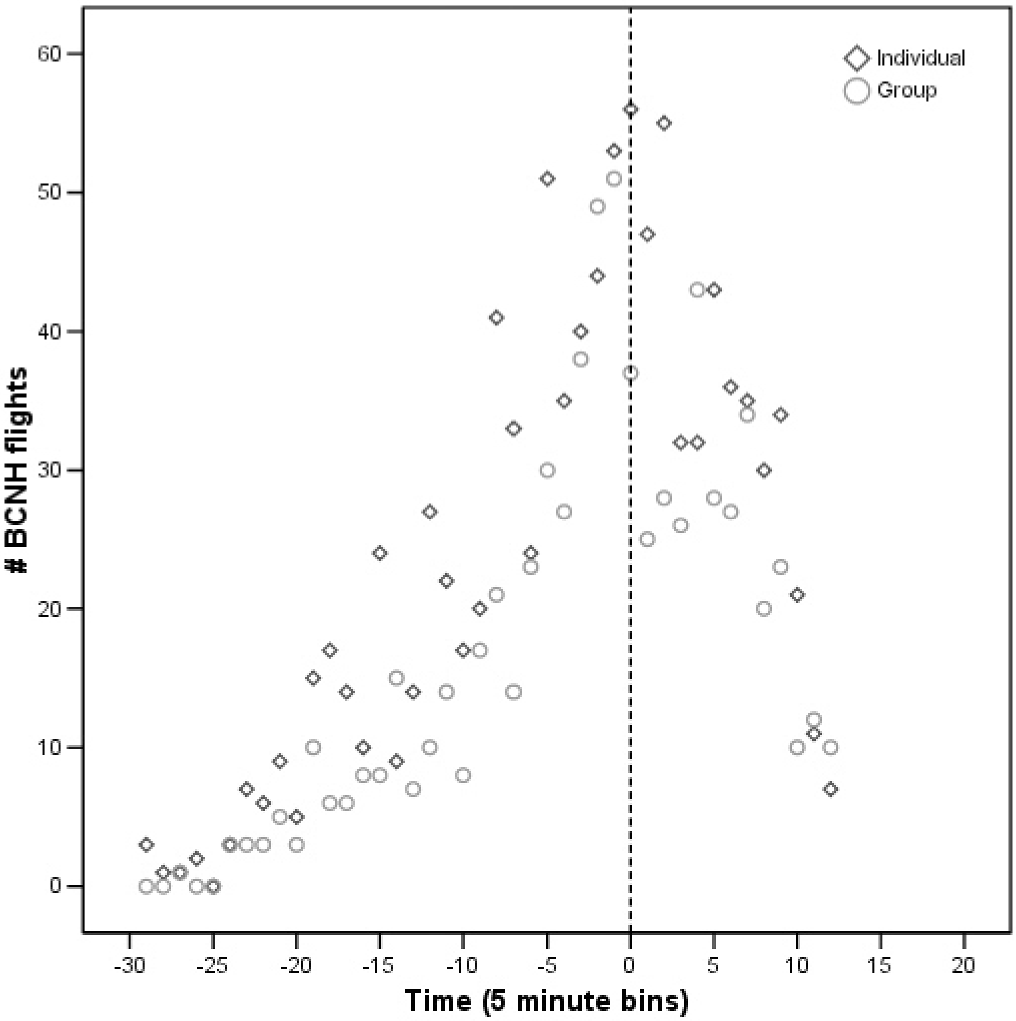

Figure 9: Timing of individual and group Black-crowned Night-Heron flights, 2002-2004. The dotted reference line at time 0 represents sunset.

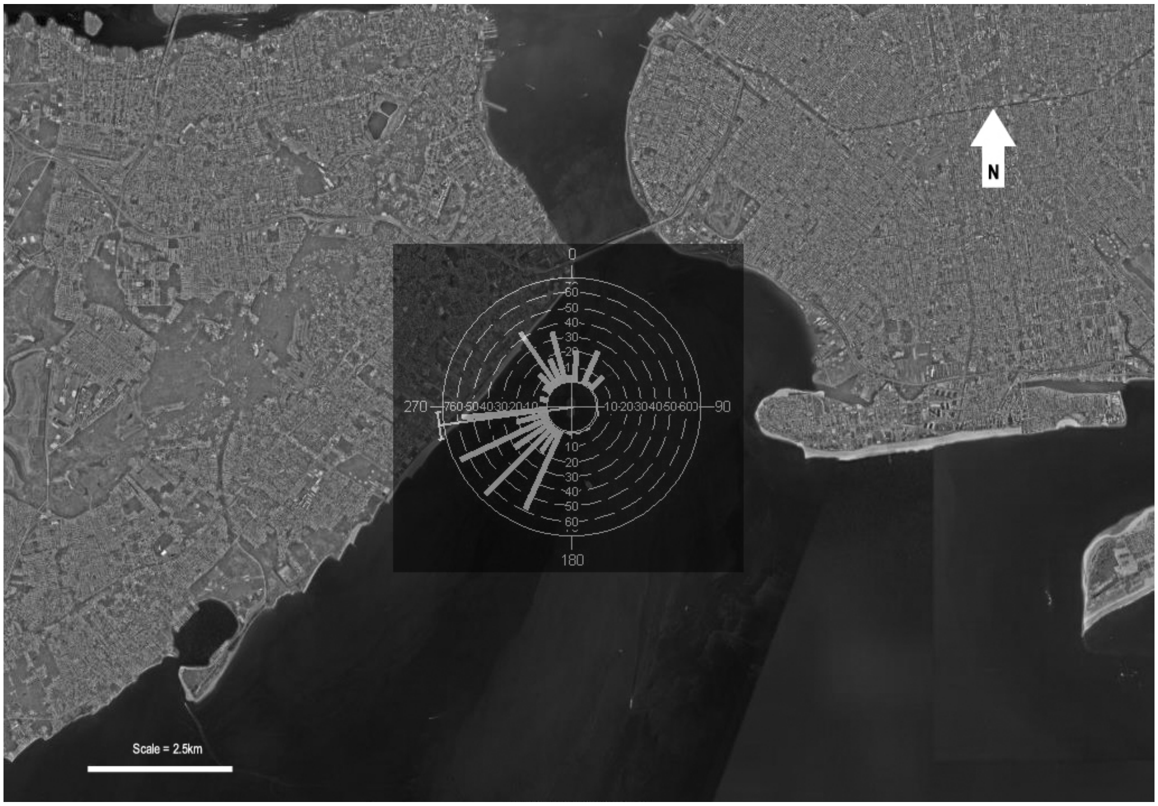

Figure 10: Circular plot of foraging flight data with reference map. White bars represent number of flights in a given direction (10º arcs), dashed lines represent increments, and the mean flight direction (with 95% CI) is denoted by the T-shaped graphic. The following circular plots represent outgoing flights from Hoffman Island, without the underlying reference map.

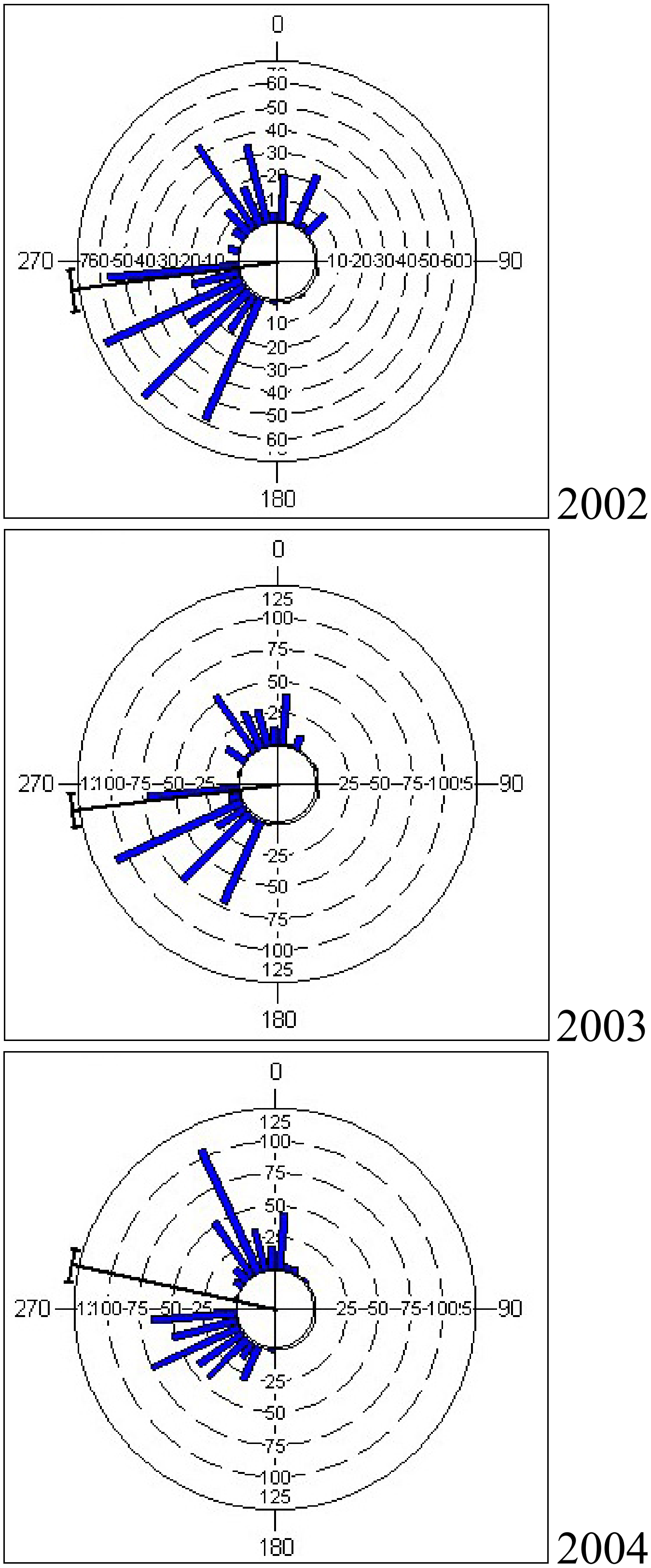

Figure 11: Flight direction of Black-crowned Night-Herons by year (2002-2004). All flights were generally directed towards the southwest and northwest.

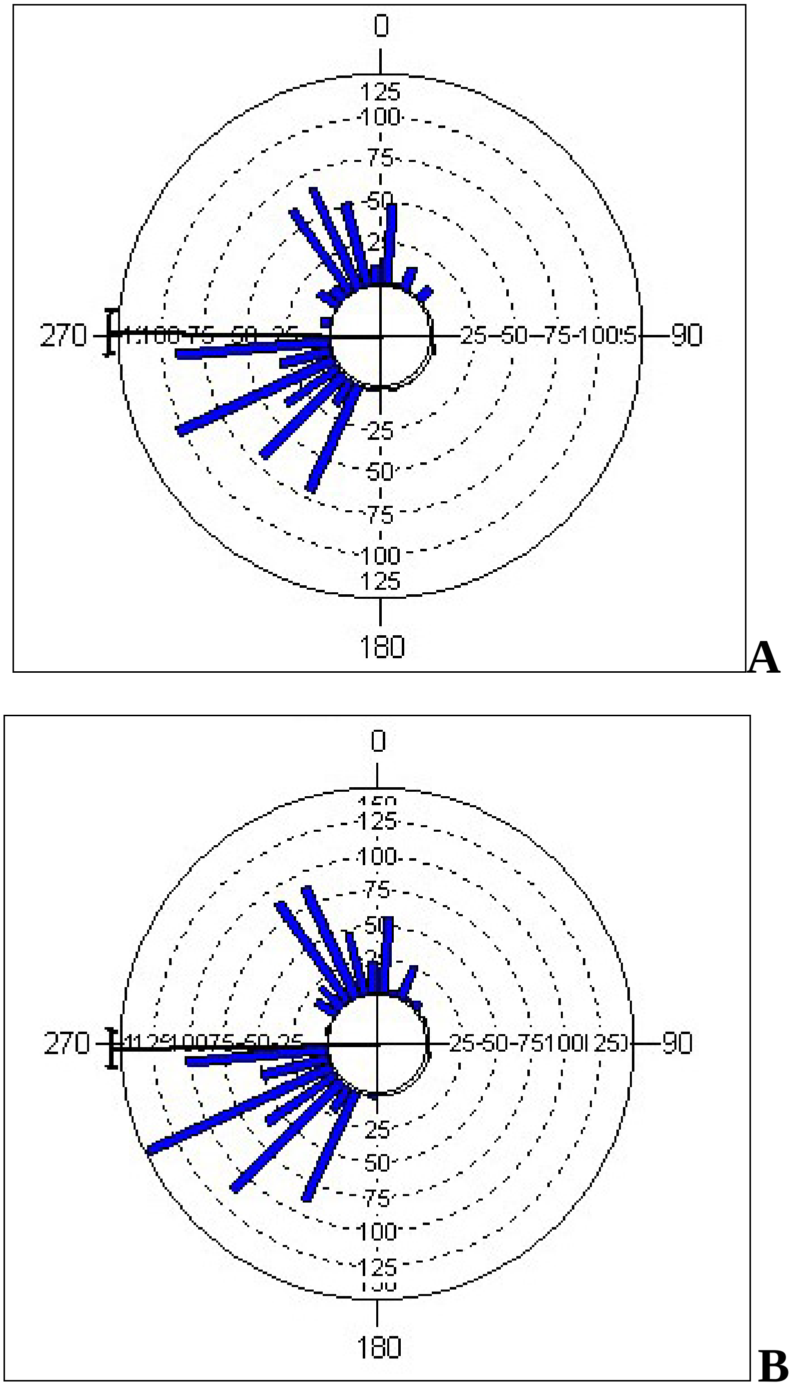

Figure 12: Flight direction of Black-crowned Night-Herons by tide. These figures represent Black-crowned Night-Herons leaving Hoffman Island during high (A) and low (B) tides. All flights were generally directed towards the southwest and northwest, with no significant difference in directionality between flights during high or low tide.

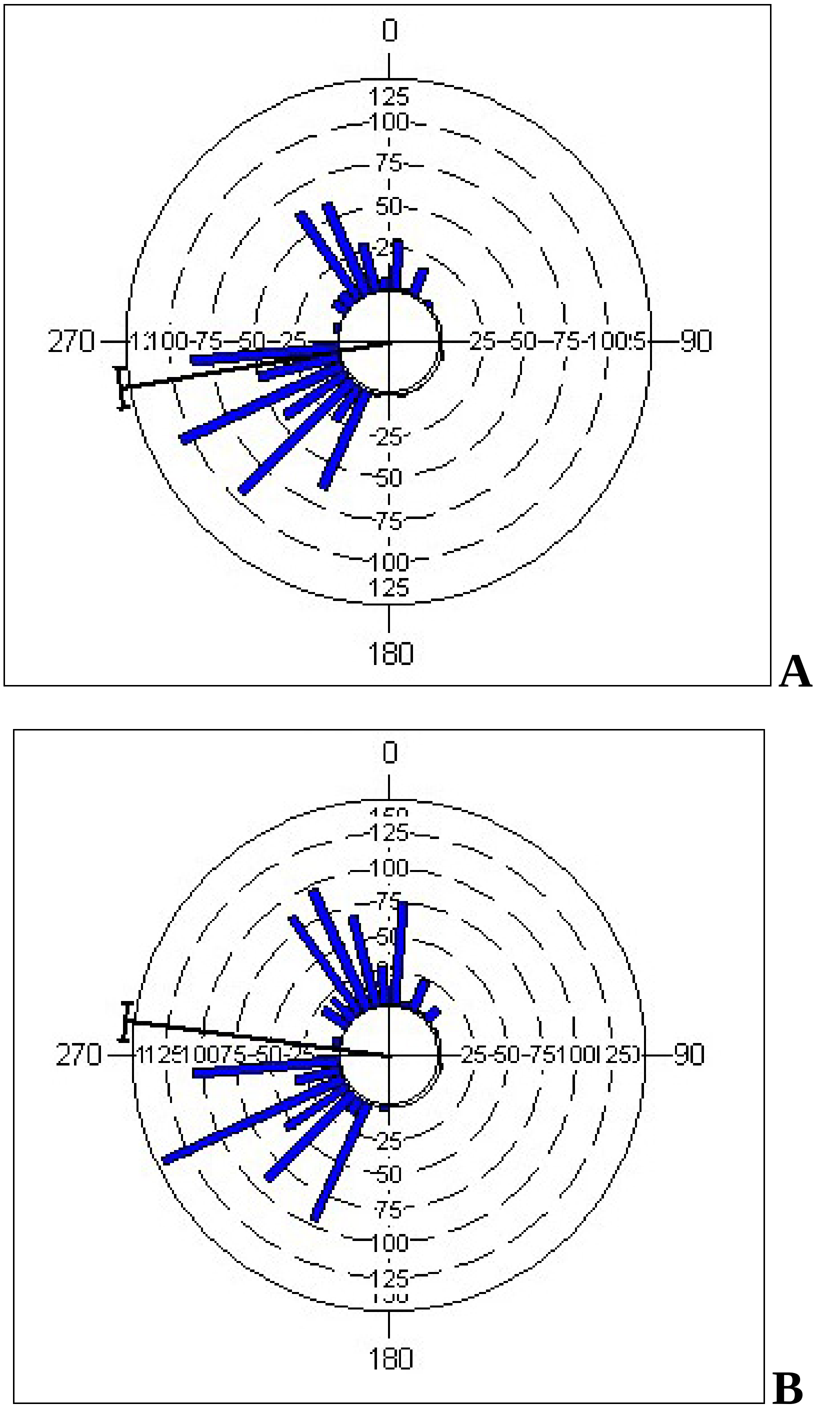

Figure 13: Flight direction of Black-crowned Night-Herons leaving Hoffman Island in groups (A) and in solitary flight (B). All flights were generally directed towards the southwest and northwest, with no significant difference in directionality between solitary and group flights.

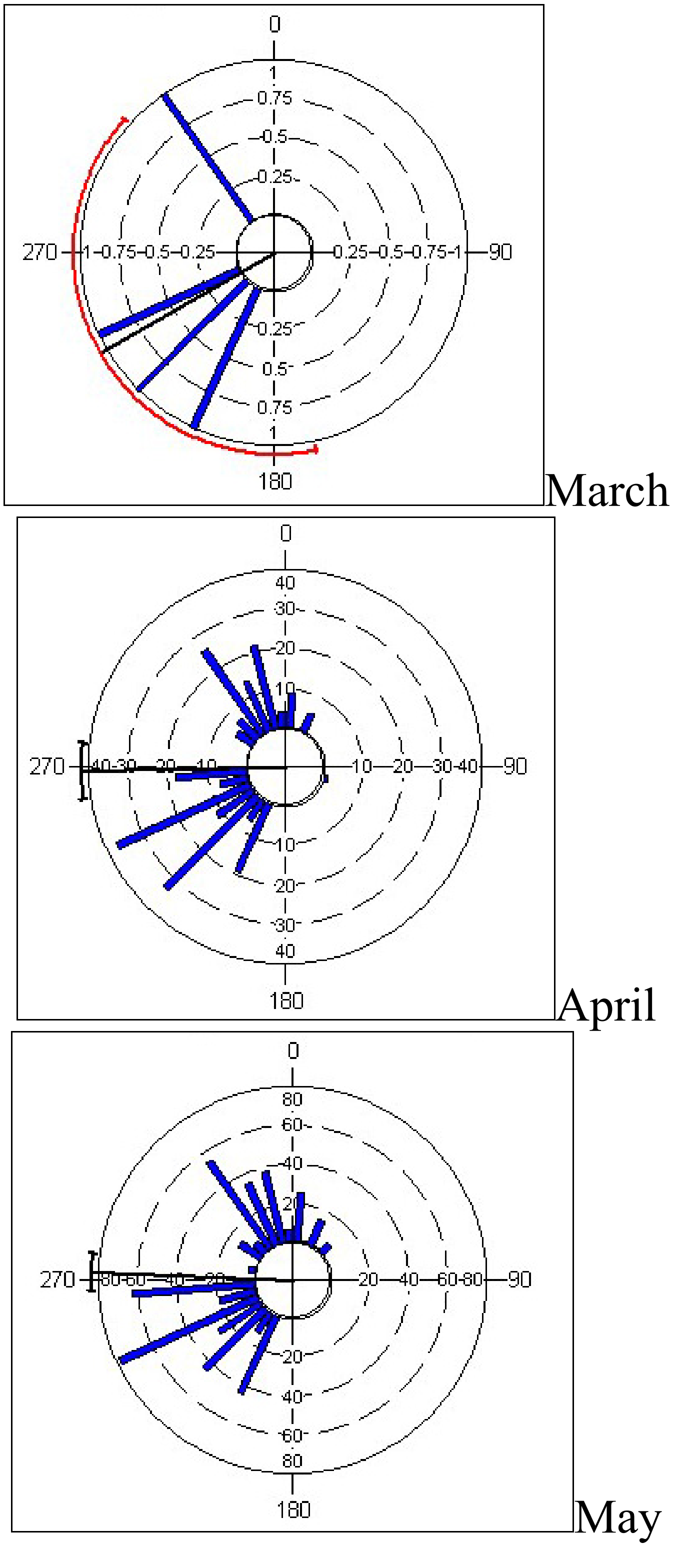

Figure 14: Flight direction of Black-crowned Night-Herons by month (March-May, 2002-2004). All flights were generally directed towards the southwest and northwest. Fewer flights were observed in March (N=4).

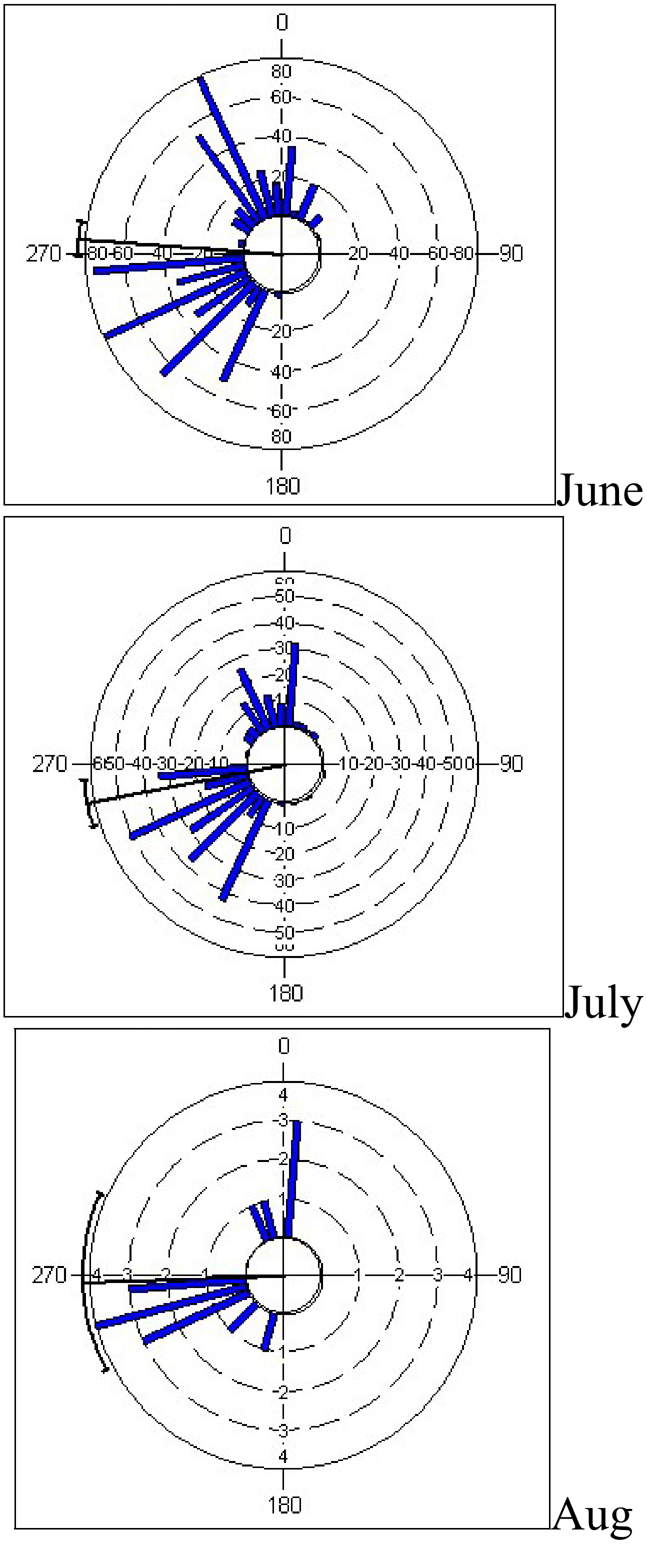

Figure 15: Flight direction of Black-crowned Night-Herons by month (June-August 2002-2004). All flights were generally directed towards the southwest and northwest. Fewer flights were observed in August, resulting in a larger 95% CI.

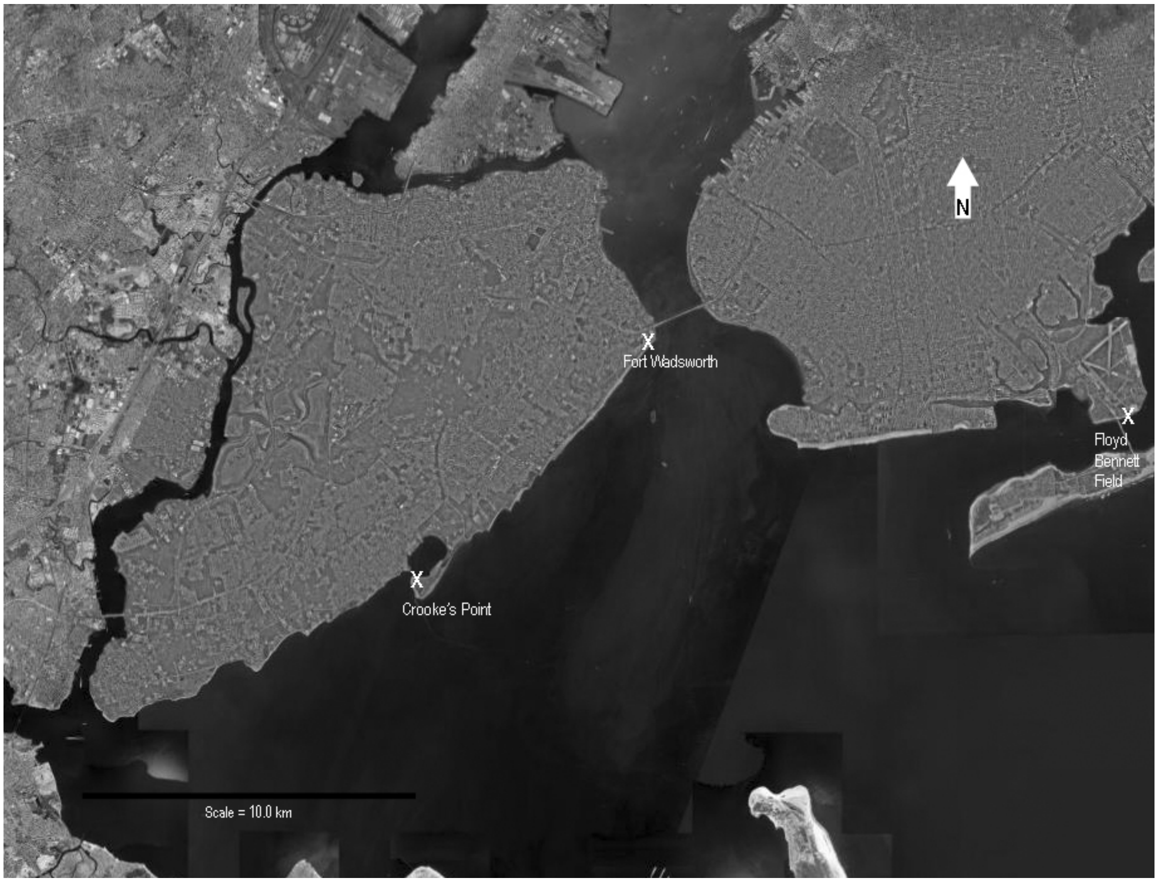

Figure 16: Trapping locations for attachment of radiotransmitters to adult Black-crowned Night-Herons, 2004 to 2005. Individuals were captured at Crooke's Point (N=4) in Great Kills National Park and Floyd Bennett Field (N=3) in Jamaica Bay.

