

DISTRIBUTION AND PREDATION OF DIAMONDBACK TERRAPIN NESTS
AT SIX UPLAND ISLANDS OF JAMAICA BAY UNIT AND SANDY HOOK
UNIT, GATEWAY NATIONAL RECREATION AREA

THESIS

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ABSTRACT

Northern diamondback terrapins, *Malaclemys terrapin terrapin*, are declining in number throughout their range as a result of habitat degradation and urbanization. Human activities have altered habitat and predator-prey relationships. Recent increases in raccoon populations play a significant role in limiting terrapin numbers.

I studied predation rates on terrapin nests in 2000 and 2001 at the Jamaica Bay Unit (JBU), Staten Island Unit (SIU), and, in 2002, at the Sandy Hook Unit (SHU) of Gateway National Recreation Area (GNRA) in New York and New Jersey. Most of my research was conducted on six of the islands of JBU (Canarsie Pol, Elder's Point, Little Egg Marsh, Pumpkin Patch, Ruffle Bar, and Subway Island) and SHU of NJ. On Canarsie Pol, Little Egg Marsh, and Ruler's Bar, (total of 192.8 ha) approximately 20 nests/year are deposited and about 318 hatchlings are produced annually. Predators destroyed approximately 32.6% (14/43) of nests; additional natural causes, (e.g. flooding, infertility, and maggots) caused 14.7% (55/373) of eggs to fail to hatch, yielding egg viability as 86.3% (322/373). No predation occurred on Canarsie Pol, probably due to the very low number of nesting females. Other islands in JBU--Elder's Point, Pumpkin Patch, and Subway Island--not appear to have terrapin nesting in 2000 nor 2001. Mammal and bird surveys on RB and LEM showed that few possible turtle predators are present on these islands. Smaller islands may be an important recruitment source of Jamaica Bay's terrapin population, whereas RBH now may be a sink population.

At the SHU, predation and egg viability rates were similar to those in RBH. I found 203 nests in eight different locations.

INTRODUCTION

Life History of Terrapins

Diamondback terrapins (*Malaclemys terrapin*) are medium-sized, brackish water turtles belonging to the family Emydidae, which also includes cooters, sliders, and painted turtles. Although found in salt water, they are not sea turtles; they have webbed feet with claws, not flippers. Terrapins are one of the most latitudinally extensive species of turtles in North America, ranging from Cape Cod to the Florida Keys, and as far west as the Gulf Coast of Texas (Conant and Collins 1998). There are seven known subspecies (Conant and Collins 1998): the Northern Diamondback terrapin (*Malaclemys terrapin terrapin*), the Carolinian Diamondback terrapin (*M. terrapin centrata*), the Florida East Coast Diamondback terrapin (*M. terrapin tequesta*), the Mangrove Diamondback terrapin (*M. terrapin rhizophorarum*), the Ornate Diamondback terrapin (*M. terrapin macrospilota*), the Mississippi Diamondback terrapin (*M. terrapin pileata*), and the Texas Diamondback terrapin (*M. terrapin littoralis*). The subspecies found in New York and New Jersey is *Malaclemys terrapin terrapin* (Ernst et al. 1994).

Terrapins are the only turtles in the United States that regularly inhabit tidal creeks, bays, coastal marshes, estuaries, and salt marshes, where the salinity ranges from zero to almost full salt water. The diet of terrapins mainly consists of dead fishes and invertebrates such as crabs, snails, shrimps, and clams. Terrapins may be an important component of estuarine food webs (Hurd et al. 1979), but more research needs to be done to determine their role in estuarine ecosystems.

In the early spring, terrapins come out from hibernation and spend their time feeding and mating. During June, July, and early August, adult females cross the

intertidal zone to nest on sandy dunes. Through late summer, terrapins spend most of their time feeding in deep water in preparation for the winter hibernation (Roosenburg 1991). Hatchlings emerge from their nests from late August through September and early October, if the weather permits. Hatchlings may overwinter in the nest in some cases, but this has never been documented (pers. obs.).