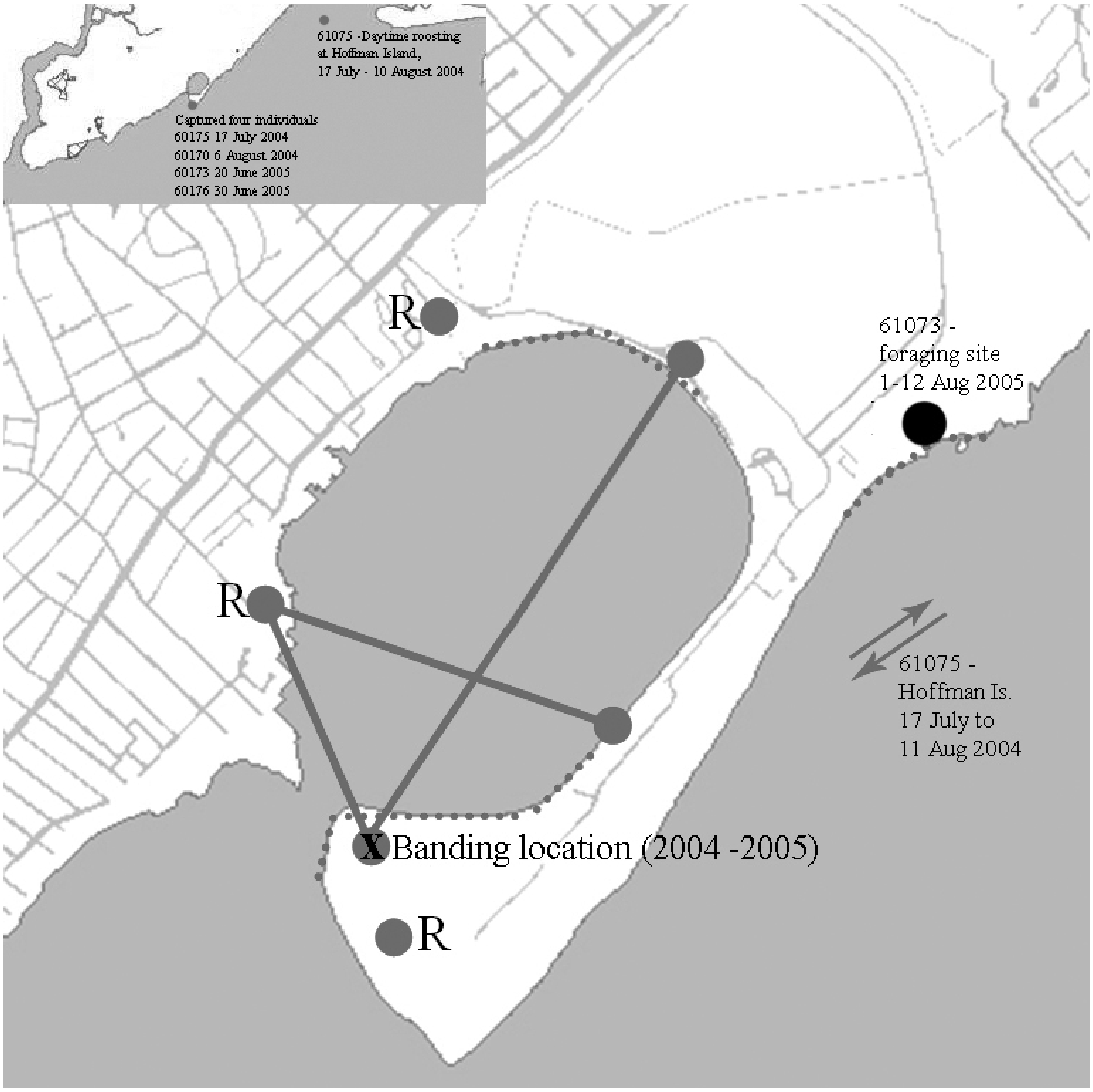

Figure 17: Radiotracking map for Black-crowned Night-Heron individuals 61070, 61073, 61075, and 61076. R represents core roost sites, dotted lines represent areas with numerous observations or fixes, solid lines represent most commonly observed flight paths. Arrows represent flights to and from Hoffman Island.

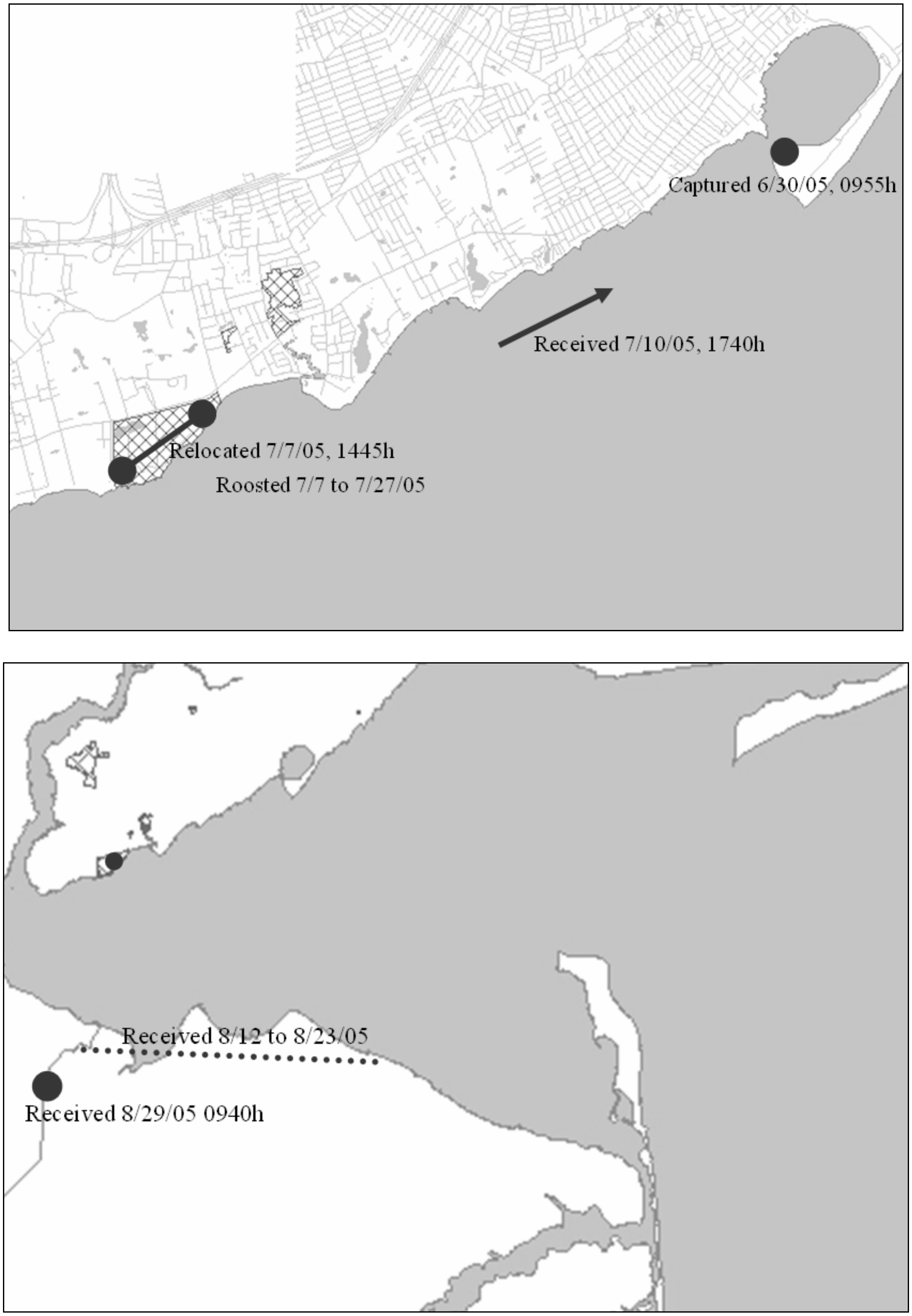

Figure 18: Radiotracking map for Black-crowned Night-Heron individual 61076. Dots represent roost sites, solid lines represent most commonly observed flight paths, dotted lines represent a general area of signal reception, and arrows represent direction of foraging flights observed.

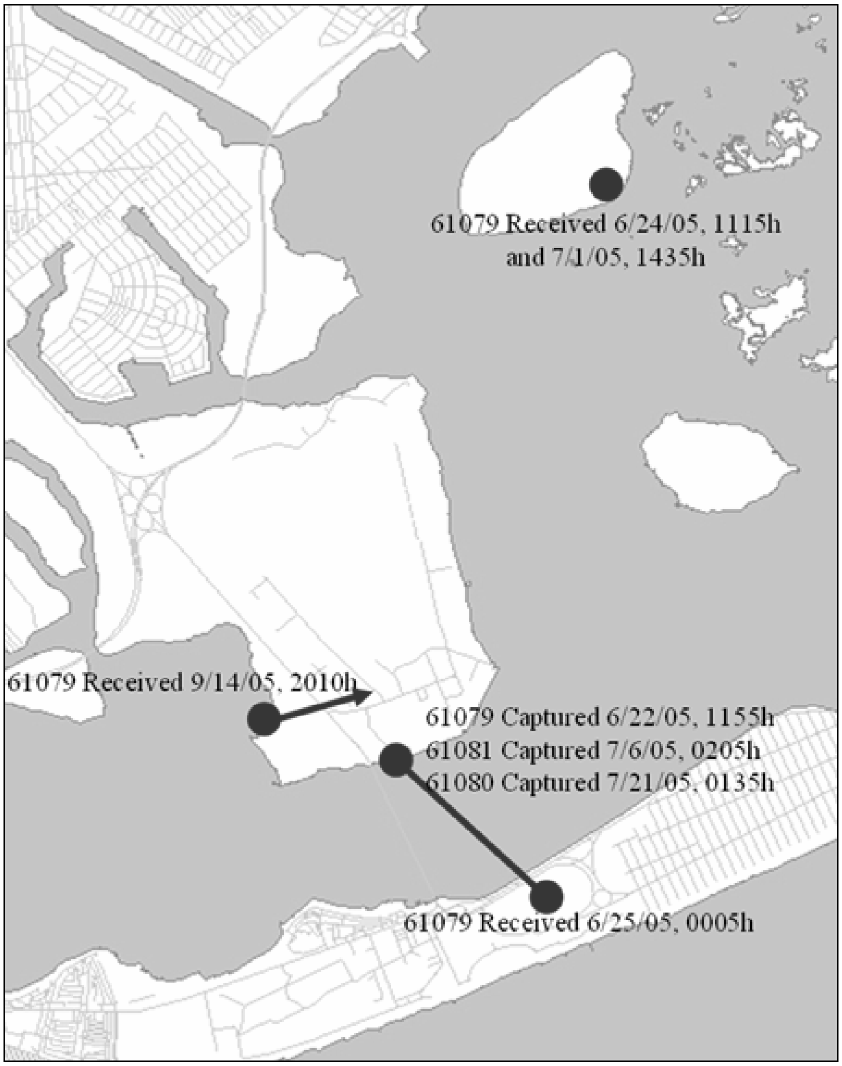

Figure 19: Radiotracking map for Black-crowned Night-Heron individuals 61079, 61080, and 61081 in Jamaica Bay, Brooklyn. Dots represent roost or breeding sites, the solid line represents most commonly observed flight path, arrows represent observed flight direction.

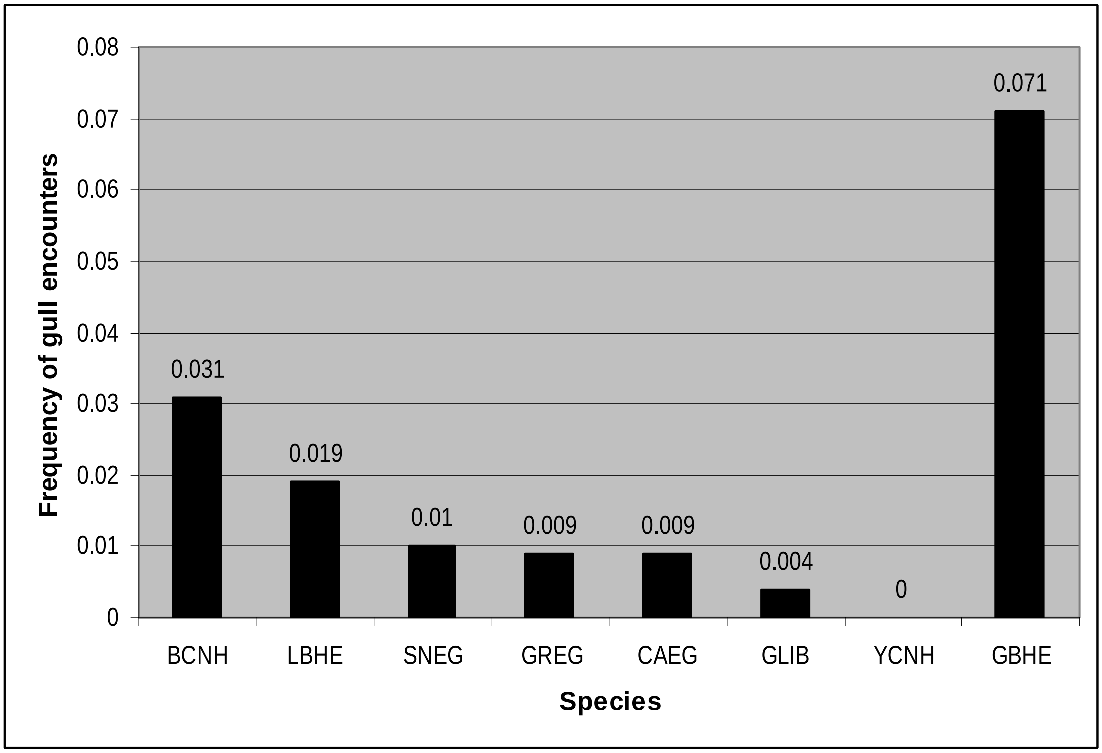

Figure 20: Frequency of gull encounters by species at Hoffman Island, 2001-2004. Of breeding species on Hoffman Island, Black-crowned Night-Herons were pursued most often by gulls, in 3.1% of total flights. Great Blue Herons (GBHE) were pursued most often; however, they typically used Hoffman Island as a roosting location before and after the breeding season.

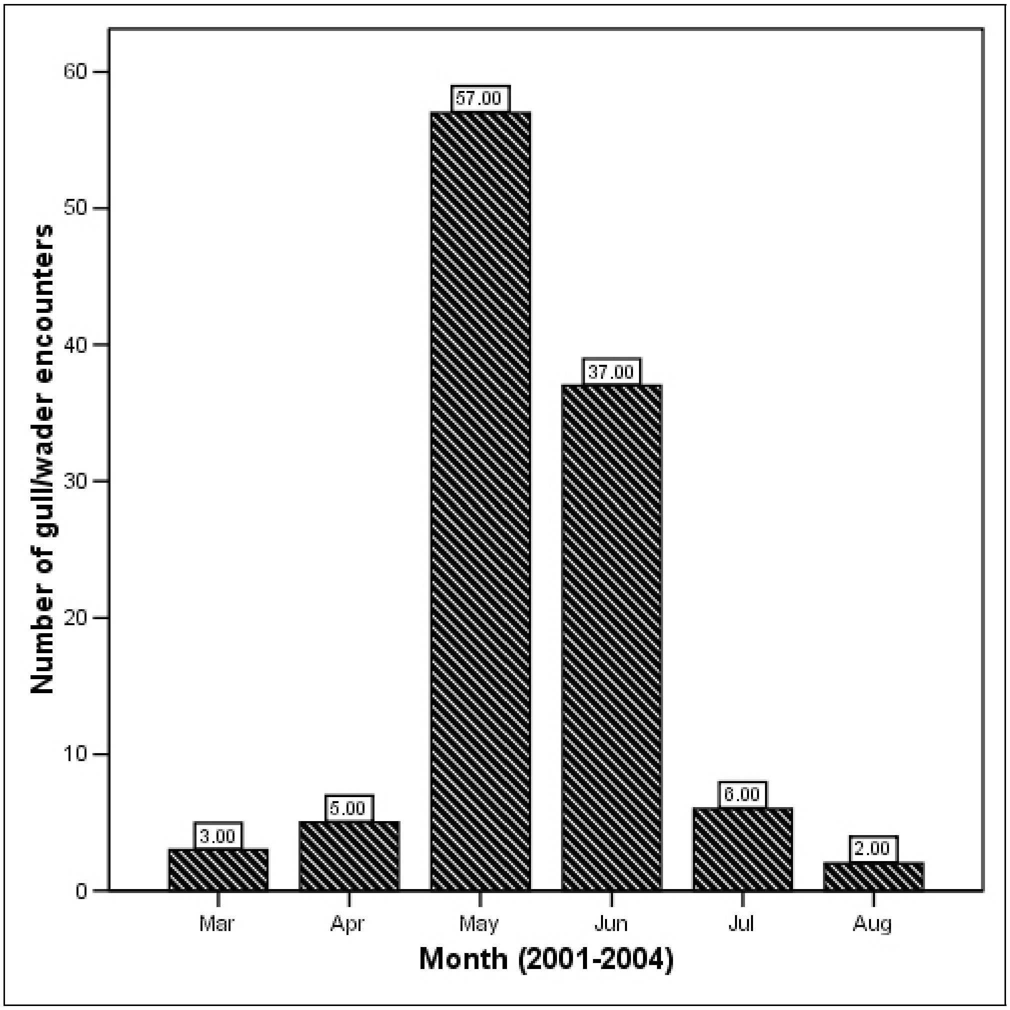

Figure 21: Total number of gull encounters by month at Hoffman Island, 2001-2004. May-June, the peak months for foraging flight activity, were when the majority of gull-wading bird encounters occurred.

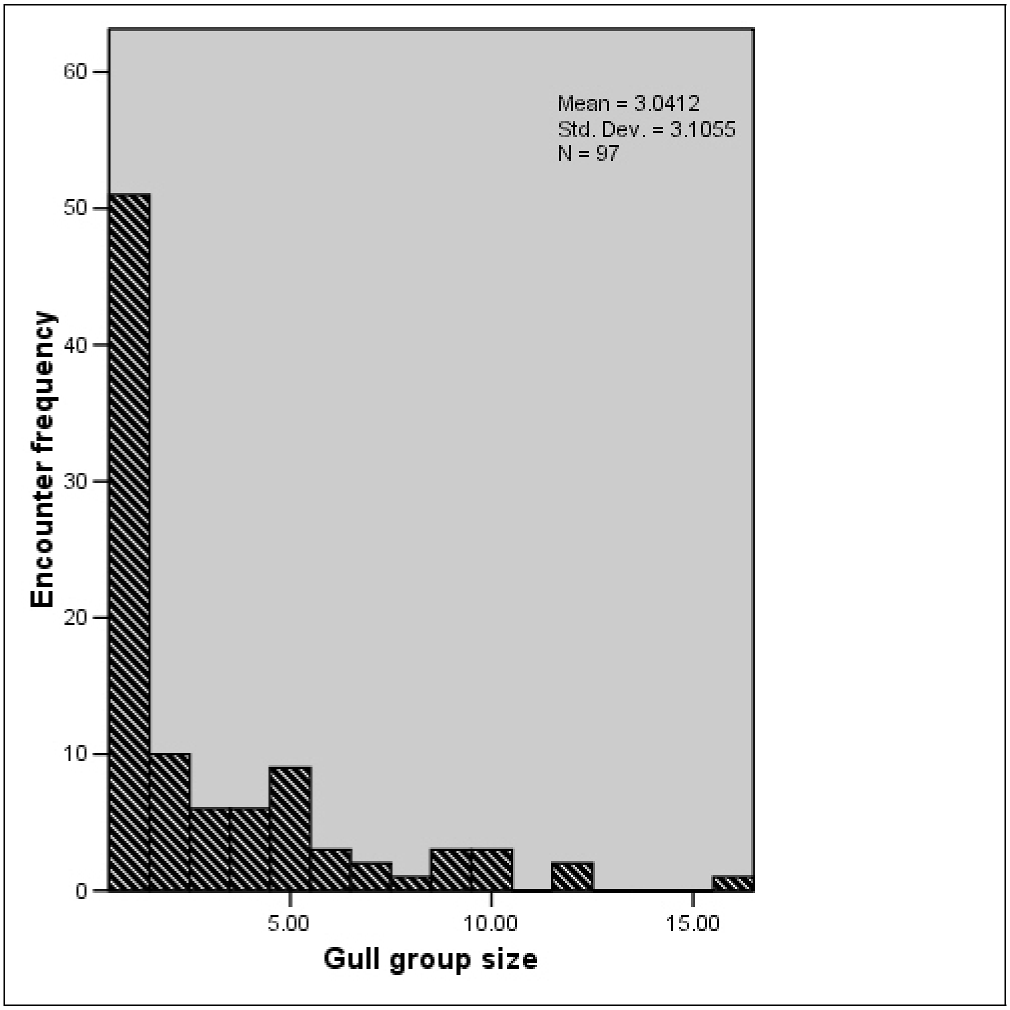

Figure 22: Gull group size relative to encounters with wading birds at Hoffman Island, 2001-2004.

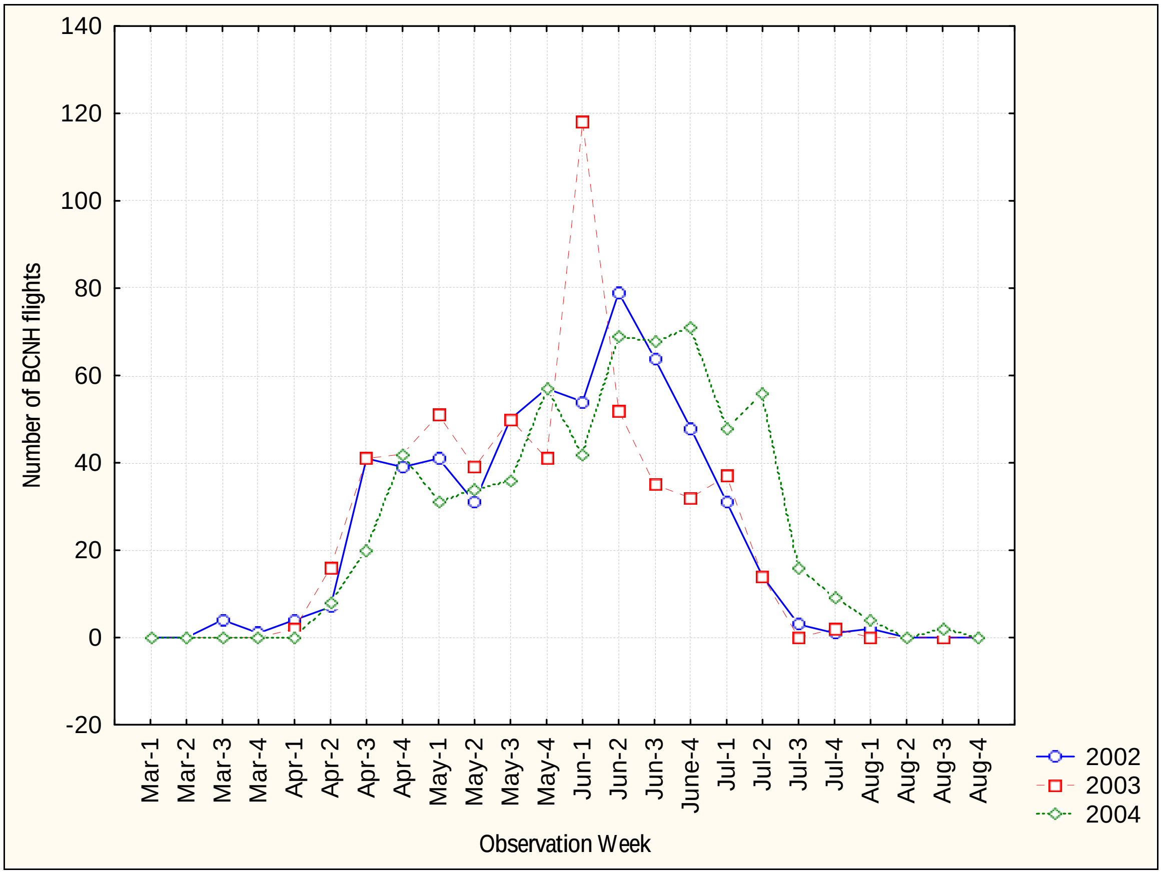

Figure 23: Black-crowned Night-Heron outgoing flights per week, 2002-2004. The cases on the x-axis represent weeks (i.e., Mar-1 = first week in March).

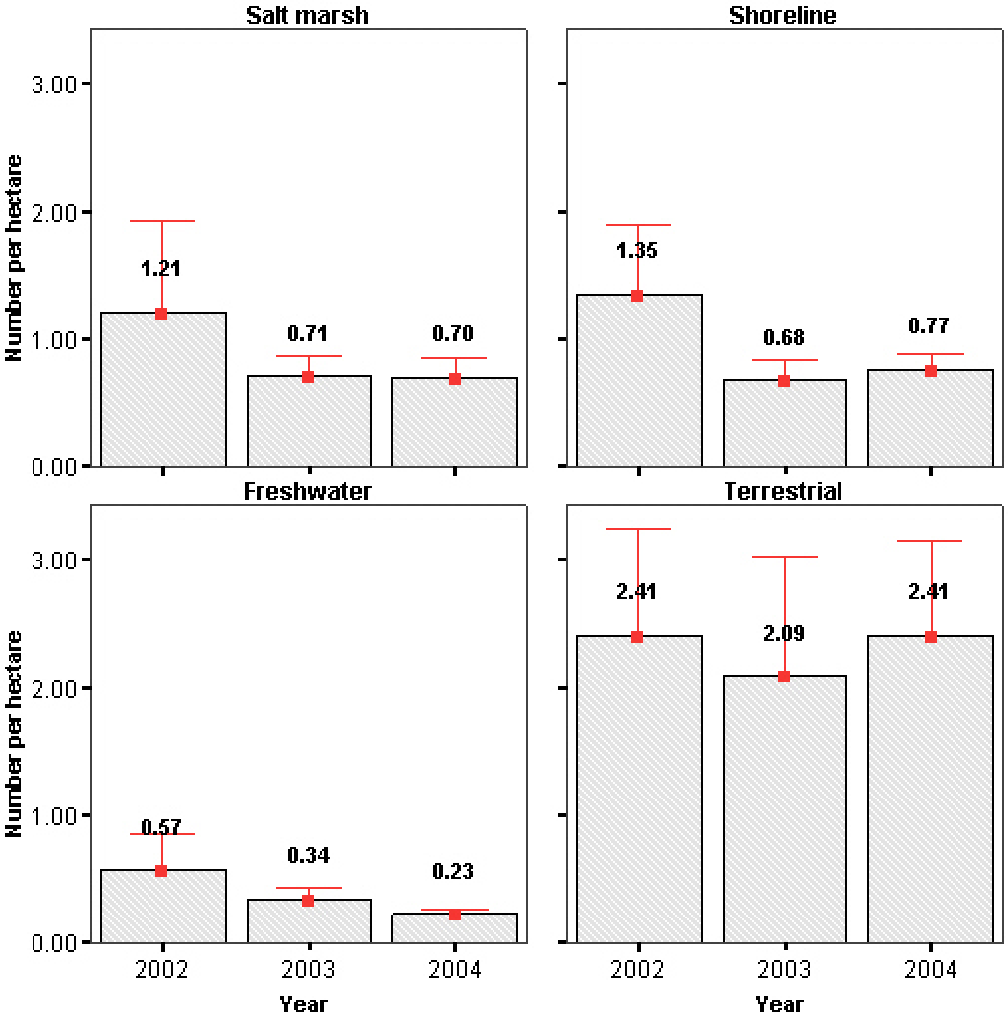

Figure 24: Black-crowned Night-Heron abundance by year on Staten Island, 2002-2004. Bars represent mean number of individuals per hectare; error bars represent 95% confidence intervals.

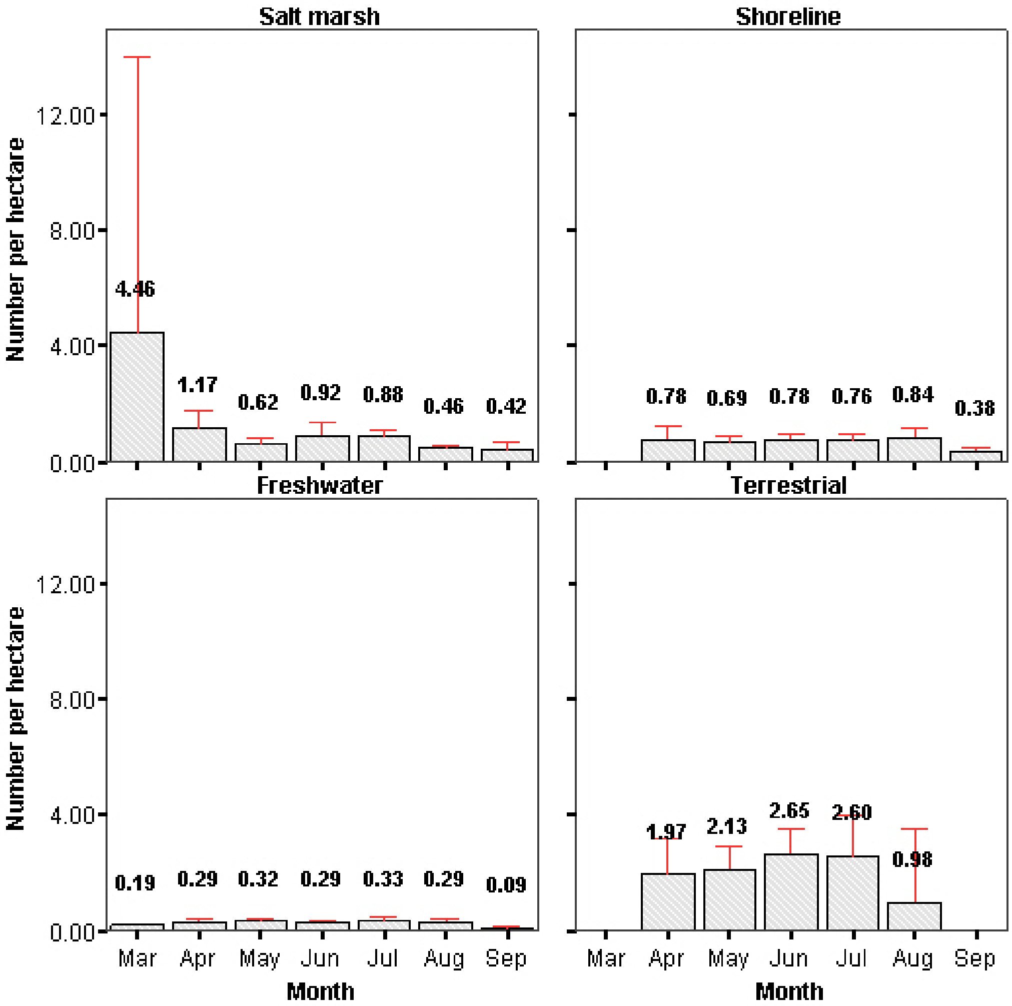

Figure 25: Black-crowned Night-Heron abundance by month on Staten Island, 2002-2004. Bars represent mean number of individuals per hectare; error bars represent 95% confidence intervals.

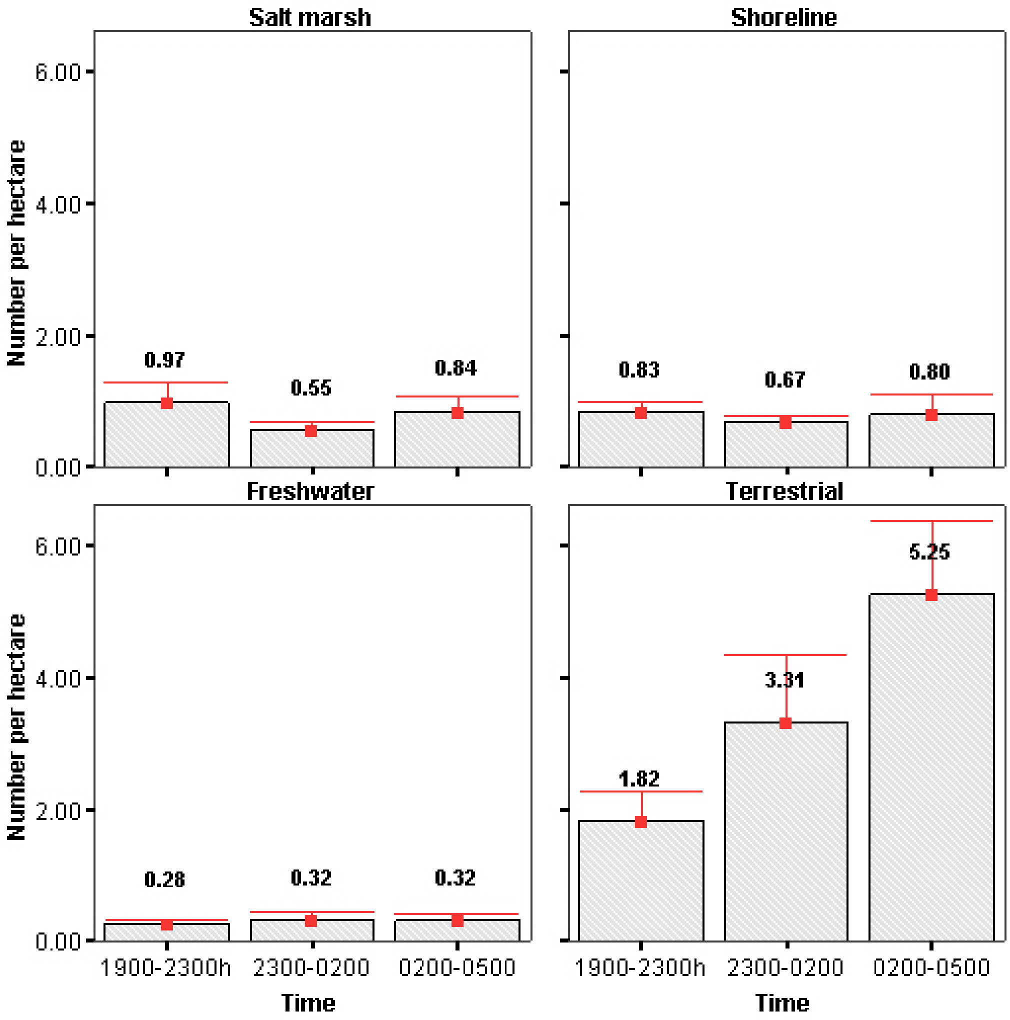

Figure 26: Black-crowned Night-Heron abundance by time interval on Staten Island, 2002-2004. Bars represent mean number of individuals per hectare; error bars represent 95% confidence intervals.

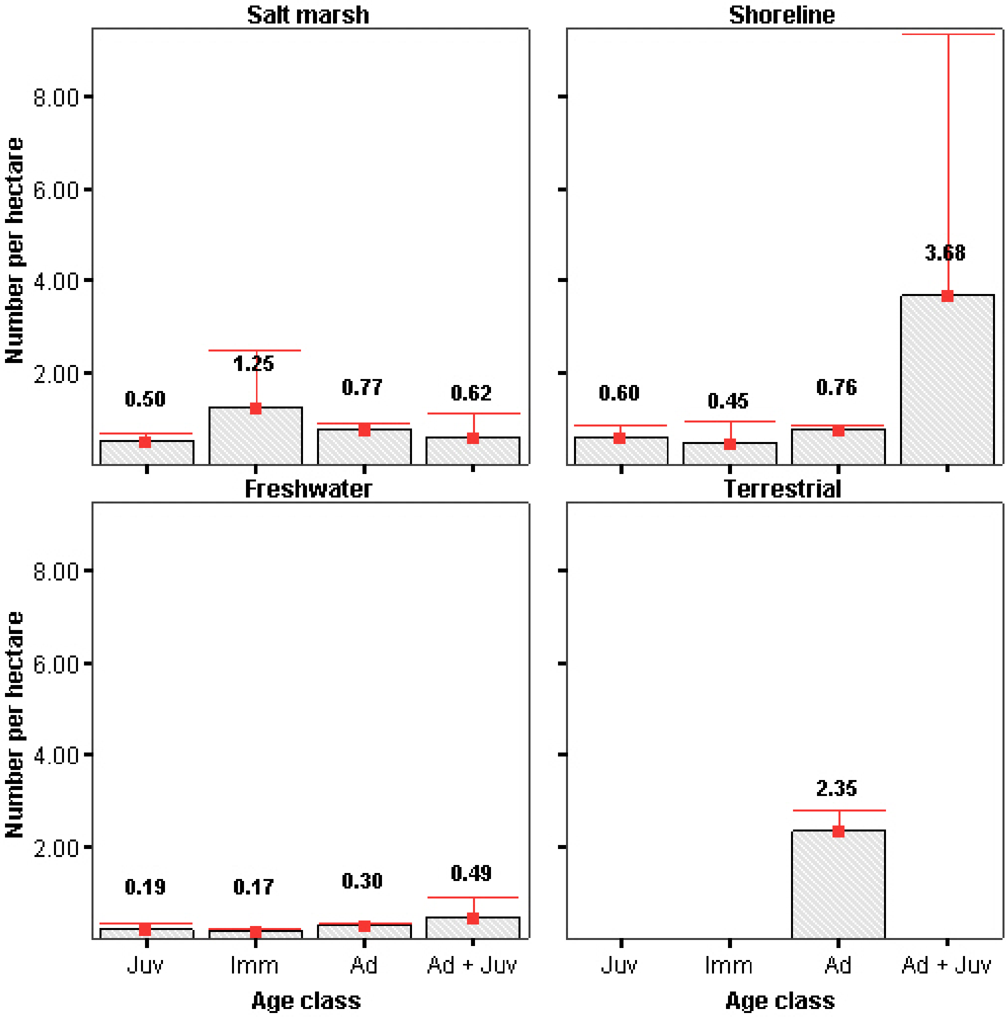

Figure 27: Black-crowned Night-Heron abundance by age class on Staten Island, 2002-2004. Bars represent mean number of individuals per hectare; error bars represent 95% confidence intervals.

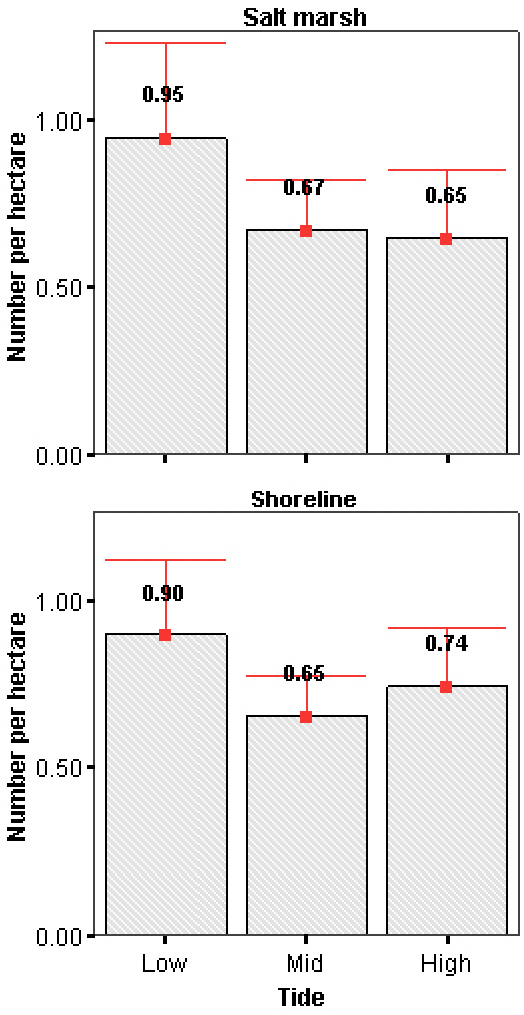

Figure 28: Black-crowned Night-Heron abundance in estuarine habitats by tidal stage on Staten Island, 2002-2004. Bars represent mean number of individuals per hectare; error bars represent 95% confidence intervals.

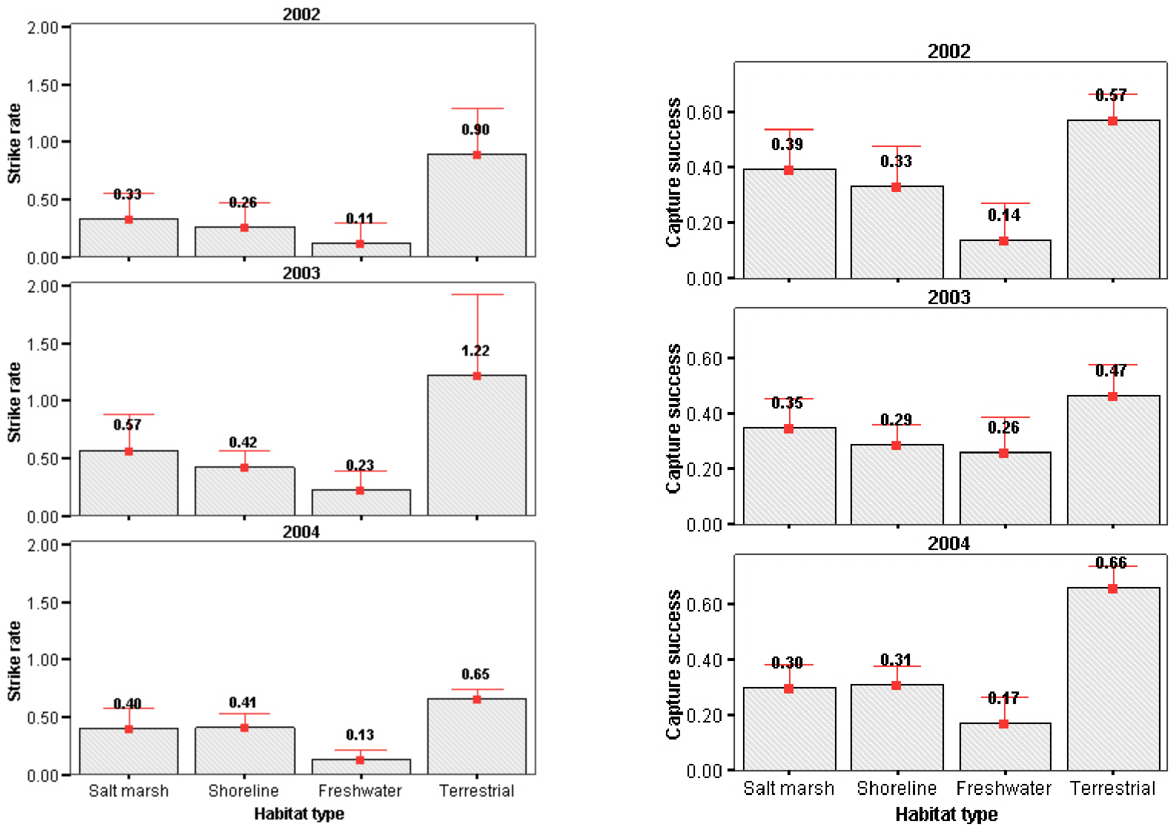

Figure 29: Strike rate (L) and capture success (R) of Black-crowned Night-Herons by year. Bars represent means; error bars represent 95% confidence intervals.

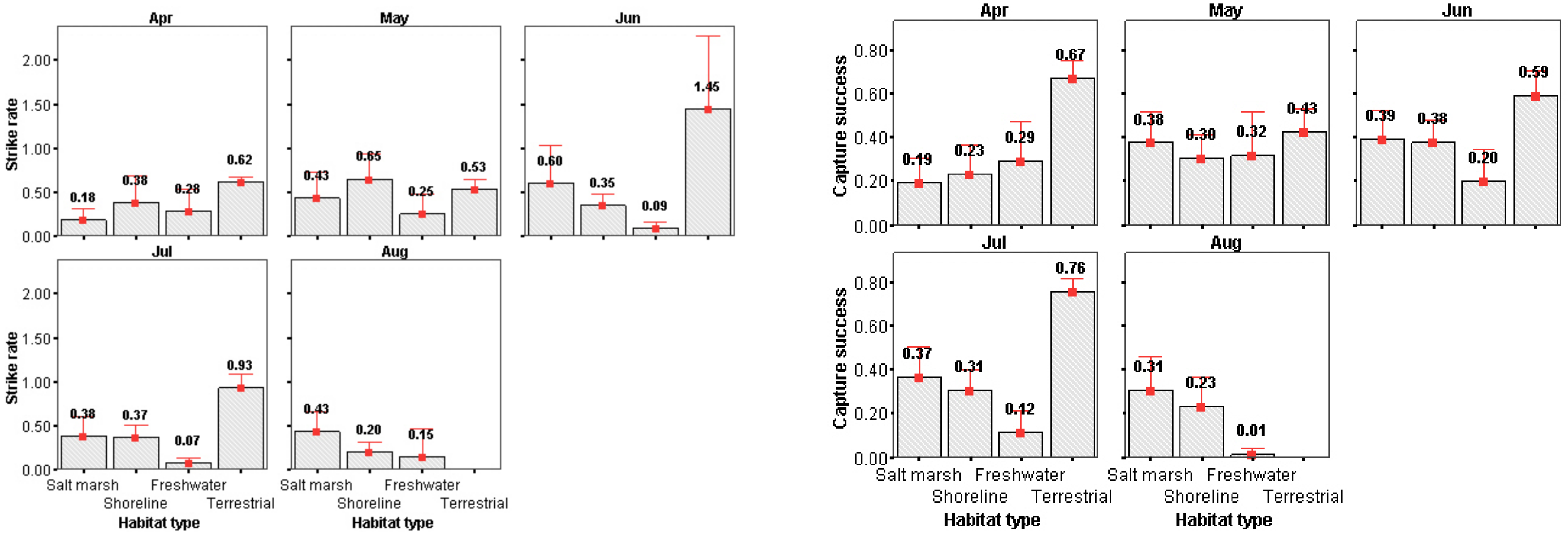

Figure 30 Strike rate (L) and capture success (R) of Black-crowned Night-Herons by month. Bars represent means; error bars represent 95% confidence intervals.

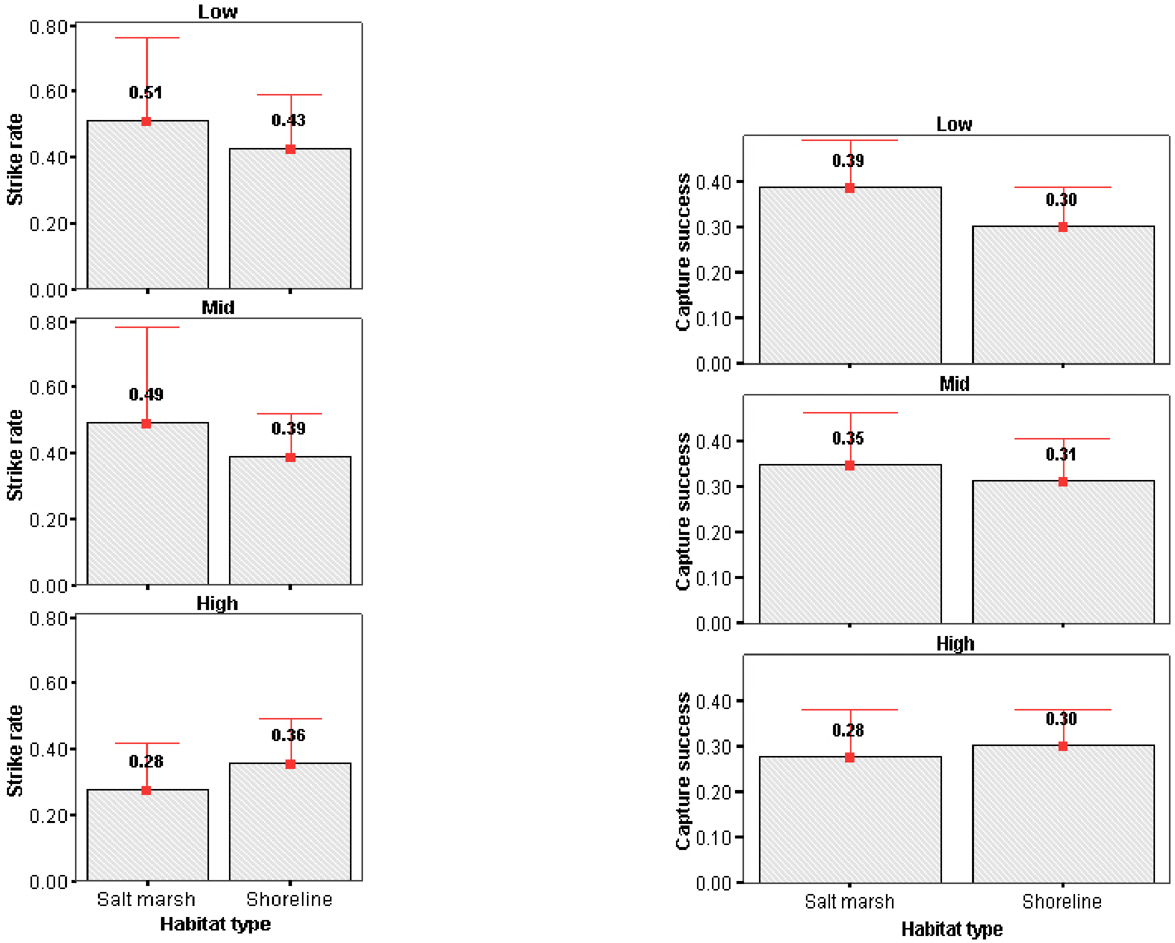

Figure 31: Strike rate (L) and capture success (R) of Black-crowned Night-Herons by tide. Bars represent means; error bars represent 95% confidence intervals.

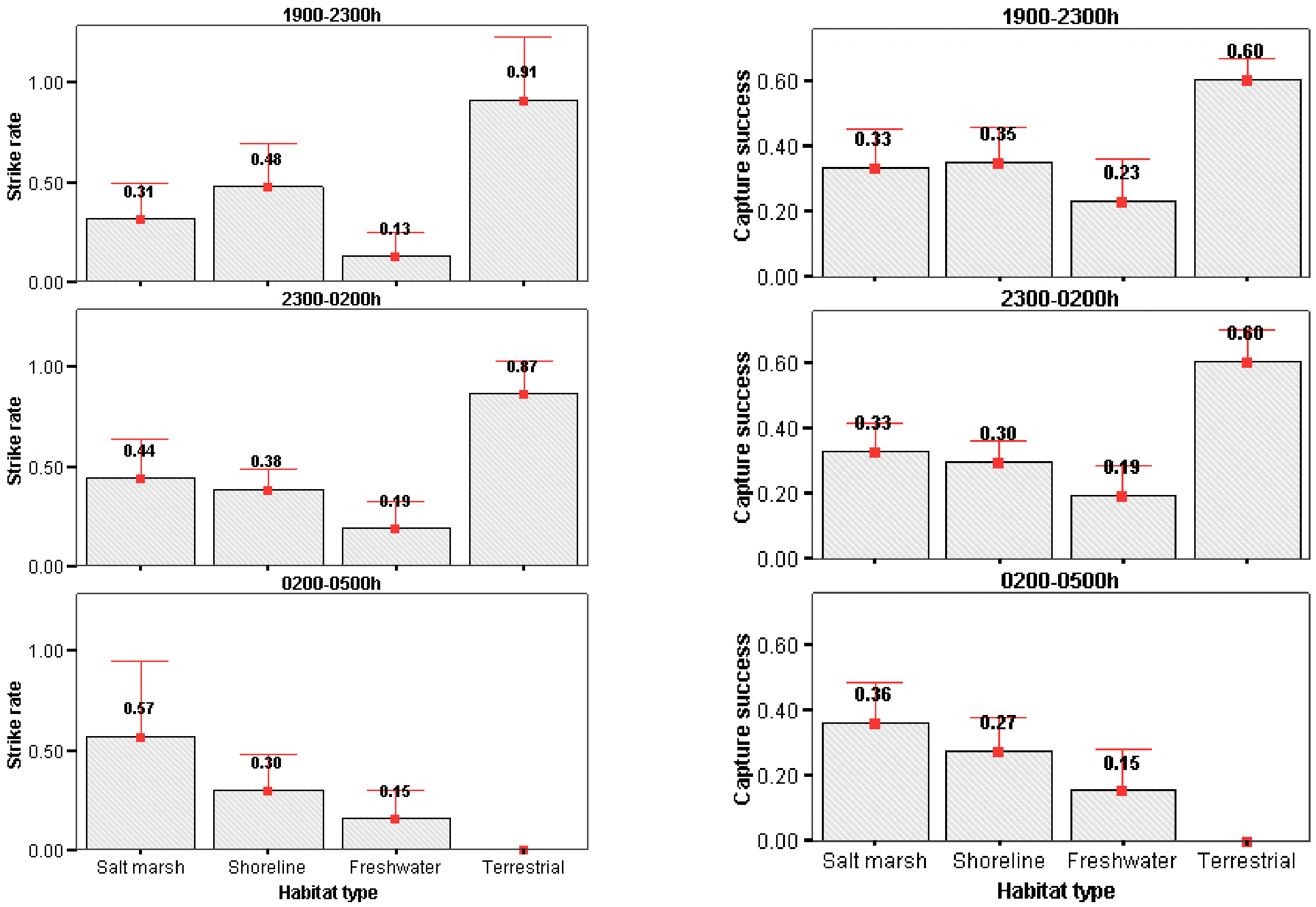

Figure 32: Strike rate (L) and capture success (R) of Black-crowned Night-Herons by time of night. Bars represent means; error bars represent 95% confidence intervals. No birds were observed foraging in terrestrial habitats from 0200-0500h.