Terrapin meat was a gourmet delicacy from the late 1800s to the 1900s; hence they were heavily harvested. Terrapins of the New York/New Jersey area appear to have been affected by the trade in terrapin meat because of their proximity to a major market (New York City) and their reputation as the best-flavored meat (Marganoff 1970). According to Spagnoli and Marganoff (1975), by the mid-1930s, the Long Island terrapin population was severely depleted; there were no more turtles to be found and this species was thought to be locally extinct. There were sightings of few terrapins around South Oyster Bay, the Cold Spring Harbor region, and Orient Point (Spagnoli and Marganoff 1975).

Although terrapins have managed a partial comeback over the past several decades since harvest for human food has slowed, they face new threats from habitat degradation, pollution, traffic, drowning in crab pots (Roosenburg 1992), and raccoon (*Procyon lotor*) predation (Seigel 1980a). If caught alive in crab pots the terrapins are still sold to the fish market. In recent years, many terrapin nest sites have been destroyed due to human-induced changes, such as the development of coastal areas. This not only depletes the terrapin-nesting habitat, but also causes other environmental problems, such as the destruction of salt marshes. Female terrapins unable to find nesting sites due to heavily developed beaches are forced to seek out alternative sites

to lay their nests. While crossing busy streets in search of nesting grounds, many gravid females and viable eggs are lost due to car traffic (Gibbs and Shriver 2002).

Raccoons are another threat to the terrapin existence. Raccoon predation on nests is common in most turtle populations, but this may be a recent phenomenon, because raccoon populations were formerly much smaller than they are now (Zeveloff 2002). Raccoon predation is a potentially limiting factor for turtle populations because raccoons not only eat turtle eggs, but also eat the adults (Wilbur & Morin 1988). According to Congdon et al. (1993), raccoon predation on eggs and adults severely impacts turtle populations to cope with additive mortality associated with high egg and adult predation. Similarly, Seigel (1980b) found that raccoons were responsible for death of many female terrapins. Numerous tracks were found around the carcasses, their necks were broken, internal organs were pulled out, and their hind legs were usually severed.

Past Research in Jamaica Bay

One of the places where *Malaclemys terrapin terrapin* currently thrives is Gateway National Recreation Area (GNRA) (Fig. 1). GNRA is a large, federally operated, estuarine park managed by the National Park Service (NPS). GNRA is located within New York and New Jersey. GNRA is comprised of three distinct units that contain a total of 10,500 hectares of land and water, much of it providing good habitat for terrapins. The three units are the “Jamaica Bay” (JBU) and “Staten Island” (SIU) units of New York, and the “Sandy Hook” (SHU) unit of New Jersey (Fig. 1). The JBU contains the westernmost salt marshes that lie behind a system of barrier beaches

along the south shore of Long Island separating Jamaica Bay from the Atlantic Ocean. Jamaica Bay was originally mostly salt marshes, tidal flats, and a large bay (Englebright 1975). The upland marshes of Jamaica Bay began naturally developing about 3-4,000 years ago (Englebright 1975). In the past century, uplands have been created in and around Jamaica Bay through landfill and dredge spoil deposition. Areas of shoreline around the bay have been built up and significantly urbanized.

Two native grasses dominate the Jamaica Bay salt marshes: *Spartina alterniflora*, a grass that provide attachment for mussels and other organisms living in the bay, and *Spartina patens*, found on the edges of the water. Both grasses are invaluable for terrapins in different stages of their growth. Another grass abundantly found in different areas of Jamaica Bay is the common reed, *Phragmites*. Although *Phragmites australis* was native to the area and probably always present in low densities, *P. australis* type "M," an invasive genotype from Europe, is rapidly dominating many salt marshes and uplands of Jamaica Bay (Saltonstall 2002).