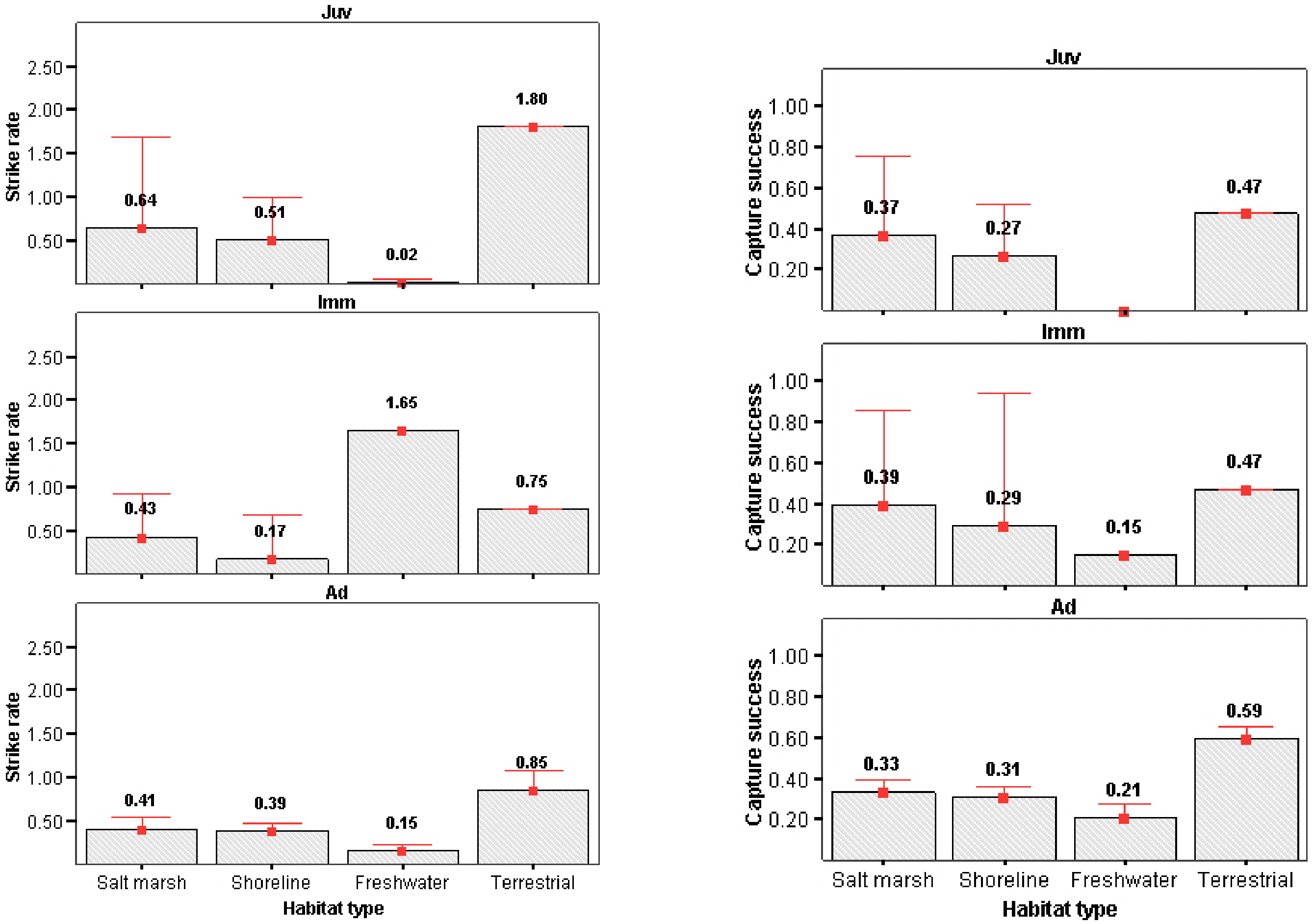

Figure 33: Strike rate (L) and capture success (R) of Black-crowned Night-Herons by age class. Bars represent means; error bars represent 95% confidence intervals.

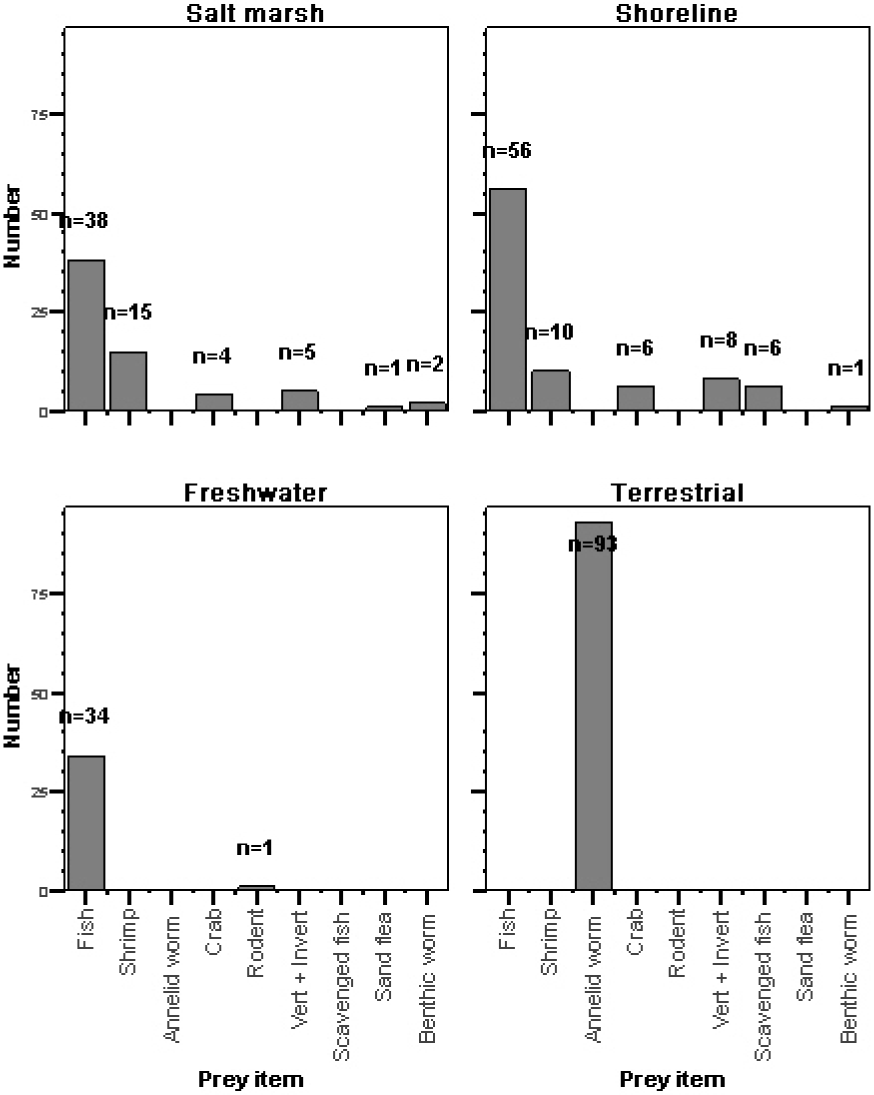

Figure 34: Prey items captured by Black-crowned Night-Herons during foraging observations. Bars represent number of captures observed per habitat type.

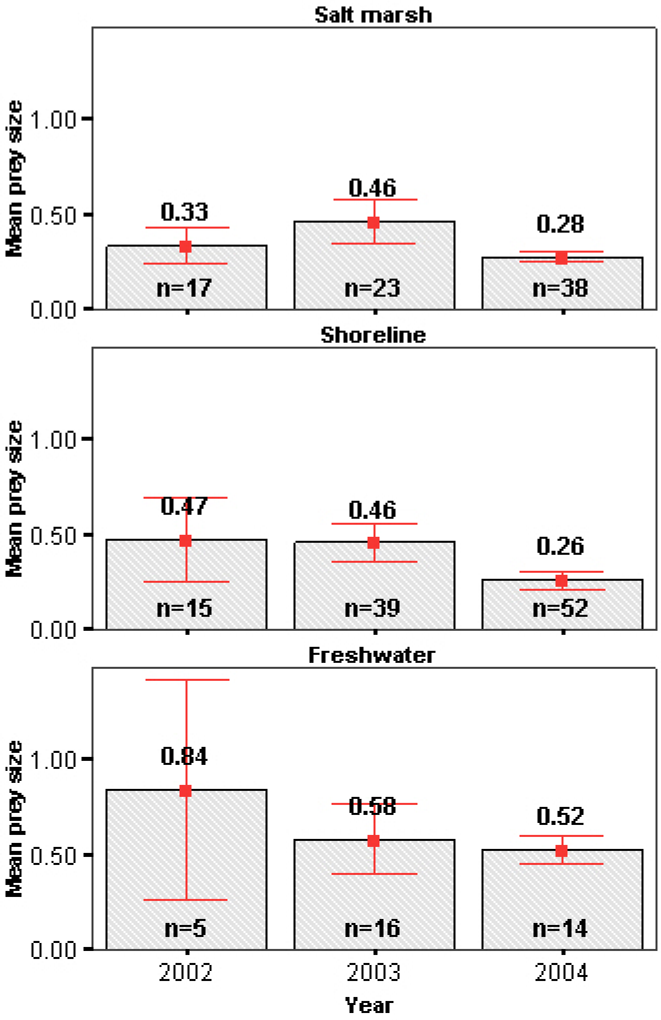

Figure 35: Size of prey captured by Black-crowned Night-Herons during foraging observations. Bars represent mean prey size expressed as a proportion of bill length by habitat type; error bars represent 95% confidence intervals.

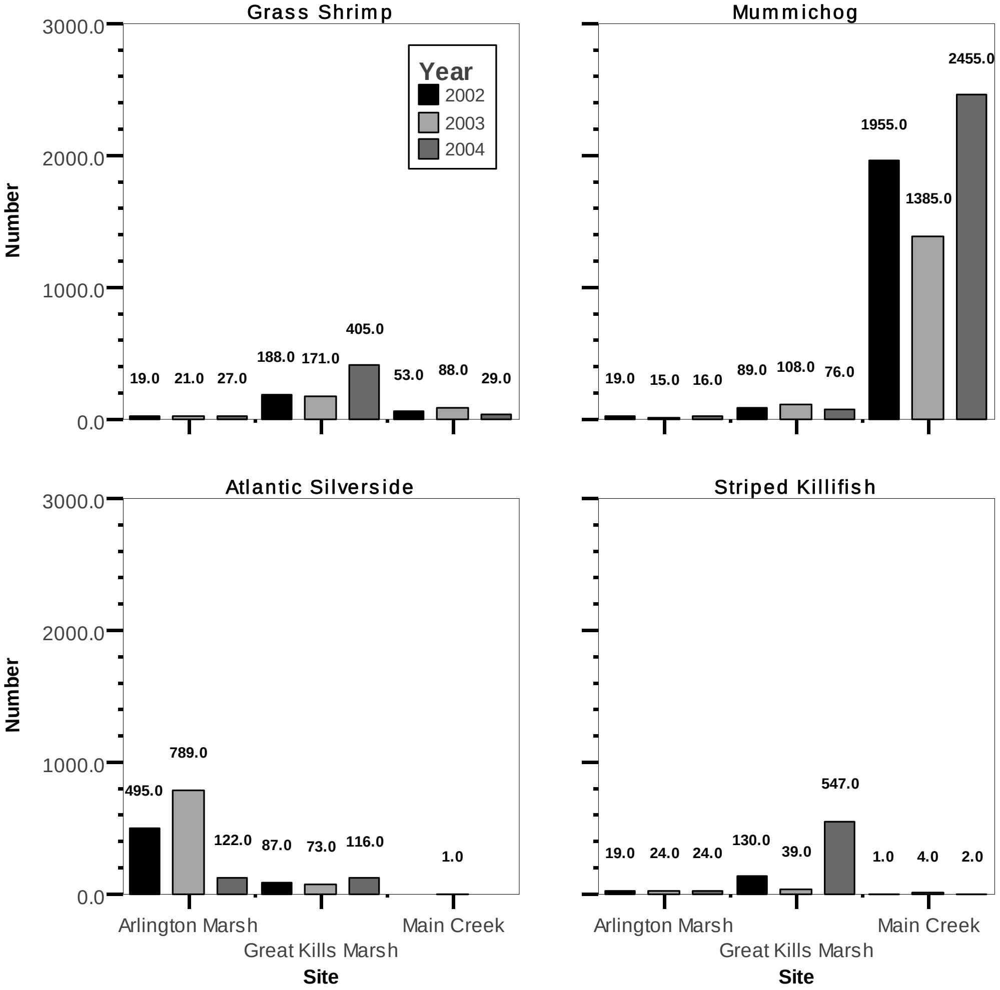

Figure 36: Abundance of common prey species (1 invertebrate and 3 fishes) in salt marsh habitats on Staten Island, NY. Year totals are represented at the end of each bar.

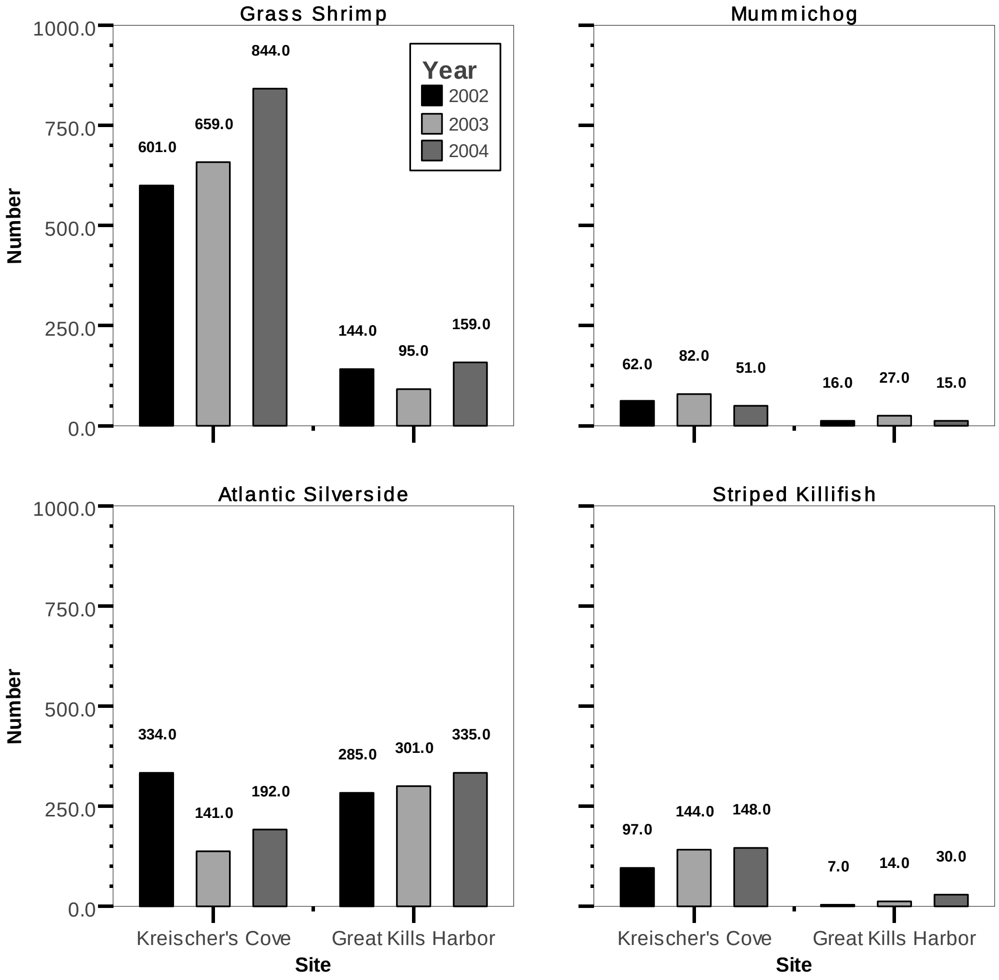

Figure 37: Abundance of common prey species (1 invertebrate and 3 fishes) in shoreline habitats on Staten Island, NY. Year totals are represented at the end of each bar.

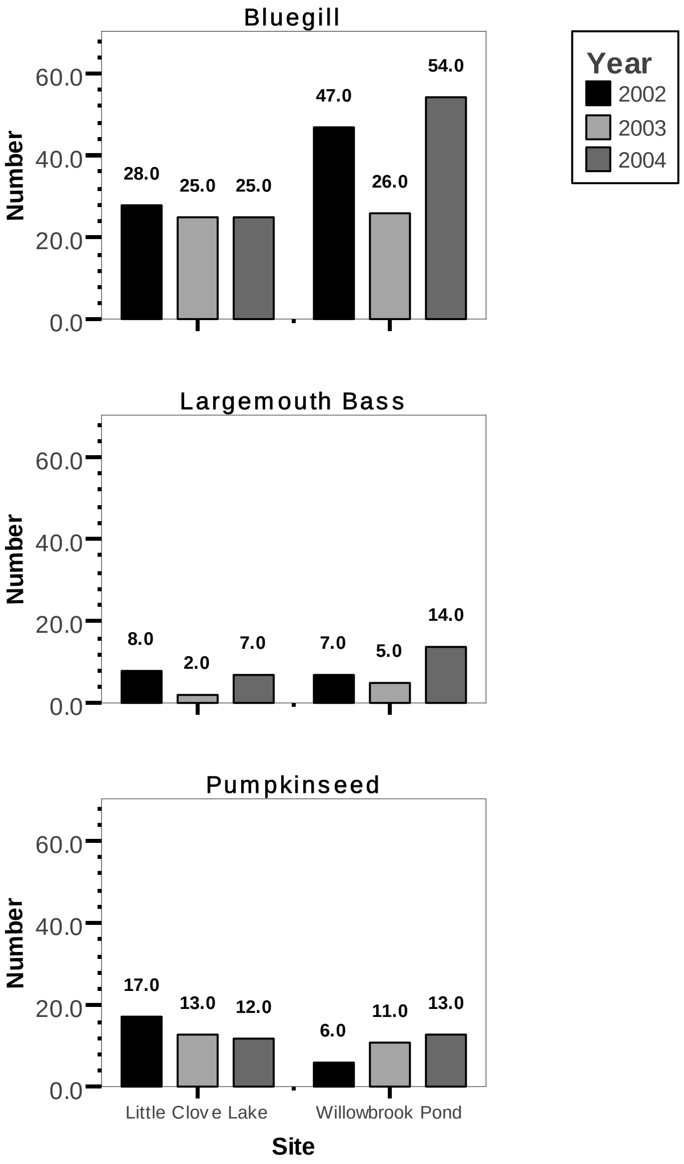

Figure 38: Abundance of common fishes in freshwater ponds on Staten Island, NY. Year totals are represented at the end of each bar.

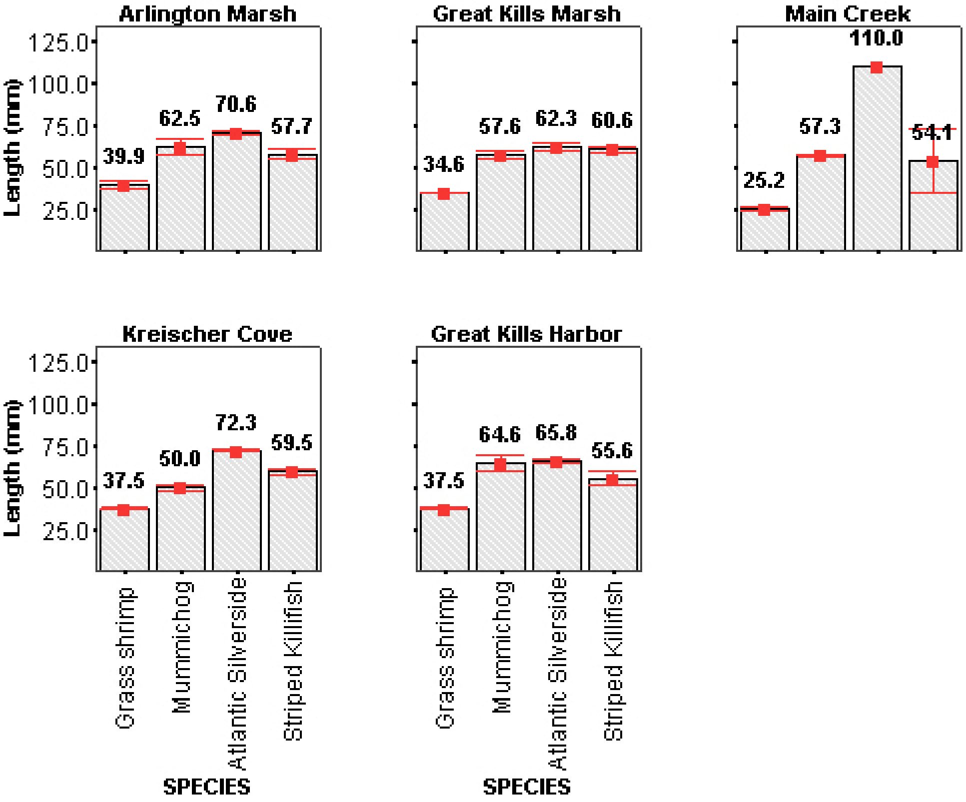

Figure 39: Mean body length of an estuarine invertebrate and fishes at salt marsh and shoreline sampling sites, Staten Island, NY (Richmond Co.). Error bars represent 95% confidence intervals, and mean values are located above bars.

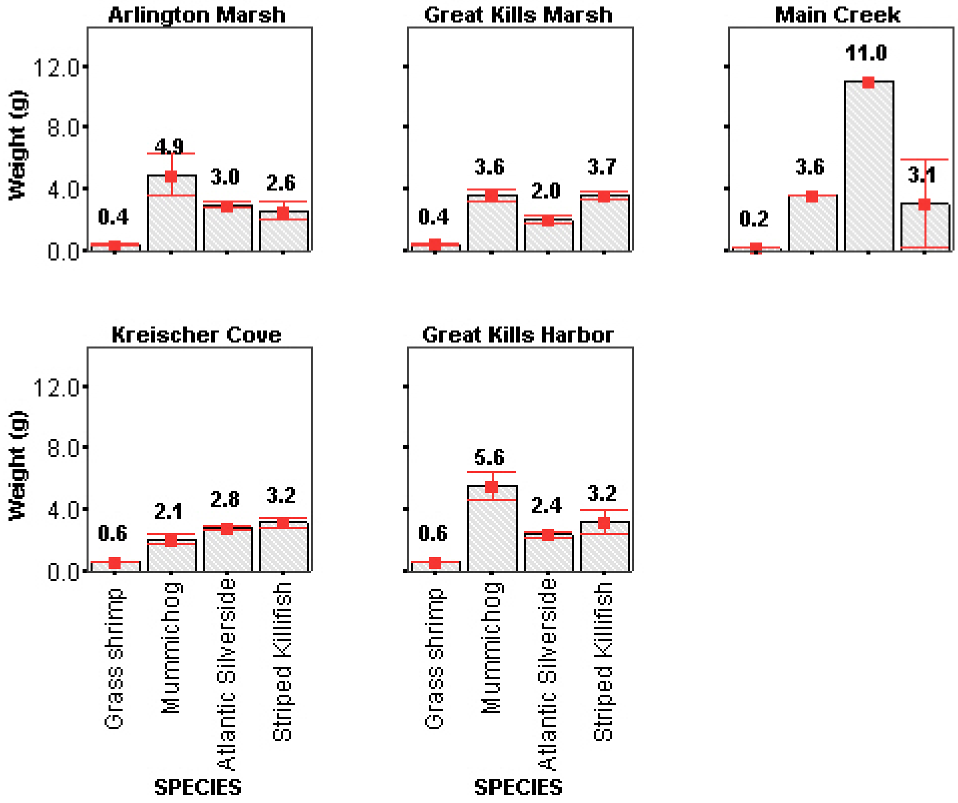

Figure 40: Mean individual weight of an estuarine invertebrate and fishes at salt marsh and shoreline sampling sites, Staten Island, NY (Richmond Co.). Error bars represent 95% confidence intervals, and mean values are located above bars.

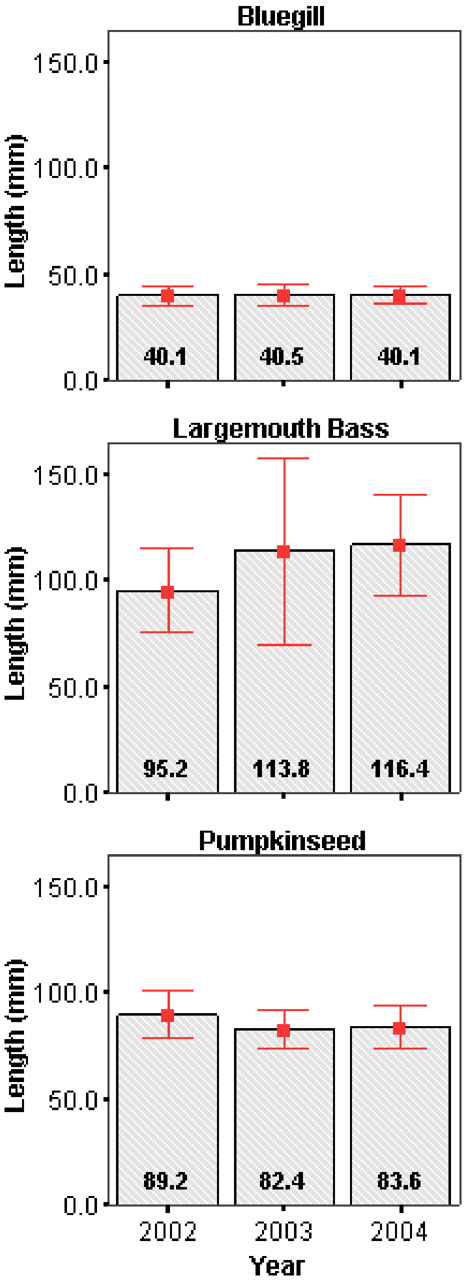

Figure 41: Mean body length of freshwater fishes at Little Clove Lake and Willowbrook Pond, Staten Island, NY (Richmond Co.). Error bars represent 95% confidence intervals, and mean values are located above bars.

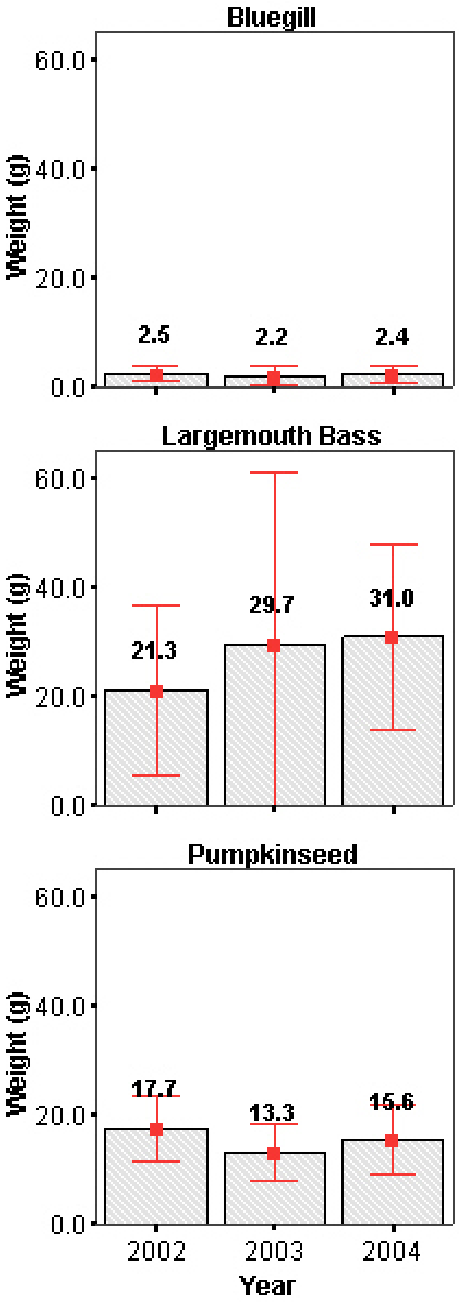

Figure 42: Mean individual weight of freshwater fishes at Little Clove Lake and Willowbrook Pond, Staten Island, NY (Richmond Co.). Error bars represent 95% confidence intervals, and mean values are located above bars.

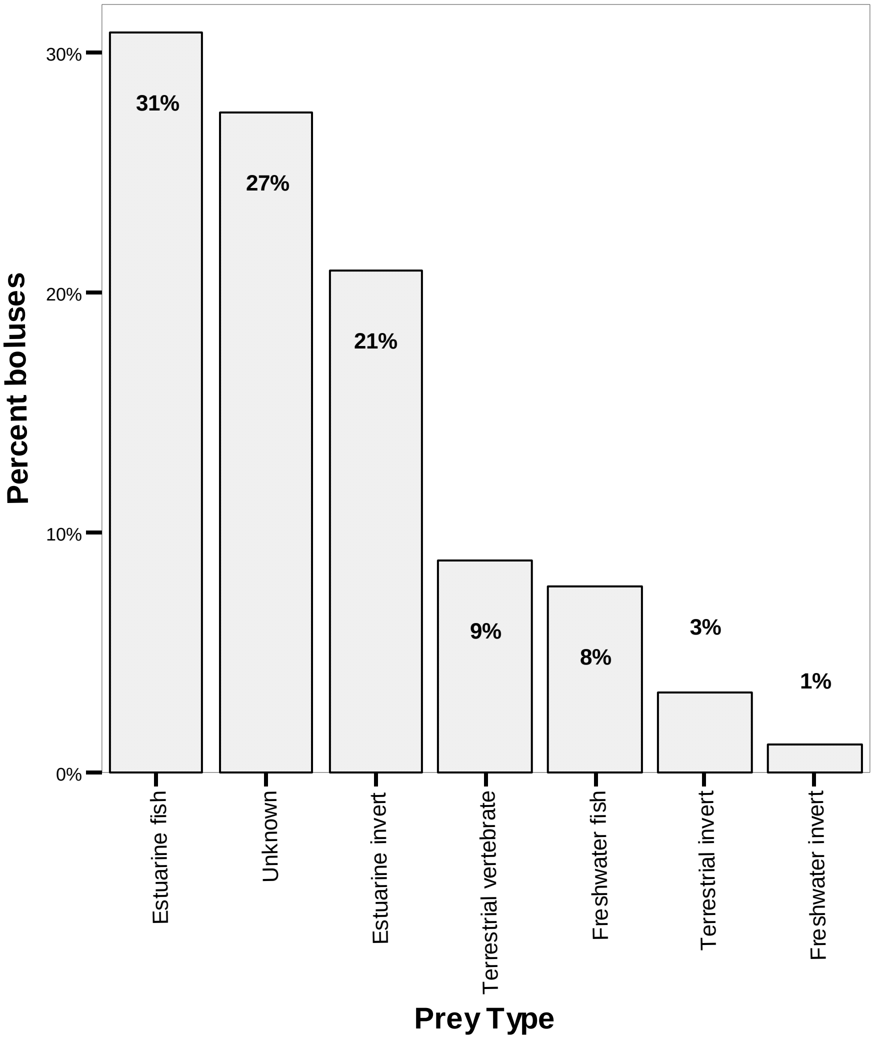

Figure 43: Vertebrate and invertebrate prey identified in Black-crowned Night-Heron regurgitated boluses from Hoffman Island, 2002-2005. The category “unknown” represents digested material that could not be identified. Bars represent percent of boluses containing each prey category.

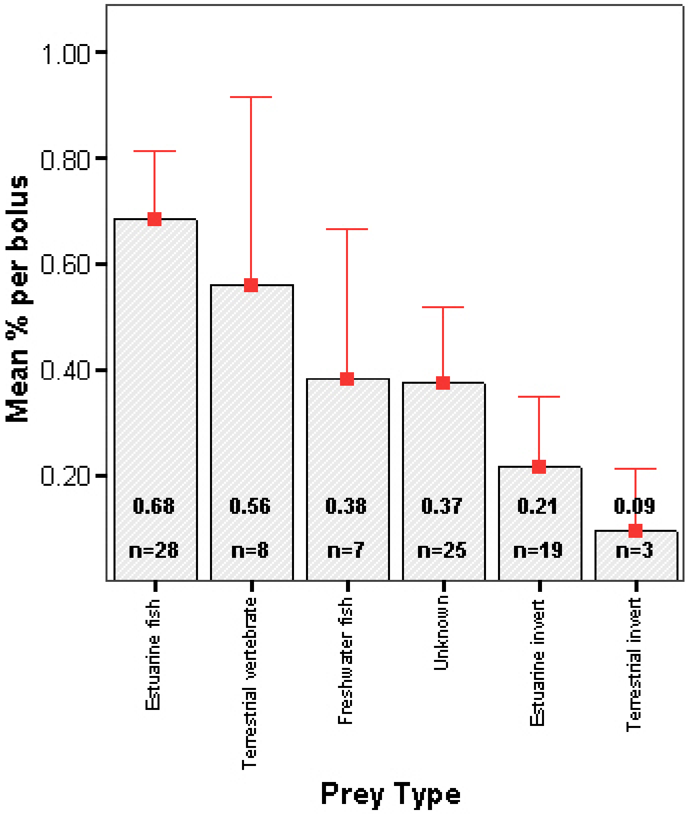

Figure 44: Composition of regurgitated boluses from Hoffman Island, 2002-2005. Vertebrate and invertebrate prey varied in proportion of boluses examined. The category "unknown" represents heavily material that could not be identified. Error bars represent 95% confidence intervals.

APPENDIX A

Aerial images of sampling sites, Staten Island, NY (Richmond Co.)

Figure A- 1: Site code AKRD1 – Blazing Star marsh at Arthur Kill Road, Staten Island, NY (Richmond Co.).

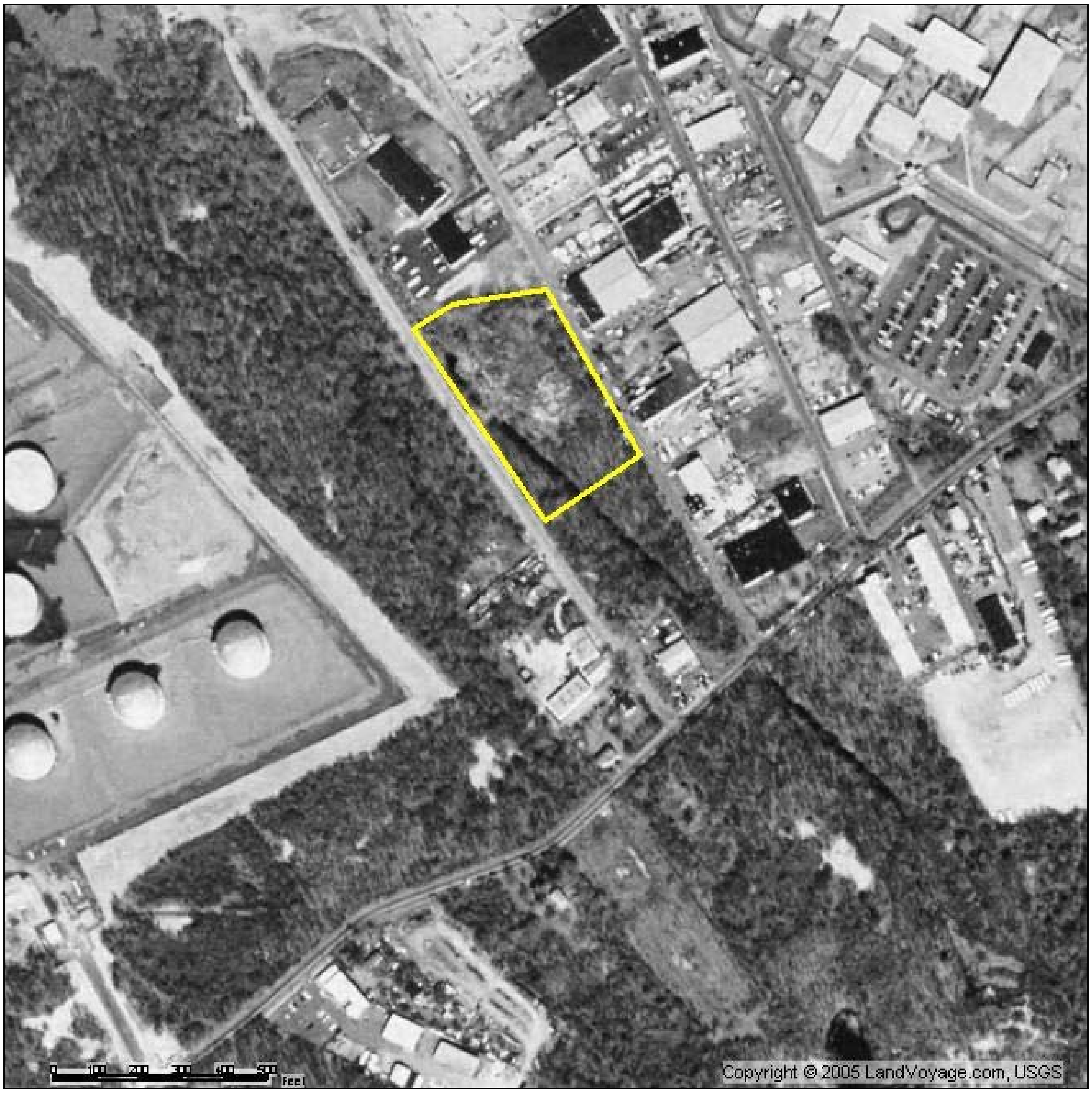

Figure A- 2: Site code AKRD2 – Johnson Avenue, Staten Island, NY (Richmond Co.)

Figure A- 3: Site code AKRD3 – Ellis Avenue and Arthur Kill, Staten Island, NY (Richmond Co.)

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Figure A- 4: Site code AKRD5 – Kreischer's Cove, Staten Island, NY (Richmond Co.)

Figure A- 5: Site code AKRD6 – Mill Creek, Arthur Kill Road south of Richmond Valley Road, Staten Island, NY (Richmond Co.)

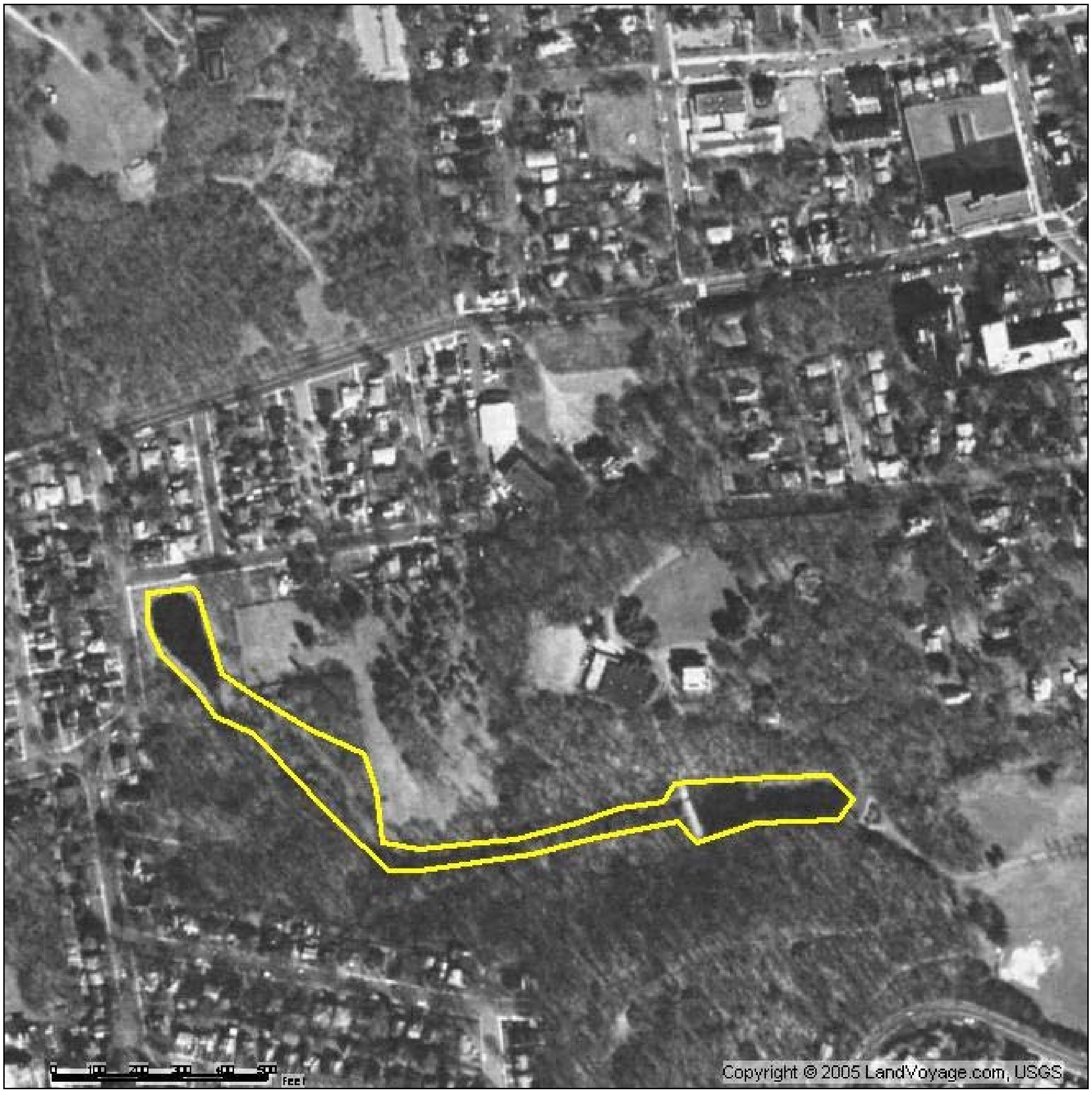

Figure A- 6: Site code APGO – Allison Pond Park/Goodhue School property, Brentwood and Prospect Avenues, Staten Island, NY (Richmond Co.)

Figure A- 7: Site code ARMA – Arlington Marsh, north-east of Richmond Terrace and Western Avenue, Staten Island, NY (Richmond Co.)

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Figure A- 8: Site code AUST – Edgewater Street and Hylan Boulevard (near Alice Austen House), Staten Island, NY (Richmond Co.)

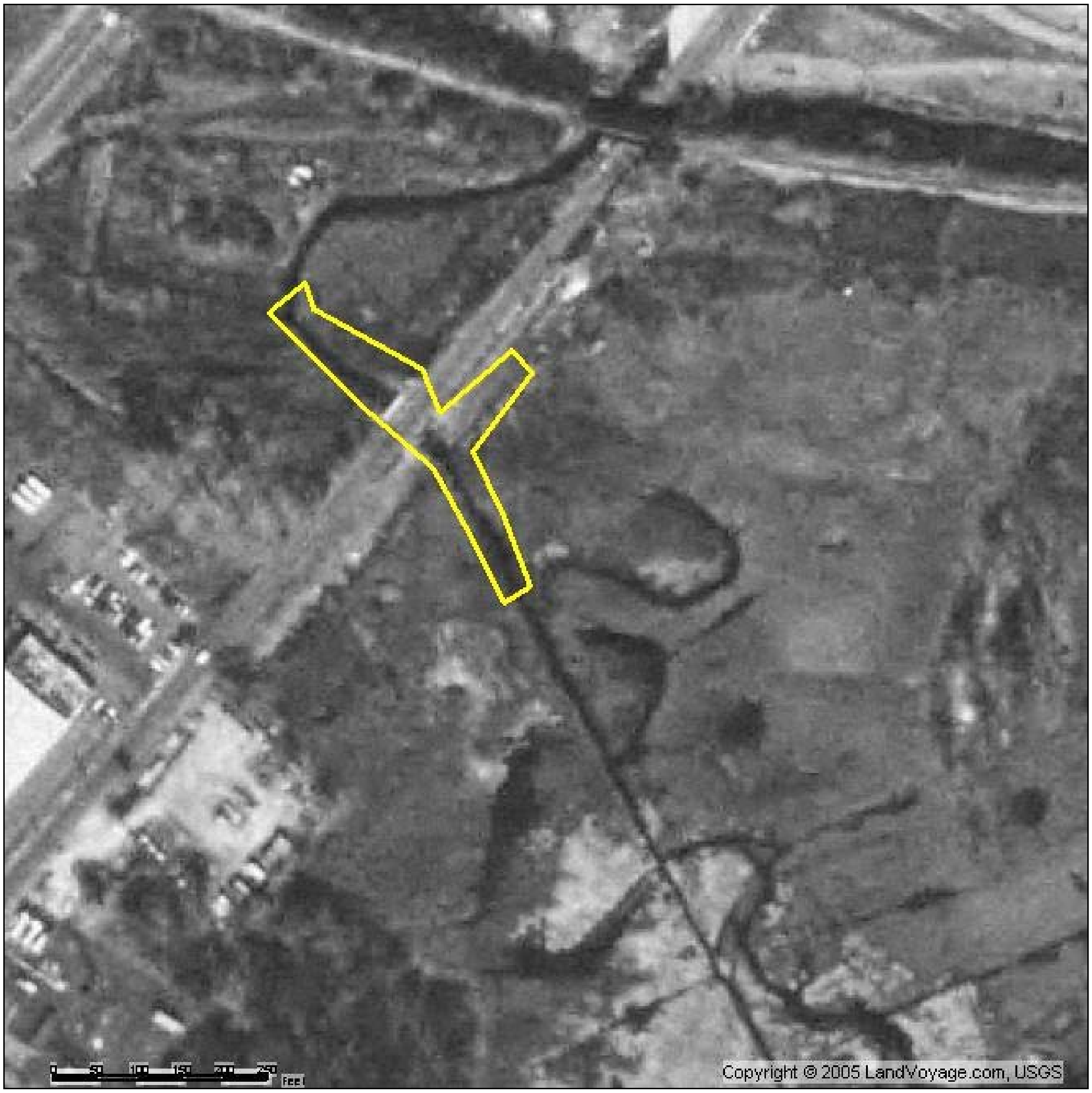

Figure A- 9: Site code BRCK – Bridge Creek, Western Ave, Staten Island, NY (Richmond Co.)

Figure A- 10: Site code BRTN – Brighton Street (east of Conference House Park), Staten Island, NY (Richmond Co.)

Figure A- 11: Site code CLOV – Clove Lakes Park between Forest Avenue and Victory Boulevard, Staten Island, NY (Richmond Co.)

Figure A- 12: Site code CONF – Conference House Park shoreline, Staten Island, NY (Richmond Co.)

Figure A- 13: Site code CRES – Armstrong Avenue, shoreline at Crescent Beach, Staten Island, NY (Richmond Co.)

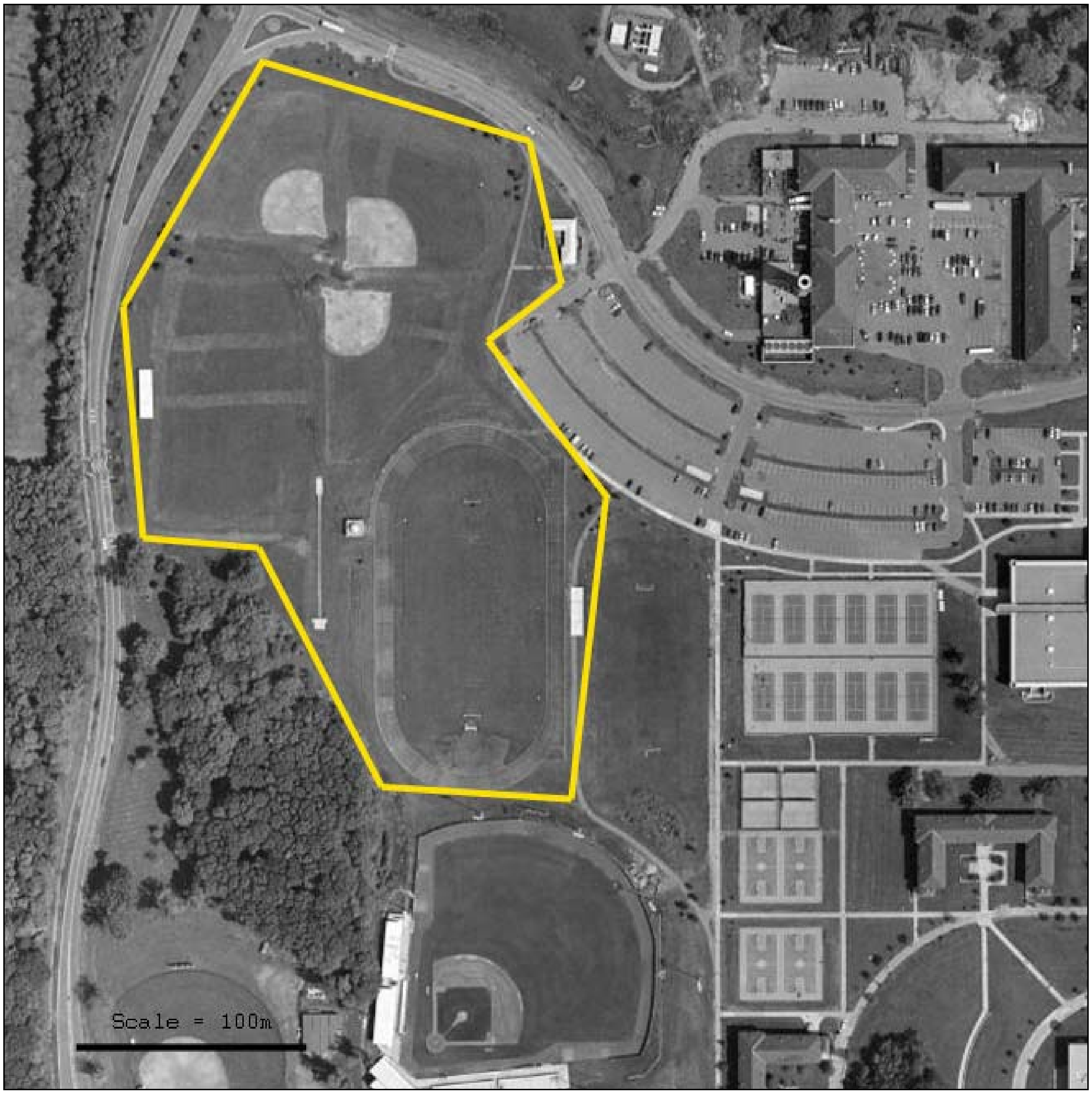

Figure A- 14: Site code CSIF – College of Staten Island playing fields, Staten Island, NY (Richmond Co.)