According to Black (1981), prior to the Civil War, the islands of Jamaica Bay east of Barren and Bergen Islands (Fig. 2) remained uninhabited and unmodified, with the exception of Ruffle Bar. After 1865, a few structures were built on Ruffle Bar without a permit from the town. In 1907, Jamaica Bay was 24,640 acres in extent (Englebright 1975). Of this, 16,170 acres were marsh and the rest of it was open water. All the islands except Barren, Bergen, Mill Islands, and Ruffle Bar were marshes without uplands. In 1923, Cross Bay Boulevard was constructed by filling in Big Egg Marsh, the marshes and islands located to the north in the bay. In 1926 there were more than 40 buildings on Ruffle Bar (Black 1981). The shore and the island center were filled as

needed. In 1930, Robert Moses proposed that Jamaica Bay become the largest waterfront park in America (Black 1981). By 1937, the Marine Parkway Bridge was constructed, which connected Ruler's Bar Hassock (formerly called the West Island) to the western tip of Rockaway Peninsula with Flatbush Avenue and the Belt Parkway. In 1938, in order to maintain the Cross Bay Railroad and Idlewild Airport (later John F. Kennedy airport) more filling and dredging altered islands and salt marshes. By 1940, fisherman abandoned the buildings. Around the same time, the Cross Bay Railroad was built to Broad Channel, which facilitated population growth (Black 1981). The fisherman burned their houses in 1951 when RB became a city park property. In the 1950s Robert Moses made a deal with the Staten Island borough president to build West Shore Expressway in exchange for approval to build the Fresh Kills landfill. In 1956, digested sludge from the Hendrix Creek Treatment Plant was applied to Canarsie Pol (Englebright 1975). After this treatment, Canarsie Pol became the second largest island of Jamaica Bay. The bay side was bulk headed and backfilled to create valuable real estate. The dune field of Broad Channel was filled and leveled to create a platform for residential housing (Englebright 1975). By 1970, dredging and filling had reduced the bay to only 13,000 acres, with 4,000 acres as marshes. The dredging of shipping channels eliminated some smaller islands and added to the uplands of others. Finally in 1972, the National Park Service took over nearly all of the islands, marshes, and open water of Jamaica Bay and created Jamaica Bay Unit of Gateway National Park. All houses/buildings were removed before the Jamaica Bay became a wildlife refuge. The fisherman burned their houses in 1951 when RB became a city park property.

In the early 1980s Cook carried out amphibian, reptile, and mammal surveys in JBU (Cook pers. comm.). He discovered a 93-percent egg-survivorship rate and no predation on the terrapin nests (Cook's pers. comm. in Feinberg 2000). At that time there were no predators of turtle nests present in the refuge. Eighteen years later, in 1998, Feinberg started research at GNRA to determine the status of terrapins (Feinberg 2000). He restricted his research mostly to Ruler's Bar Hassock (RBH), now the largest island of Jamaica Bay (520 ha). He also surveyed briefly for predated nests at some of the surrounding islands [Canarsie Pol (CP), Subway Island (SI), Ruffle Bar (RB), and Little Egg Marsh (LEM)], (Fig. 2), but found evidence of terrapin nesting (predated nests) only at RBH and LEM. Additionally he surveyed Sandy Hook Unit (SHU), Great Kills Park (GKP), Miller Field (MF), Breezy Point (BP), Dead Horse Bay (DHB), Floyd Bennett Field (FBF), Bergen Beach (BB), and Canarsie Pier (CP) (Fig. 2, Table 1). Of these, he found evidence of nesting only at SHU. At RBH, he found that raccoons predated 93% of the nests. However, he was unable to measure predation rates elsewhere. Other than on RBH, Feinberg (2000) depended solely on the evidence of nest predation to locate nests, so he was unable to find nests that had not been predated. Therefore, although considerable information was available concerning the number of terrapins nesting, predation rates, and the approximate number of annual hatchlings at RBH, little was known about the other islands of Jamaica Bay. Nesting may have occurred on the other six Jamaica Bay islands, but they apparently were not predated. Given that nesting and predation rates on the six smaller islands were unknown; the value of these islands as a source of terrapin hatchlings was unknown.

Predation on Adult Terrapins

Predation on adult terrapins by raccoons has been reported in previous studies (Seigel 1980b, Spagnoli and Marganoff 1975). On RBH, Feinberg (2000) found that in 1998 and 1999 combined, at least 23 adult terrapin females were killed by raccoons. In the Merritt Island National Wildlife Refuge, Seigel (1980b, 1993) found that raccoons killed 86% of adult Florida terrapin females in one year. Seigel (1980b) suggested that the predation on adult terrapins over time could result in a significant decrease in populations; and may have a greater effect than predation on eggs. Adult turtles are important to the population because of their longevity, large lifetime egg production, and lengthy reproductive span, whereas eggs and hatchlings are not as important (Hendrickson 1958). Thus raccoon predation on adults is particularly threatening to conservation of this species.