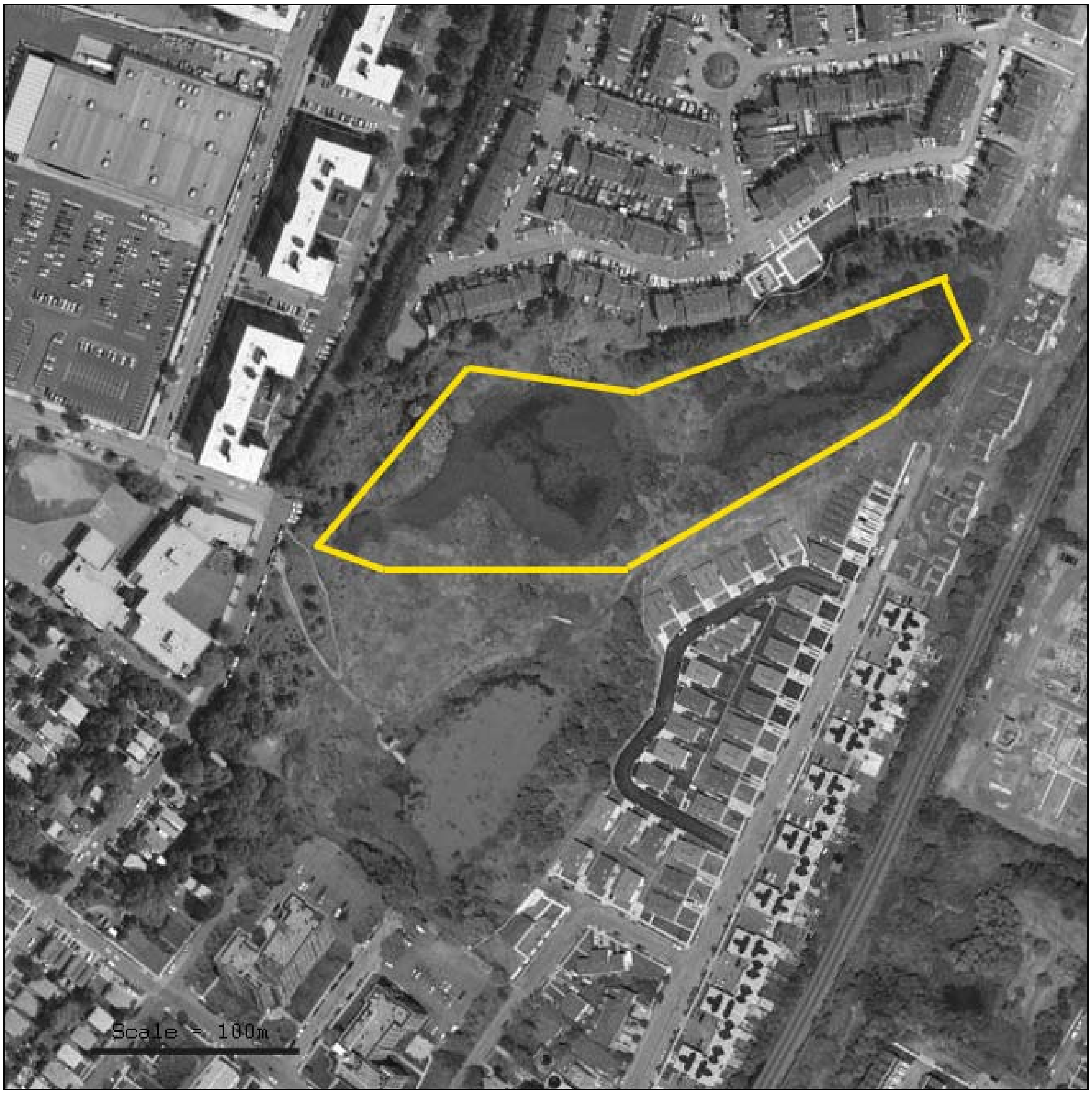

Figure A- 15: Site code EIBS – Eibs Pond shoreline, Staten Island, NY (Richmond Co.)

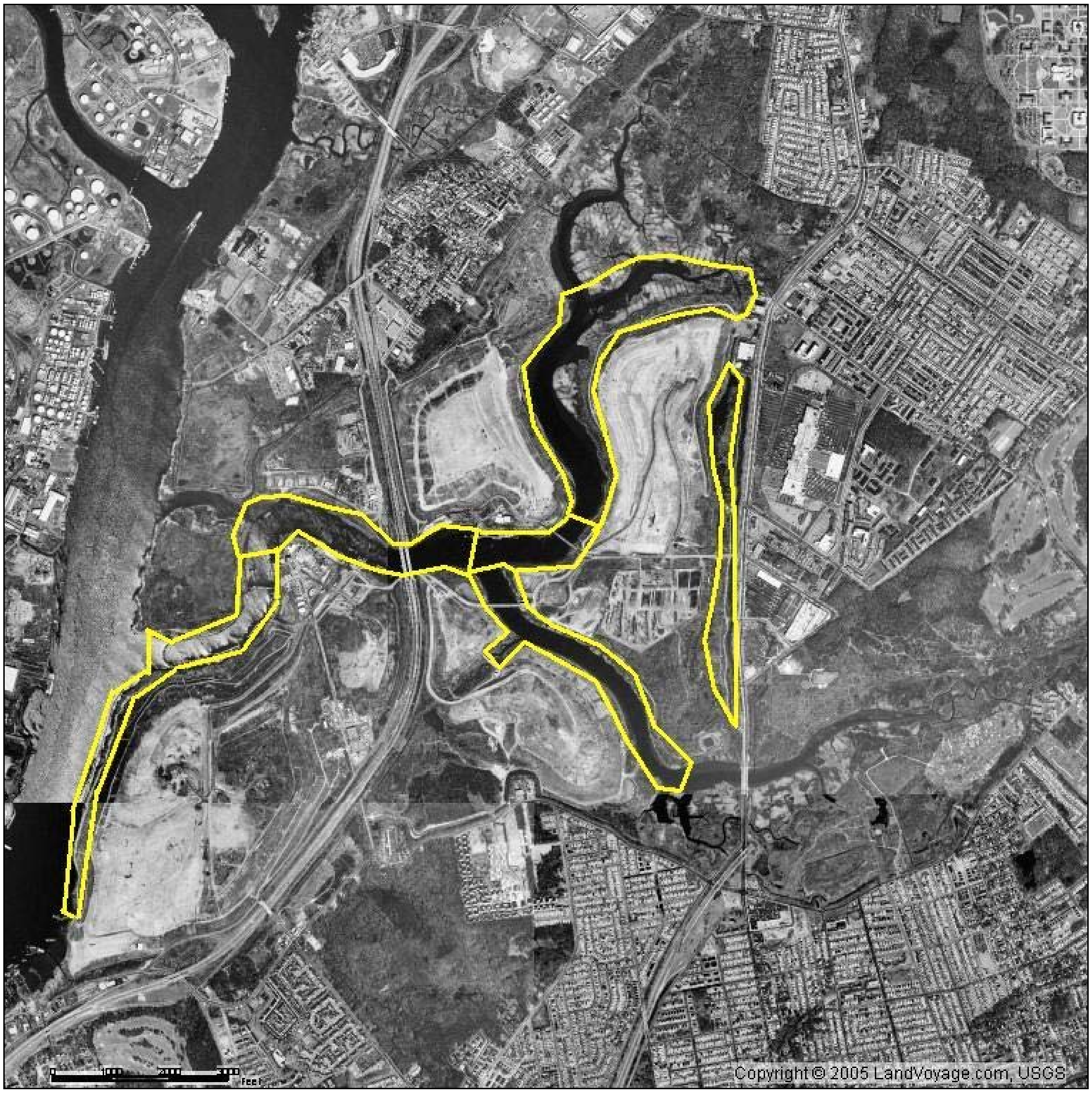

Figure A- 16: Site code FKLA – Fresh Kills Landfill (all 6 sections), Staten Island, NY (Richmond Co.)

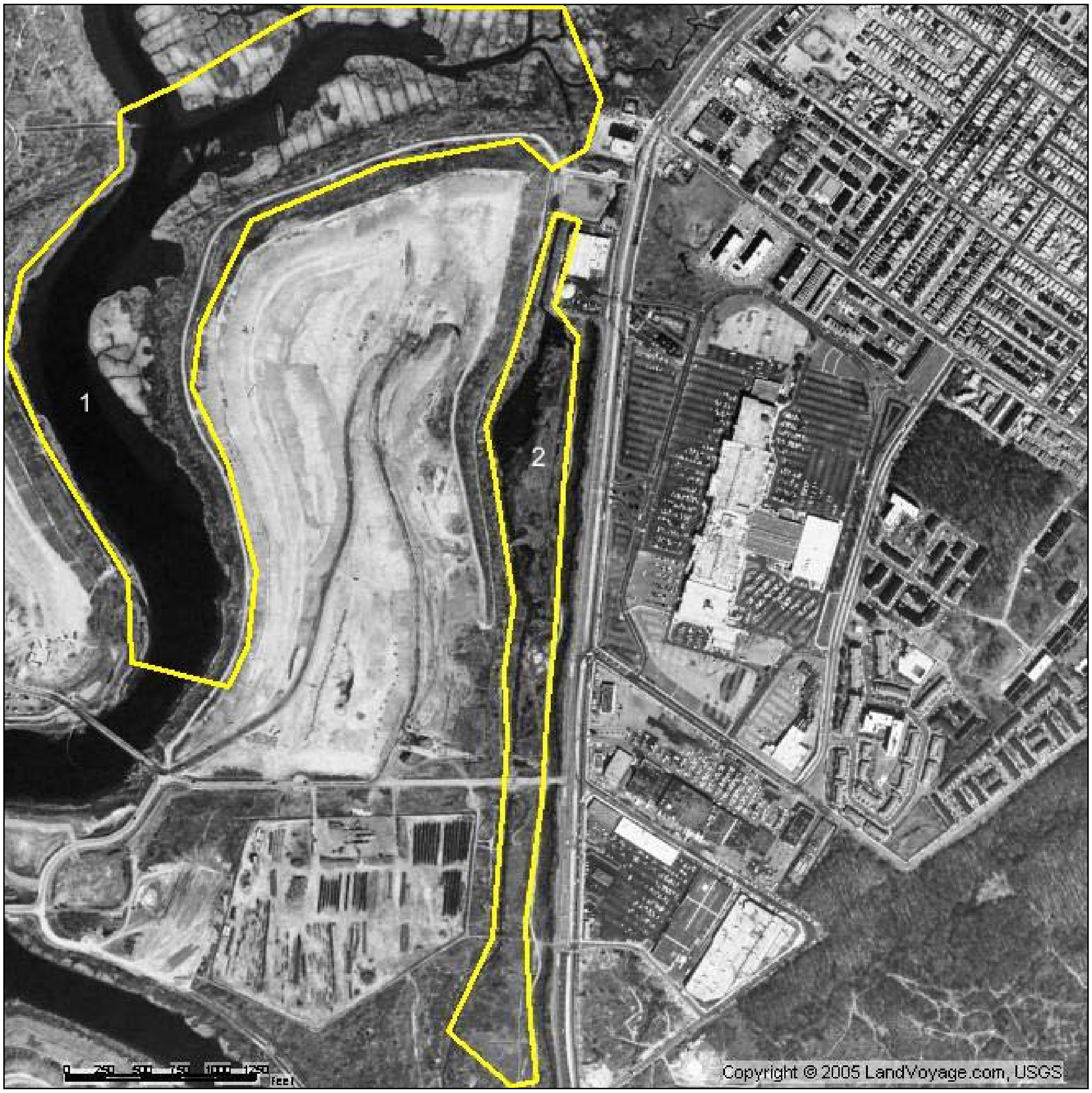

Figure A- 17: Site code FKLA1 & 2 – Fresh Kills Landfill, (1) Main Creek and William T. Davis Wildlife Refuge, and (2) retention ponds west of Richmond Avenue, Staten Island, NY (Richmond Co.)

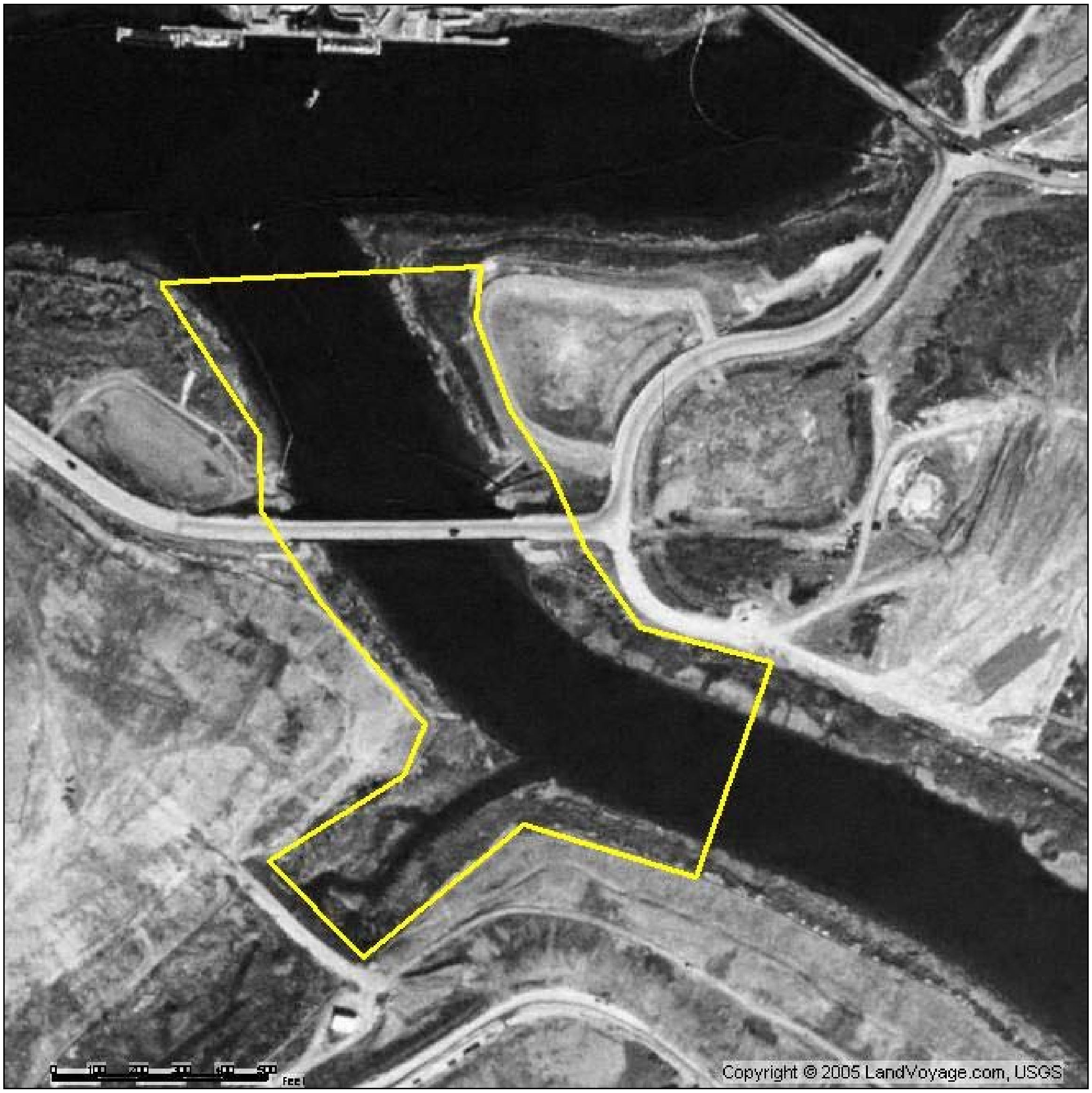

Figure A- 18: Site code FKLA3 (north) – Fresh Kills Landfill, Richmond Creek section, Staten Island, NY (Richmond Co.)

Figure A- 19: Site code FKLA3 (south) – Fresh Kills Landfill, Richmond Creek section, Staten Island, NY (Richmond Co.)

Figure A- 20: Site code FKLA4 – Fresh Kills Landfill, Main Creek east of Fresh Kills, Staten Island, NY (Richmond Co.)

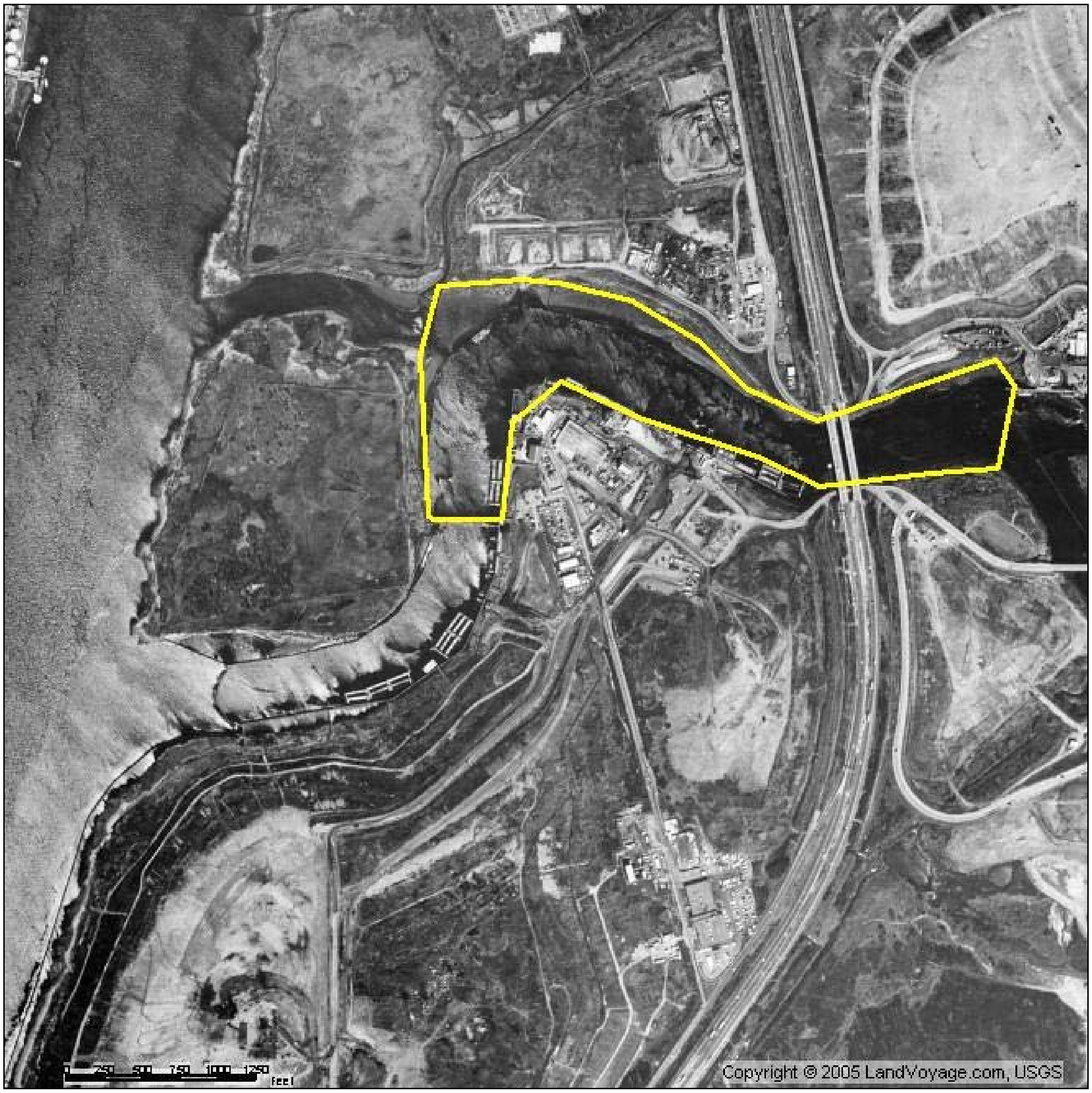

Figure A- 21: Site code FKLA5 – Fresh Kills Landfill, Fresh Kills near Route 440, Staten Island, NY (Richmond Co.)

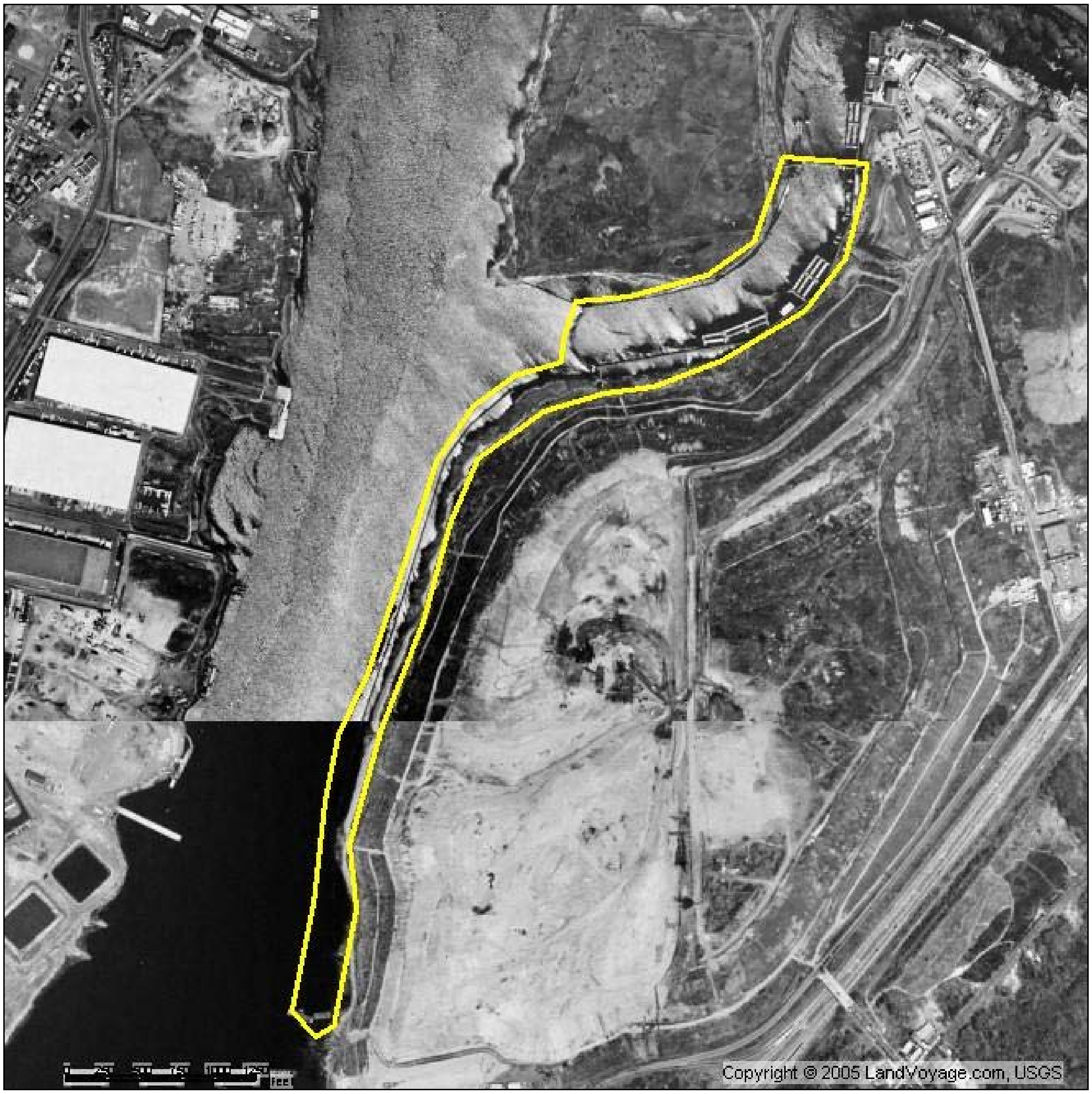

Figure A- 22: Site code FKLA6 – Fresh Kills Landfill, Great Fresh Kills (south of Isle of Meadows) to Arthur Kill, Staten Island, NY (Richmond Co.)

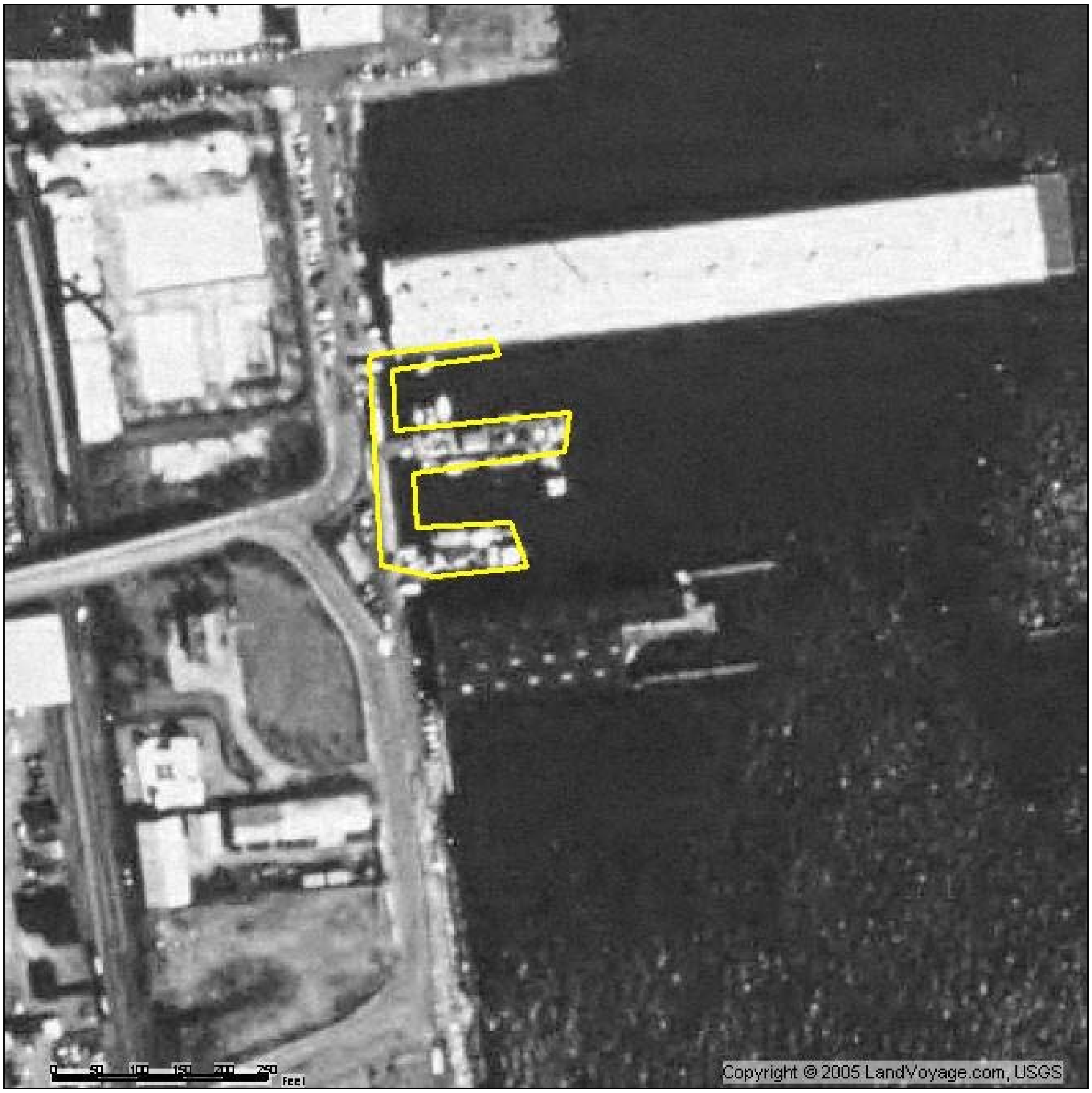

Figure A- 23: Site code FRNT1 – Hannah and Front Streets, Staten Island, NY (Richmond Co.)

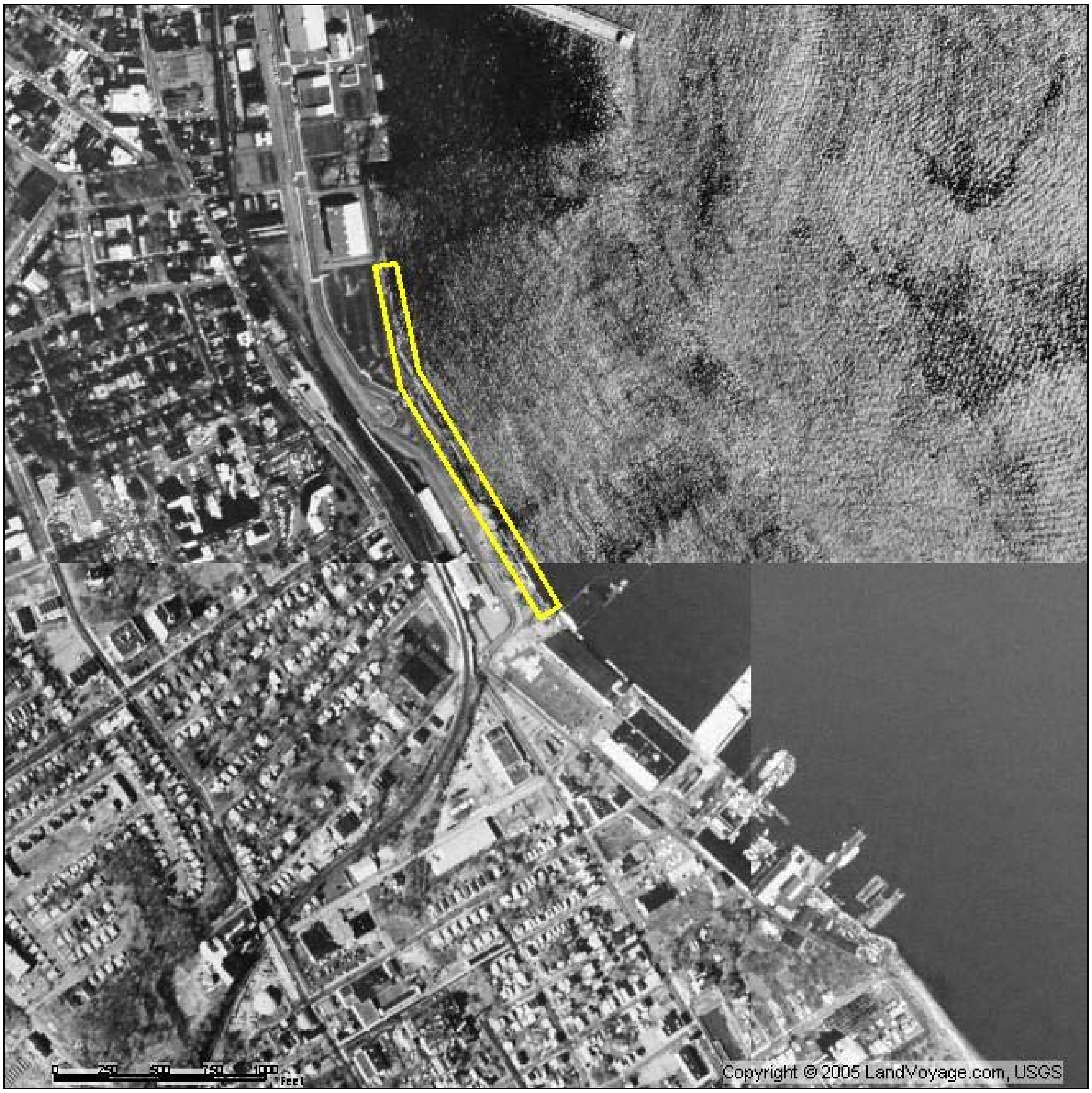

Figure A- 24: Site code FRNT2 – Front Street shoreline near Bay Street, Staten Island, NY (Richmond Co.)

Figure A- 25: Site code FTWA – Fort Wadsworth sections (1) shoreline south, (2) shoreline north, (3) playing field. Staten Island, NY (Richmond Co.)

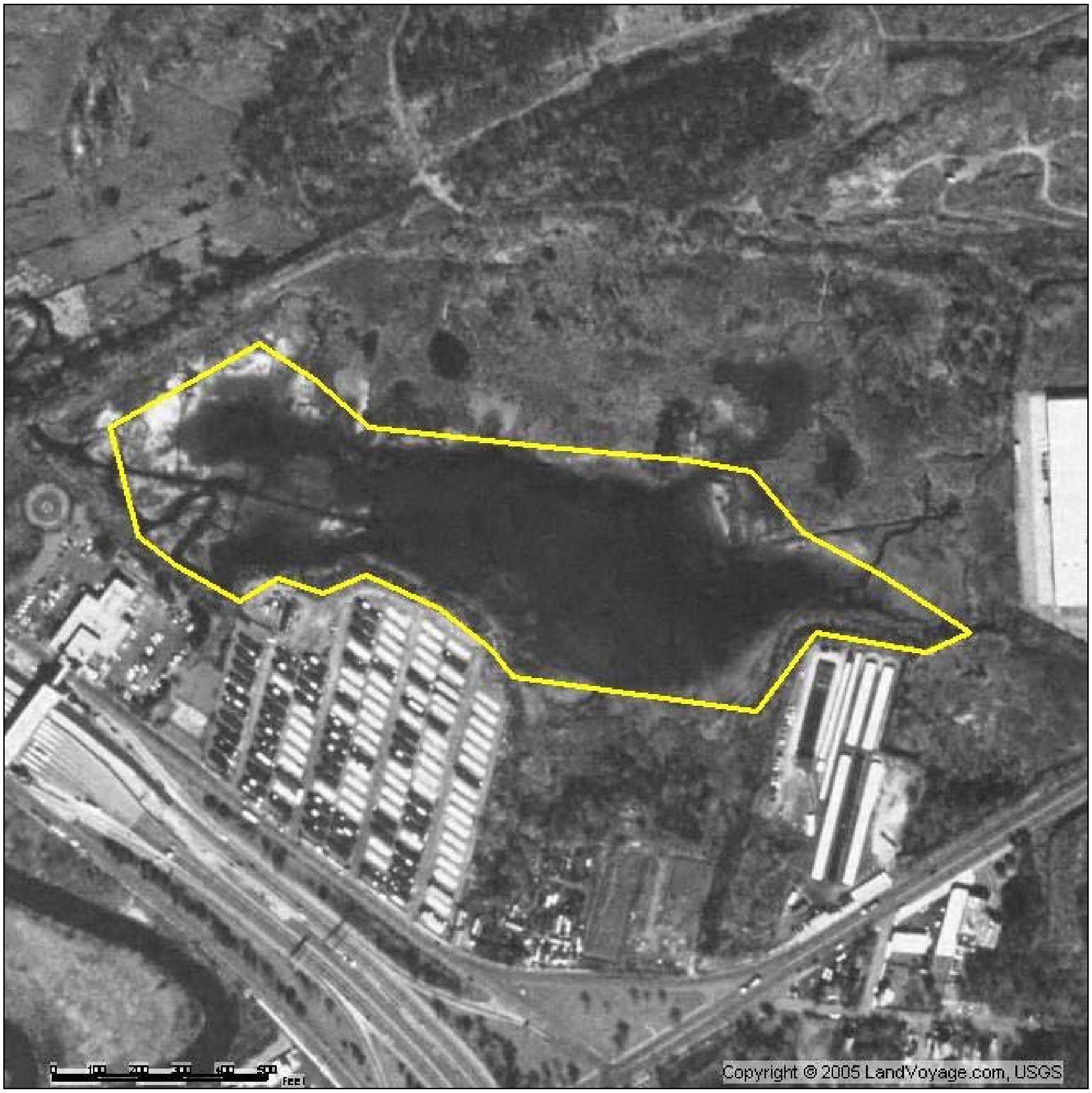

Figure A- 26: Site code GBPO – Goethals Bridge Pond, Staten Island, NY (Richmond Co.)

Figure A- 27: Site code GRKI1 – east shoreline of Great Kills National Park, Staten Island, NY (Richmond Co.)

Figure A- 28: Site code GRKI2 – Great Kills National Park, harbor and Crooke’s Point shoreline, Staten Island, NY (Richmond Co.)

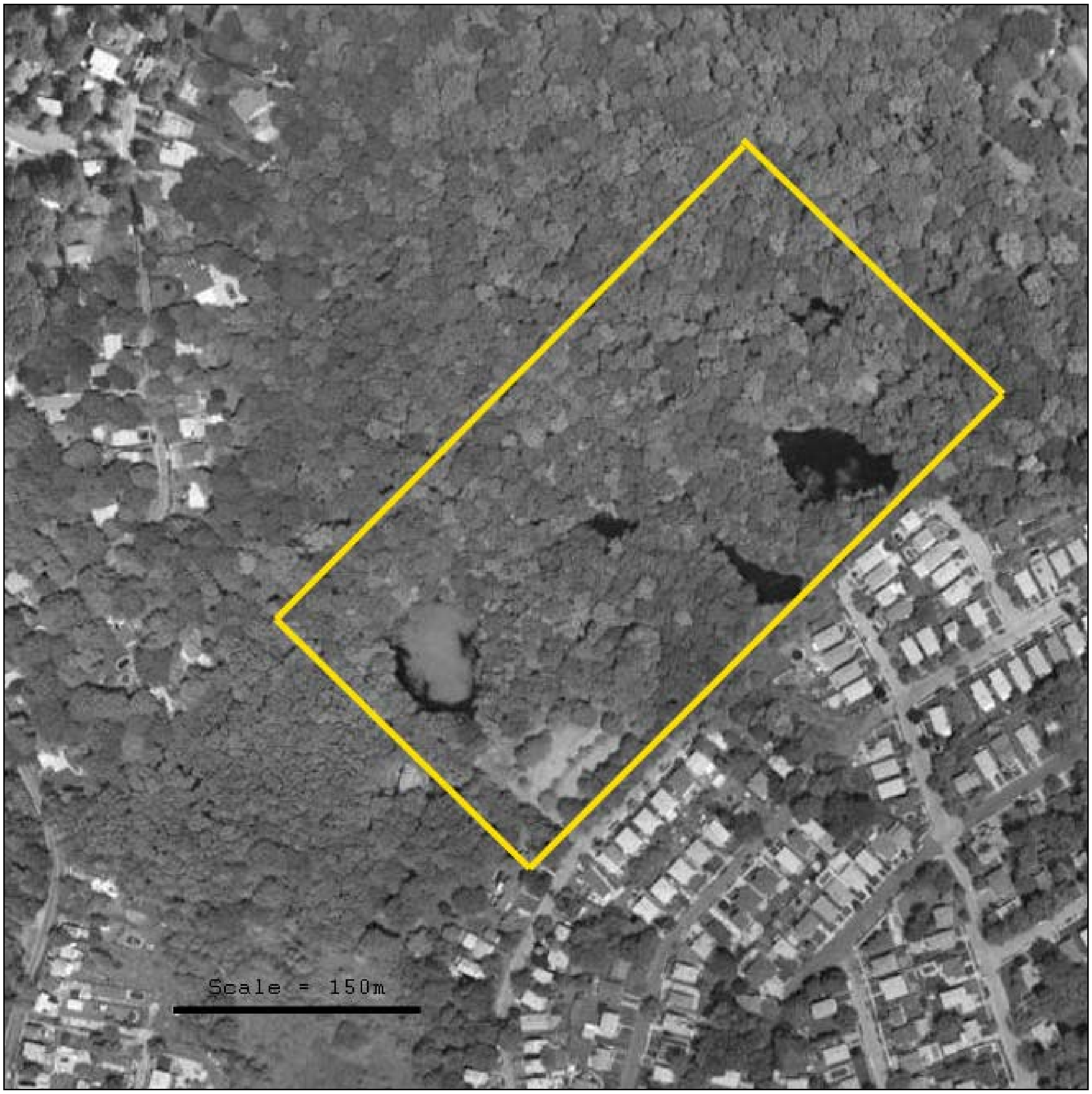

Figure A- 29: Site code HIRO – High Rock Park ponds, southwestern area of property, Staten Island, NY (Richmond Co.)

Figure A- 30: Site codes KVKS1 and SNUG – (1) Kill Van Kull shoreline north of Snug Harbor, (2) Snug Harbor fields, ponds, and creek, Staten Island, NY (Richmond Co.)

Figure A- 31: Site code KVKS2 – north of Richmond Terrace between Van Name and Van Pelt Avenues, Staten Island, NY (Richmond Co.)

Figure A- 32: Site code KVKF – Playing field south at Broadway and Henderson Ave (Lawrence C. Thompson Memorial Park), Staten Island, NY (Richmond Co.)

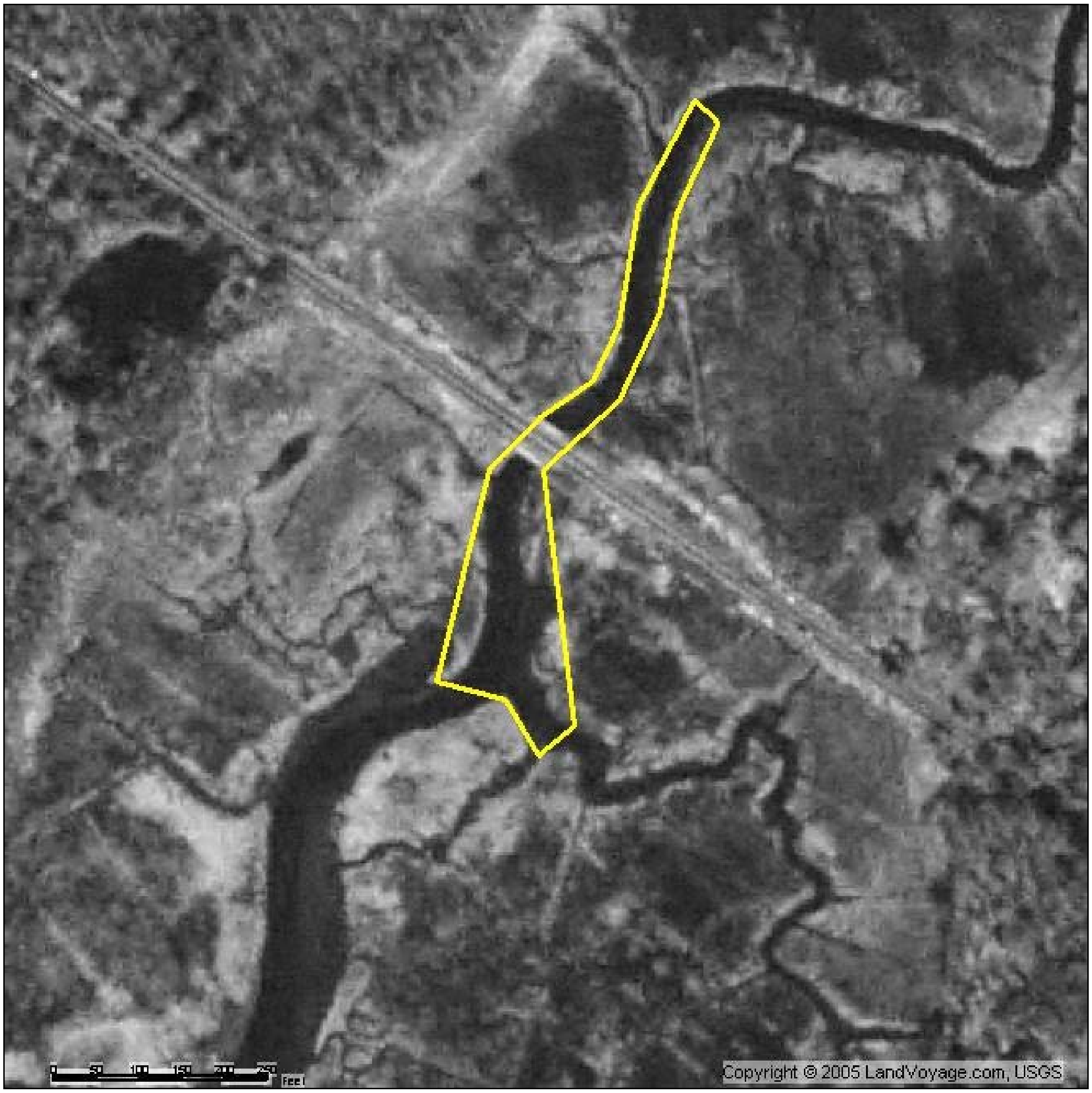

Figure A- 33: Site code MAIN1 – Main Creek section north and south of Travis Avenue bridge, Staten Island, NY (Richmond Co.)

Figure A- 34: Site code MAIN2 – Main Creek section south of Signs Road, Staten Island, NY (Richmond Co.)

Figure A- 35: Site code MILL – Miller Field playing fields and shoreline, Staten Island, NY (Richmond Co.)

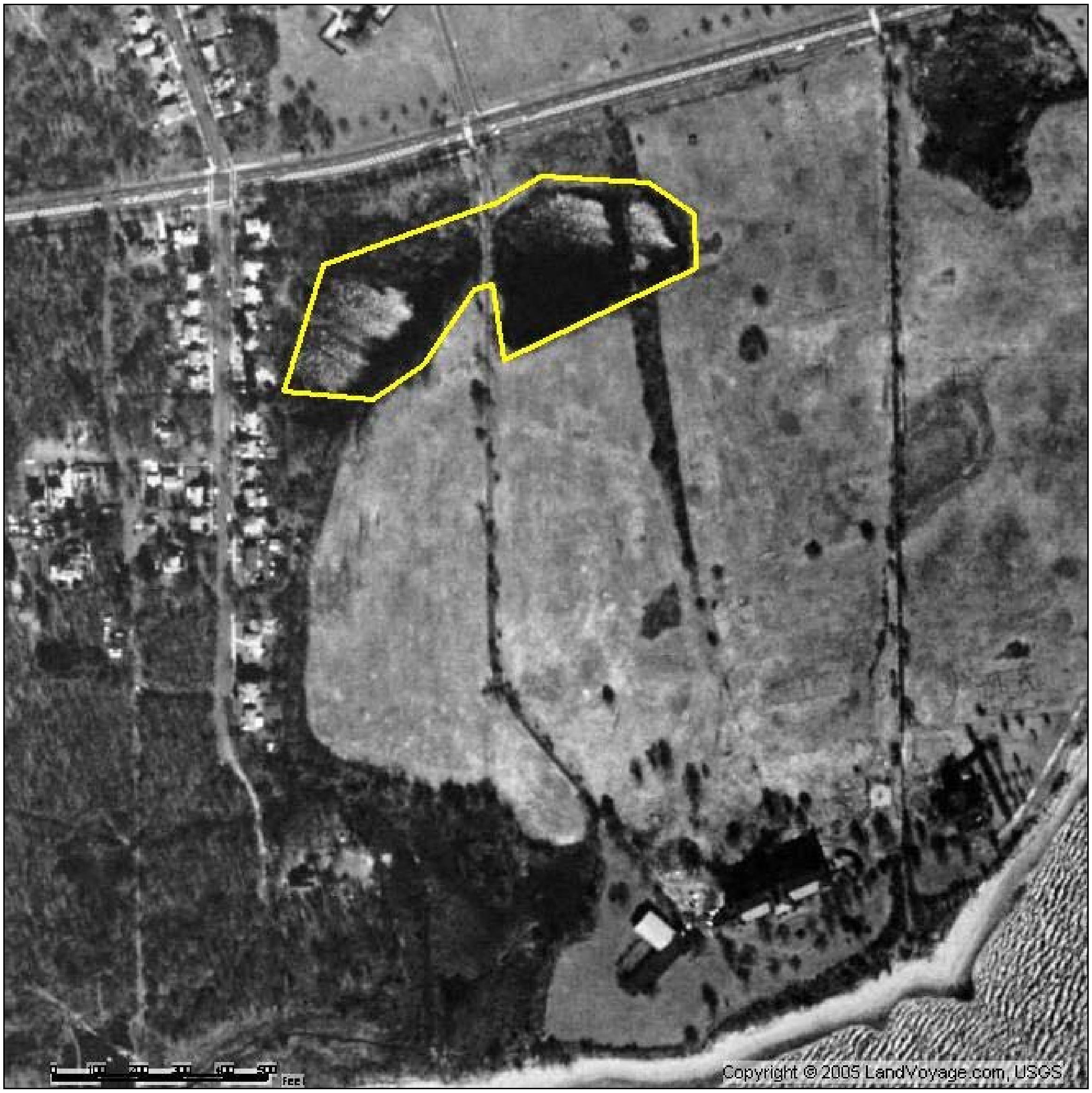

Figure A- 36: Site code MTLO – Mount Loretto northwest section, open water south of Hylan Boulevard and Cunningham Avenue, Staten Island, NY (Richmond Co.)

Figure A- 37: Site code NECK1+2 – Neck Creek waterways and marshes east (1) and west (2) south of Route 440, Staten Island, NY (Richmond Co.)

Figure A- 38: Site code OAKW – Oakwood Beach shoreline and associated marshes and creeks, Staten Island, NY (Richmond Co.)

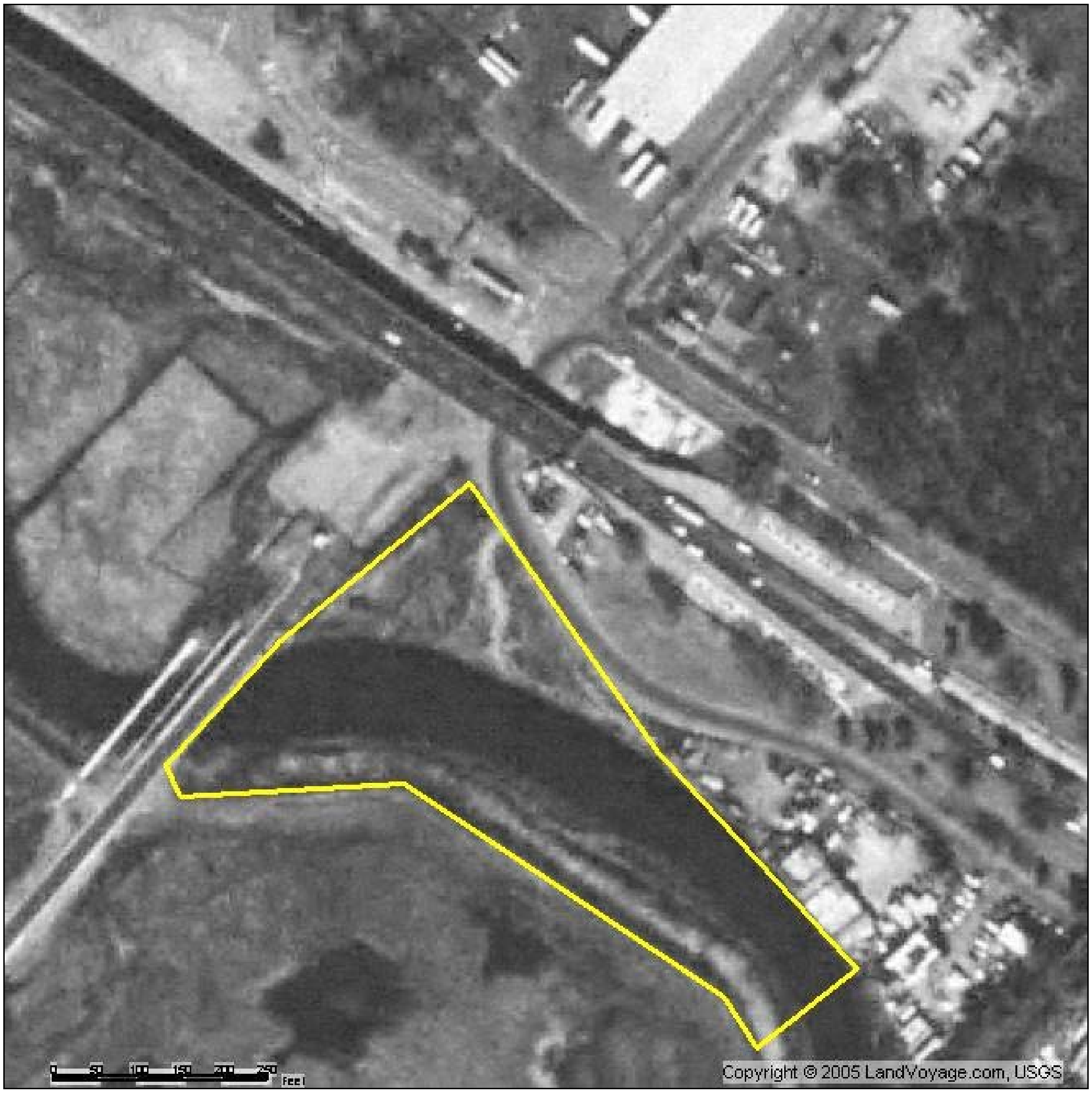

Figure A- 39: Site code OLDP2 – Old Place Creek and marsh section south of Western and Gulf Avenues, Staten Island, NY (Richmond Co.)

Figure A- 40: Site code OLDP3 – Old Place Creek and marsh section southwest of Gulf and Forest Avenues, Staten Island, NY (Richmond Co.)