Raccoons are not the only predators of adult terrapins. Watkins-Colwell and Black (1997) observed an adult male terrapin being attacked by at least two unidentified species of gulls (*Larus* spp.). The predation was interrupted, but all four legs had been severed. This attack led to the death of the turtle.

Predation on Eggs and Hatchlings

Terrapin nests and hatchlings are preyed upon by a variety of predators, including crows (*Corvus brachyrhynchos*), gulls (*Larus atricilla* and *Larus argentatus*), rats (*Rattus norvegicus*), muskrats (*Ondatra norvegicus*), foxes (*Vulpes vulpes*), and raccoons (Seigel 1980b). Burger (1977) found that, in New Jersey, red foxes preyed 34% of terrapin nests, raccoons 48%, laughing gulls 8%, crows 6%, and others 4%.

Ernst et al. (1994) reported that raccoons are primary predators of terrapin nests. They usually eat the entire egg but may leave some eggs uneaten. The eggs left behind usually are eaten by the next morning (pers. obs.). Seventy one-percent of terrapin nests were predated within 24 hours from the egg oviposition (Feinberg 2000).

Unlike raccoons, crows and gulls predate eggs while the nest is being laid (Burger 1977). Burger (1977) reported that both species of birds flew over the dunes or perched on nearby poles watching females laying eggs. Birds landed near the egg-laying female and ate two or three eggs, and flew away with an egg in their beak. After nests were covered up, gulls did not prey on them, but crows were able to dig up eggs with their bills.

Lazell and Auger (1981) reported that some terrapin nests were damaged by the invasion of beach grass (*Ammophila breviligulata*) roots. Beach grass roots can withdraw nutrients from terrapin eggs, presumably an advantage for plants living in the poor soil of dunes (Stegmann et al. 1988). Roots stopped egg development and in some cases, killed all eggs in a nest. In most cases, eggs became deflated but some maintained their shape and hatched. According to Stegmann et al. (1998), within 45 days beachgrass roots were able to absorb nutrients more than 30 centimeters away from terrapin eggs. Beach grass also affects the microclimatology of beach area, lowering soil temperature (Roosenburg 1990). Because terrapins have environmental sex determination (ESD), *A. breviligulata* roots might skew the hatchling sex ratio towards males.

Other Island Research in Jamaica Bay

In addition to work on RBH, it was important to determine nesting and predation rates on Jamaica Bay's other islands (CP, EP, LEM, PP, RB, and SI), because these islands may serve as an important source of terrapin hatchlings, necessary for sustaining the JB terrapin population. These islands are not connected to the mainland, as is RBH, and have no fresh water. This makes it unlikely that raccoons, the main nest predator on RBH, live on these islands. If so, and predation rates are therefore low, these islands may produce many terrapin hatchlings despite their small size. Therefore, they have the potential to be safer nesting sites than RBH. In addition, Feinberg (2000) found ten nests that appeared to have been predated by raccoons on Little Egg Marsh, where raccoons had not been reported previously. The small number of predated nests Feinberg (2000) found on Little Egg Marsh could indicate extremely low predation rates upon the nests, low nesting rates, or very few predators. The lack of predated nests on the other islands could be the result of low predation rates, rather than a lack of nesting. If the smaller Jamaica Bay islands are free of raccoons, as had been assumed by NPS personnel (D. Avrin pers. comm.), it is important to determine what predator(s) predated nests found during Feinberg's study. In order to determine the importance of the smaller islands, it was important to monitor them during a nesting season and estimate the number of nesting terrapins that nest there.

To make rational decisions about the future of populations, biologists need to understand how populations grow, how they change through time, and how they are structured. Understanding these factors will help to predict the future of the Jamaica Bay terrapin population. It is important to know the number of reproductively active

individuals, as well as the recruitment rate. If recruitment into the adult population is insufficient to replace adults as they die, the population will inevitably decrease.