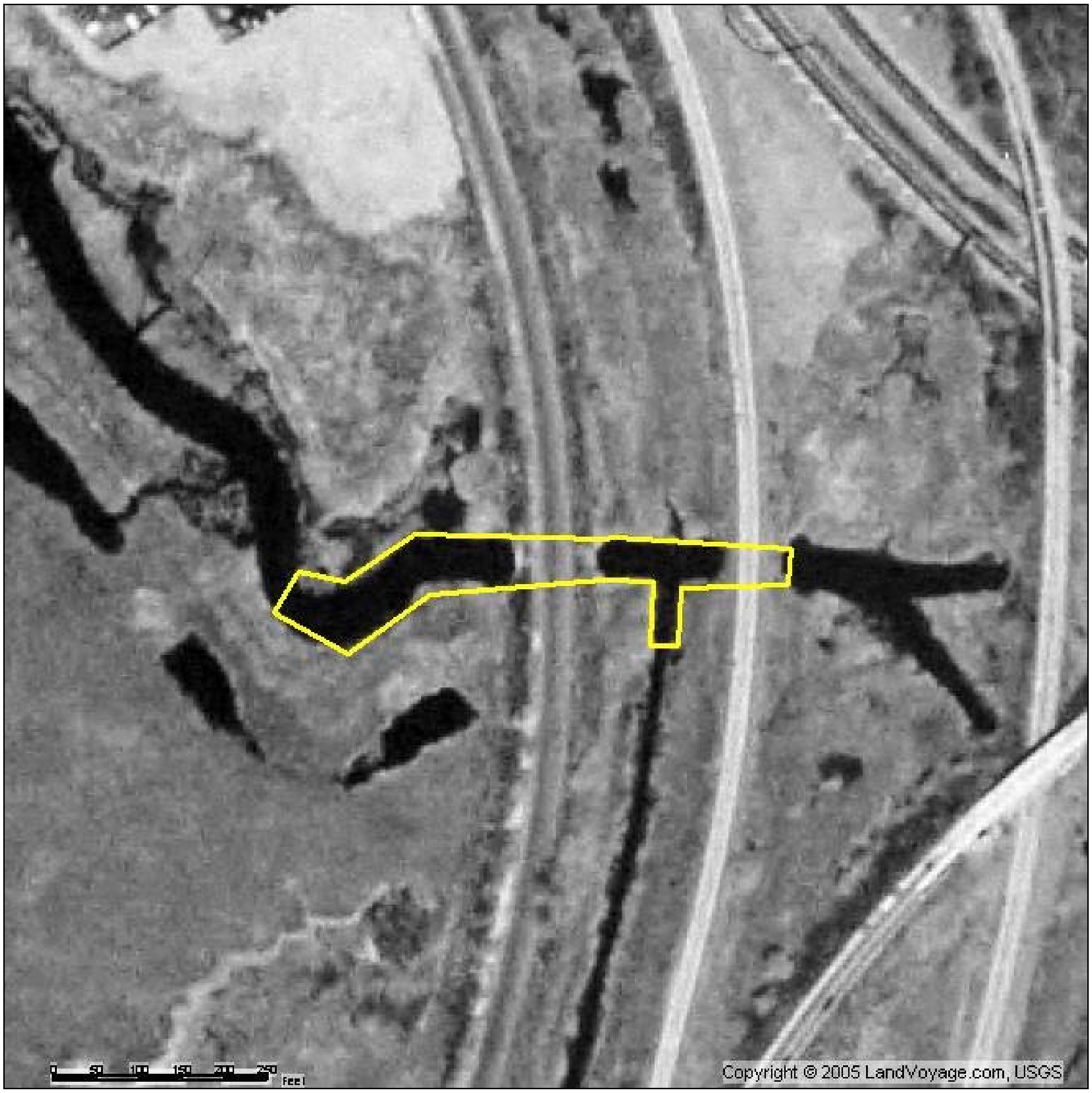

Figure A- 41: Site code OLDP4 – Old Place Creek, marsh, and culvert east and west of Gulf Avenues, Staten Island, NY (Richmond Co.)

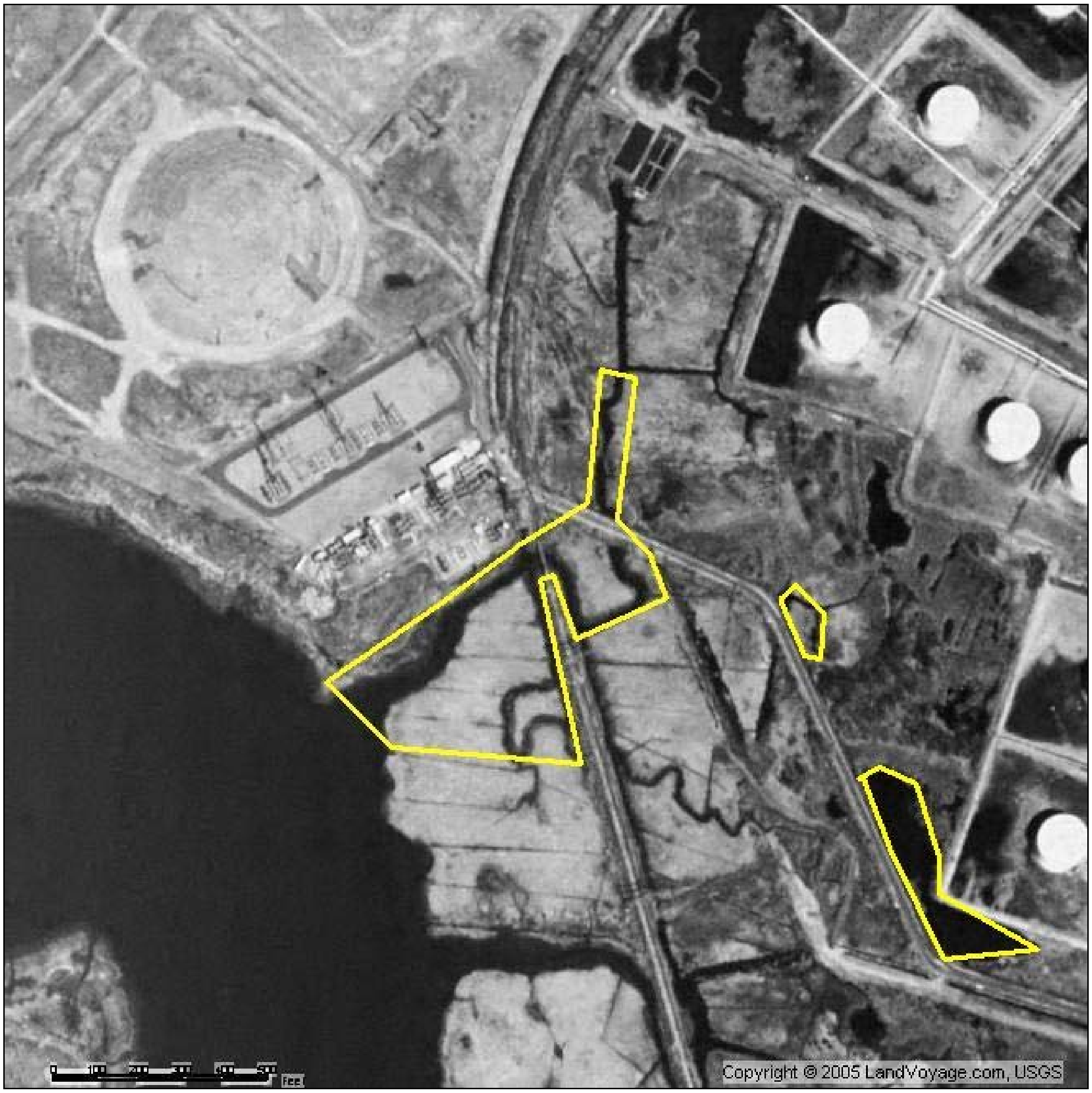

Figure A- 42: Site code RVRD – River Road vicinity creeks, marsh, and freshwater, Staten Island, NY (Richmond Co.)

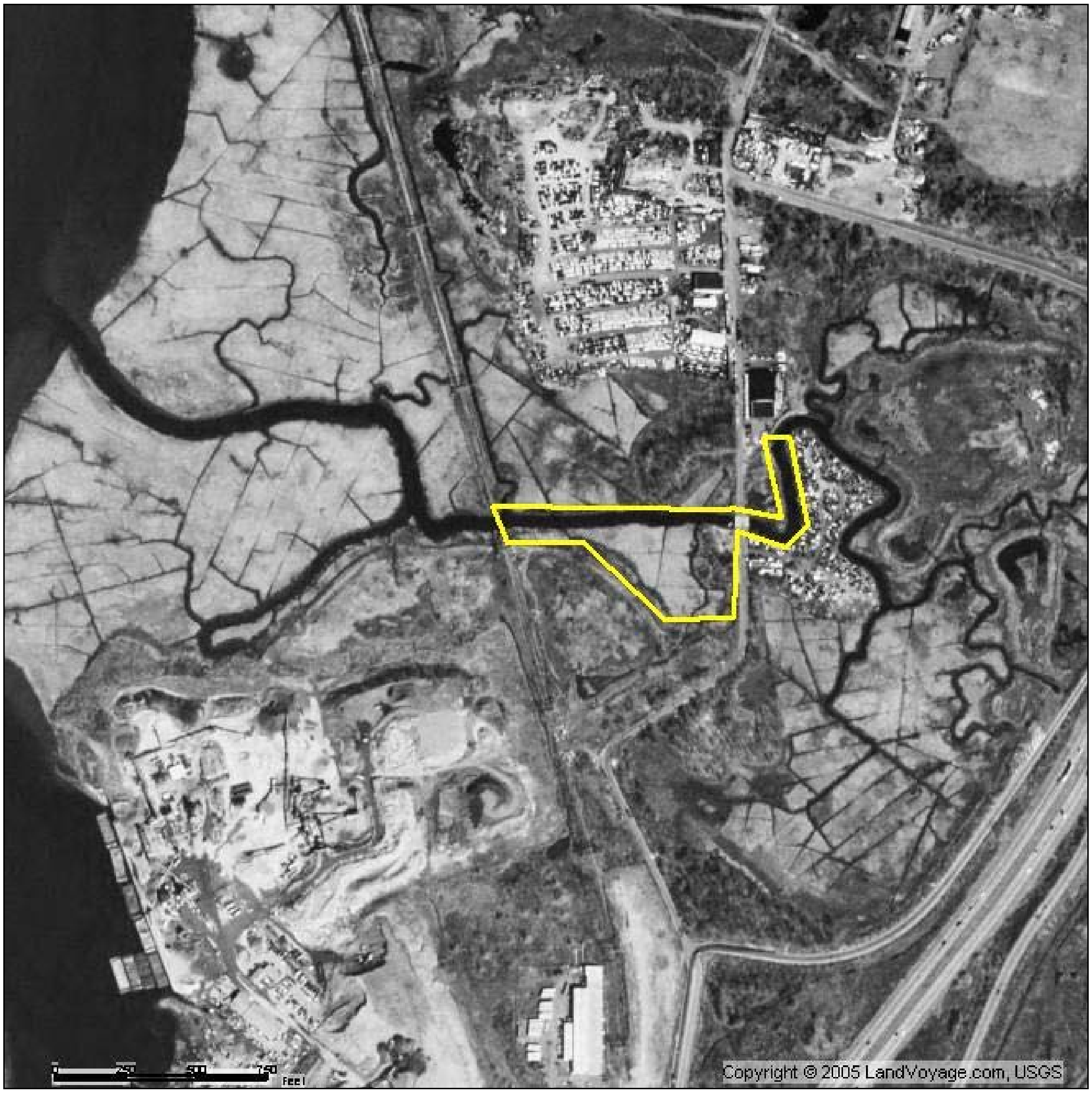

Figure A- 43: Site code SAWM – Saw Mill Creek and marsh section east and west of Chealsea Road, Staten Island, NY (Richmond Co.)

Figure A- 44: Site code SBEA – South Beach shoreline east of Sand Lane and Father Capodanno Boulevard, Staten Island, NY (Richmond Co.) Asterix denotes location of flight line observation point.

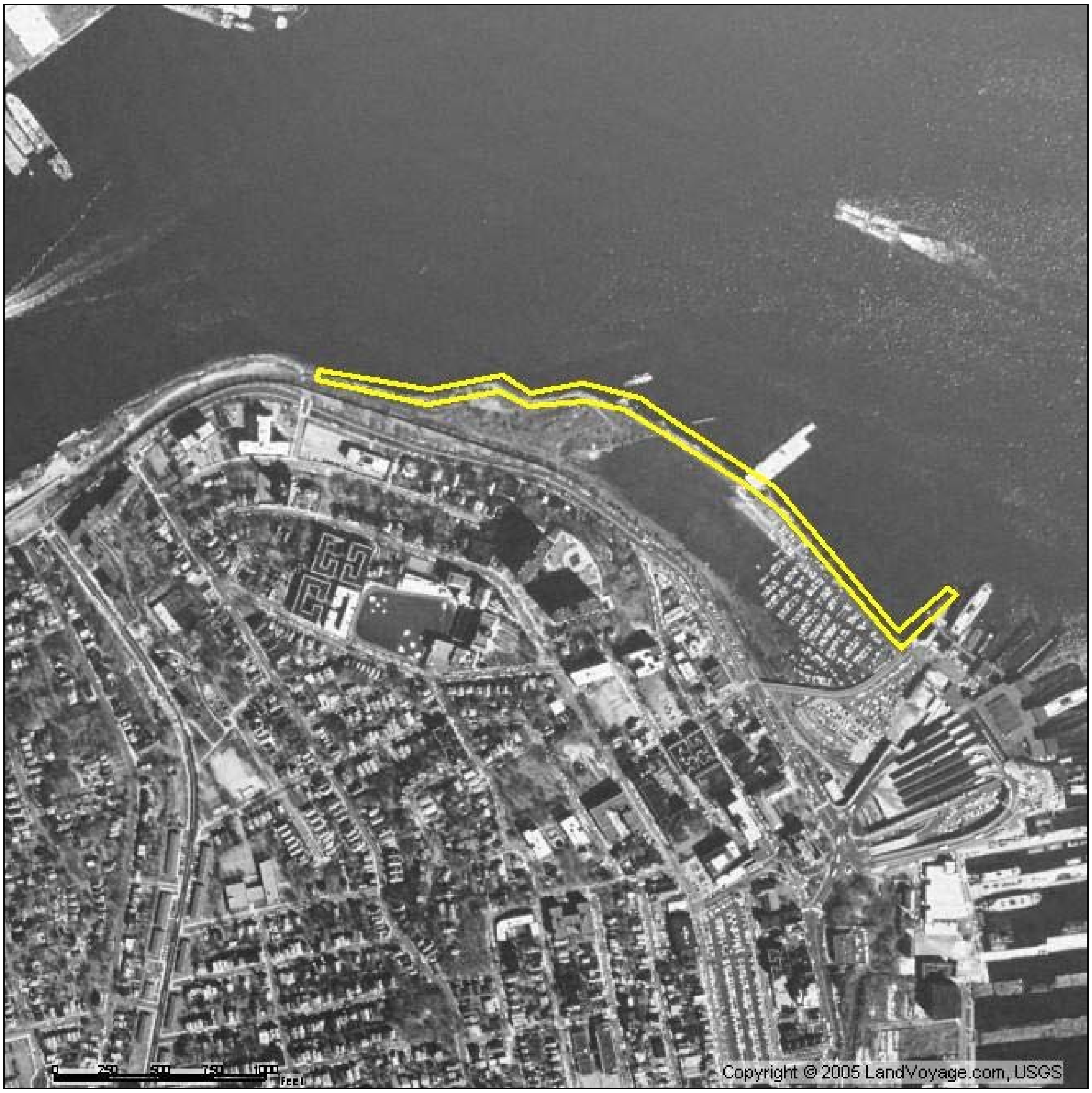

Figure A- 45: Site code SGEO1 – Saint George shoreline west of ferry terminal, Staten Island, NY (Richmond Co.)

Figure A- 46: Site code SGEO2 – Saint George shoreline southeast of ferry terminal, Staten Island, NY (Richmond Co.)

Figure A- 47: Site code SHAR – Sharrott Avenue and Hylan Boulevard shoreline and marshes, Staten Island, NY (Richmond Co.)

Figure A- 48: Site code SILV – Silver Lake Park shoreline and fields, Staten Island, NY (Richmond Co.)

Figure A- 49: Site code TOTT – Tottenville shoreline, marsh and field, northwest of Ellis Street, Staten Island, NY (Richmond Co.)

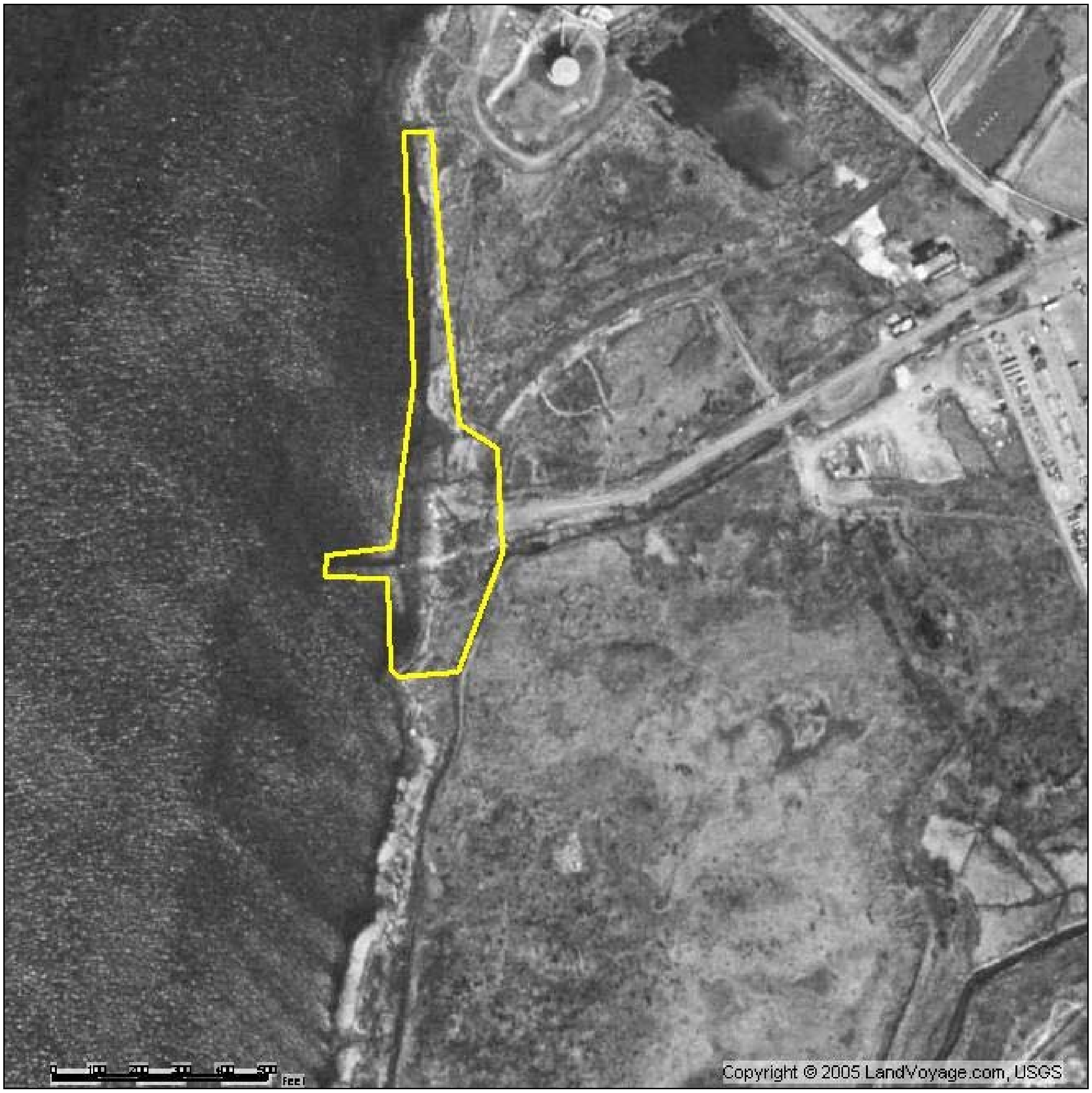

Figure A- 50: Site code VICT – Arthur Kill shoreline and marsh, east end of Victory Boulevard, Staten Island, NY (Richmond Co.)

Figure A- 51: Site code WILL – Willowbrook Park shoreline and fields, Staten Island, NY (Richmond Co.)

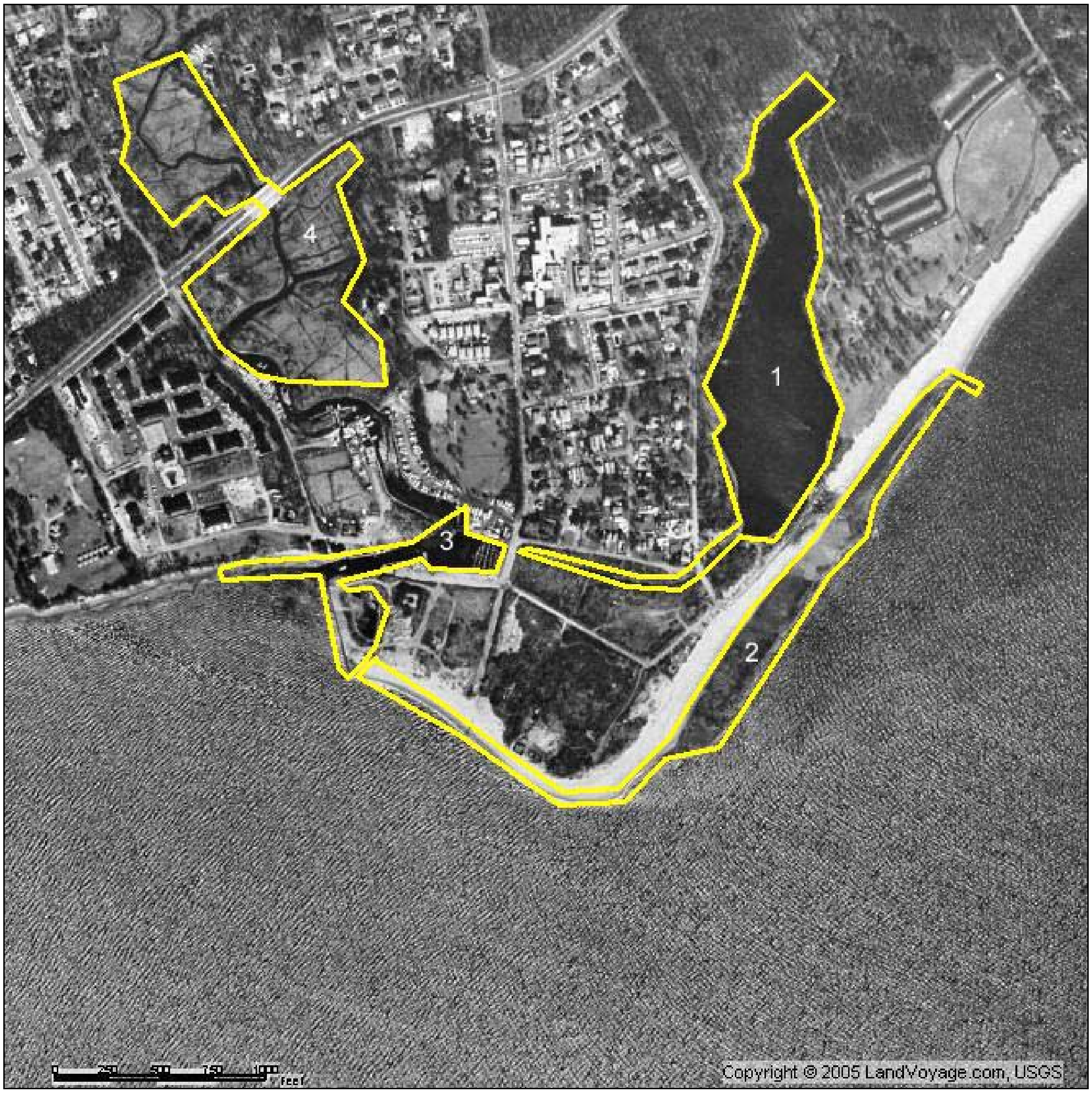

Figure A- 52: Site codes WOLF , LEWO, and LEMC3&4 – (1) Wolfe's Pond Park shoreline and drainage culvert, (2) shoreline at Wolfe's Pond Park/Prince's Bay, (3) south section of Lemon Creek at Prince's Bay, and (4) Lemon Creek section and marshes north and south of Hylan Boulevard, Staten Island, NY (Richmond Co.)

APPENDIX B

List of Common and Scientific Names

The following is a list of scientific nomenclature and common names of flora and fauna referred to in the text.

PLANTS

Spartina spp. Salt marsh grasses
Phragmites spp. Tall Reed
Celastrus orbiculatus Oriental Bittersweet
Smilax rotundifolia Greenbrier
Rhus radicans Poison Ivy
Myrica pennsylvanica Northern Bayberry
Rosa multiflora Multiflora Rose
Ligustrum spp. Privet
Betula populifolia Gray Birch
Juniperus virginiana Eastern Red Cedar
Prunus serotina Black Cherry
Celtis occidentalis American Hackberry
Robinia pseudoacacia Black Locust
Acer rubrum Red Maple
Morus alba White Mulberry

BIRDS

Somateria mollissima Common Eider
Mergus serrator Red-breasted Merganser
Pelecanus occidentalis Brown Pelican
Phalacrocorax penicillatus Brandt's Cormorant
Phalacrocorax auritus Double-crested Cormorant
Botaurus lentiginosus American Bittern
Ardea herodias Great Blue Heron
Ardea alba Great Egret
Egretta garzetta Little Egret
Egretta thula Snowy Egret
Egretta caerulea Little Blue Heron
Egretta tricolor Tricolored Heron
Bubulcus ibis Cattle Egret
Butorides virescens Green Heron
Nycticorax nycticorax Black-crowned Night-Heron
Nyctanassa violacea Yellow-crowned Night-Heron
Cochlearius cochlearius Boat-billed Heron
Plegadis falcinellus Glossy Ibis
Pandion haliaetus Osprey
Haliaeetus leucocephalus Bald Eagle
Accipiter cooperii Cooper's Hawk
Falco peregrinus Peregrine Falcon
Charadrius vociferus Killdeer

Haematopus palliatus American Oystercatcher
Actitis macularius Spotted Sandpiper
Larus delawarensis Ring-billed Gull
Larus argentatus Herring Gull
Larus occidentalis Western Gull
Larus marinus Great Black-backed Gull
Rissa tridactyla Black-legged Kittiwake
Sterna hirundo Common Tern
Rynchops niger Black Skimmer
Uria aalge Common Murre
Synthliboramphus hypoleucus Xantus's Murrelet
Ptychoramphus aleuticus Cassin's Auklet
Fratercula arctica Atlantic Puffin
Tyto alba Barn Owl
Corvus brachyrhynchos American Crow
Corvus ossifragus Fish Crow
Quiscalus quiscula Common Grackle

MAMMALS

Rattus spp. Rat
Procyon lotor Raccoon
Microtus pennsylvanicus Meadow Vole

REPTILES AND AMPHIBIANS

Lithobates catesbeianus American Bullfrog
Chelydra serpentina Snapping Turtle

MARINE FISHES

Morone saxatilis Striped Bass
Pomatomus saltatrix Atlantic Bluefish
Anguilla rostrata American Eel
Pseudopleuronectes americanus Winter Flounder
Brevoortia tyrannus Atlantic Menhaden
Fundulus heteroclitus Mummichog
Fundulus majalis Striped Killifish
Menidia menidia Atlantic Silverside
Cynoscion regalis Weakfish

FRESHWATER FISHES

Lepomis macrochirus Bluegill
Lepomis gibbosus Pumpkinseed
Micropterus salmoides Largemouth Bass

MARINE INVERTEBRATES

Gammarus lawrencianus Amphipod
Callinectes sapidus Blue Crab
Carcinus maenas Green Crab
Palaemonetes pugio Grass Shrimp

TERRESTRIAL INVERTEBRATES
Forficula spp. Earwig
Annelid spp. Earthworm
Anoplophora glabripennis Asian Longhorned Beetle

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