Many species occupy a broad area, but individuals may be clumped in populations within their range. Such species exist as metapopulations, groups of multiple local populations connected through migration (Gotelli 2001). Metapopulation structure is important for many, perhaps most, species. Over time, any one population within the larger metapopulation is likely to be eliminated. The cause could be catastrophic, such as an oil spill, fire, a hurricane, a disease outbreak, or a sudden influx of predators. In a metapopulation an influx of individuals that from a nearby population can re-establish populations in these empty habitat fragments. Populations that constantly increase in size and give rise to new individuals that regularly emigrate from this population, are known as “source populations.” Populations that are not replacing themselves in size (despite the influx of new individuals) are known as “sink populations” (Gotelli 2001). Sinks may never be self-sustaining, but may depend on immigrants from source populations. This way, the whole metapopulation is maintained, even though various subpopulations become extinct temporarily.

The terrapins of Jamaica Bay may be considered to be a metapopulation. The population cannot easily move in and out of the bay because of the narrow, deep Rockaway inlet, which connects the bay with the Atlantic Ocean (Fig. 1). Additionally, to suggest that terrapins of Jamaica Bay make up a metapopulation is to suggest that the same nesting females usually, but not always, nest on the same beaches. If so, source and sink relationships have likely shifted as raccoons have been introduced to RBH. Introduction of raccoons to RBH is a recent phenomenon. During O'Connell's (1980)

mammal trapping in these areas, no captures of raccoons were made. He observed raccoons only in the Sandy Hook unit. O'Connell further stated that there were no records of raccoons within the JBU at that time. Cook (1989a) reported that the human alteration of Jamaica Bay favored terrapins, and that raccoons were unable to colonize the human-created uplands. However, raccoons are now common at RBH. This influx of new predators may have affected these relationships in that the RBH may have become a population sink, and possibly the other islands may have become the source of terrapin hatchlings.

On RBH, more than 2,053 nests/year were laid during Feinberg's (2000) study. Approximately 22,378 eggs were deposited in the ground during each nesting season. Feinberg (2000) estimated that RBH experienced approximately 93% predation rates on terrapin eggs. This high predation rate, combined with an unknown but probably low juvenile survival rate, indicates that it is possible that the terrapin population could soon become extinct in Jamaica Bay, if RBH is the main source of terrapin hatchlings. However, RBH does not have the most "suitable" nesting habitat in Jamaica Bay; it has approximately 26.5 ha of habitat, compared to 103.6 ha for the other islands combined. Potentially, the other islands could be important sources of the JB terrapin population.

My research goals were: 1) to look for evidence of terrapin nesting at poorly studied locations in Jamaica Bay Unit and Sandy Hook Unit, 2) to document as many nesting events as possible to determine how many terrapins were using the smaller islands of JB and how many turtles nested at SHU, 3) to determine nest site fidelity in these two units, 4) monitor nests on a daily basis to measure predation rates on islands and at SHU 5) to compare the predation rates between the islands of the JB and SHU,

6) to carry out surveys of mammals and birds, possible predators of terrapin eggs, present at LEM and RB, and 7) to compare clutch sizes among these study sites.

MATERIALS AND METHODS

Description of Study Area

Gateway National Recreation Area (GNRA) is one of more than 379 parks that make up the National Park System. GNRA preserves and protects sites in and around New York Harbor, while providing recreational resources for a million people (Tanacredi and Badger 1995). GNRA is comprised of three distinct units, together containing 10,400 hectares of land and water. The three units are the Jamaica Bay Unit (JBU) and the Staten Island Unit (SIU), both located in New York, and the Sandy Hook Unit (SHU), located in New Jersey (Fig. 1). GNRA has a unique location where the Atlantic Ocean meets the land and the salt waters mix with the fresh waters of Hudson-Raritan estuary and streams. Sandy Hook, NJ, and Breezy Point, NY, peninsulas make a natural gateway to New York Harbor (Tanacredi and Badger 1995, acronyms summarized Table 1).

The JBU is located in the boroughs of Brooklyn and Queens. It is made up of 7,517 hectares of water and marshlands. This unit includes seven upland areas: RBH the largest, CP, RB, LEM, SI, PP, and EP (Fig. 2, Table 2).

The Staten Island Unit (SIU) is made up of 836 hectares of land and water, and is located along the south shore of Staten Island. It includes Miller Field (MF), Great Kills Park (GK), and Hoffman and Swinburne Islands.

The third part of GNRA, Sandy Hook Unit (SHU) is a 792-hectare barrier beach peninsula in Monmouth County, located at the northern tip of the New Jersey shore (Fig. 1). SHU includes 11 km of ocean beaches, salt marshes, hiking trails, and a maritime forest (Tanacredi and Badger 1995). The eastern side of the peninsula faces

the Atlantic Ocean and is dominated by extensive beach and dune habitats (National Park Service). From West side the peninsula faces the Hudson River Bight, creating several coves and well protected beaches, which serve as terrapin habitat.

Locating Potential Nesting Areas

I located potential terrapin nesting areas in two ways: using previous reports (Cook 1989a, Feinberg 2000) and rectifying a time series of historical, 1996 aerial photographs from the 1997 imagery from Monmouth County, NJ (Figure 4). I categorized sites into habitat types based on vegetation and amount of disturbance.

In 1999, I obtained the 1976 imagery from the New York City, including vegetation maps and aerial photographs of JBU, containing information about different vegetation cover in the different units of GNRA (Fig. 3). I used the ArcView GIS program to find possible terrapin nesting grounds with “suitable” habitat (Figs. 3 and 4). I defined “suitable” nesting habitat for diamondback terrapins as sand dunes, sparsely vegetated dune areas, low thicket, lawn, and flat sand areas with low vegetation cover.

Vegetation on the LEM was primarily beach grass, *Ammophila breviligulata*, and heather, *Calluna vulgaris*. In contrast, vegetation cover on the RB and CP was comprised of tall trees, shrubs, low marsh, high marsh, *Phragmites australis* (common reed), and only small patches of sandy areas with sparse plants, suitable for nesting. RB and CP had lower amounts of beach grass growth. Based on the results obtained from the 1976 imagery data, in 2000 I surveyed these sites that appeared to have suitable nesting habitat for *M. terrapin*.

In 2000 I spent 96 hours searching for post-emergence holes on possible terrapin nesting beaches on LEM, RB, CP, PP, EP, and SI from September 24th until October 26. Between June 9th and September 24th, 2001, my volunteers and I spent 425 total hours on LEM, RB and CP waiting for nesting females and looking for their nests.

Jamaica Bay Unit Study

In JBU my study was performed primarily on the seven islands of GNRA (Fig. 2). In 2000, surveys were conducted from late August through October, and terrapin presence was documented either by observing turtle heads at the water's surface, by finding carcasses that had washed up on shore, or by searching for hatchling post-emergence holes or predated nests. I visited the islands from early August to early October during the egg-hatching period.

In 2001 at JBU extensive surveys were conducted mainly on LEM and RB, with additional surveys at PP, EP, CP, and SI. Because access to PP, EP, CP, and SI islands was difficult, and because PP, EP, and SI had little nesting habitat (Table 2), I surveyed these areas only two times a week. Therefore, these four islands were considered "secondary study areas." The main island, RBH was monitored daily in 2000 and 2001 by another researcher (Giambanco 2003, Acronyms in Table 1)

Jamaica Bay Unit Primary Study Areas

Trained volunteers were stationed on LEM and RB in June and July 2001 to watch for nesting females, and in order to find un-predated nests. Volunteers first

usually walked in pairs along the dune and beach area. If they spotted nesting female, it was observed at a distance from behind cover. While one person observed the nesting female the other volunteer searched for more nesting terrapins. After nesting, turtles were captured by hand and brought back to the laboratory at Hofstra University to be processed. Nests were marked with orange flags and their locations documented with GPS. At the end of each day, volunteers walked two consistent transects along the shore of each island searching for additional nesting turtles or missed nesting females' tracks.

Sandy Hook Unit Study Areas

I surveyed terrapins at the Sandy Hook (SHU) in 2000 and 2001. In 2000 I visited SHU only once to determine how many nests gets predated. In 2002 I measured nesting and predation rates on terrapin nests daily from late May to September 30. I made regular surveys along the western shoreline from a point approximately 1.6 km north of the visitor center south to Plum Island (Fig. 4). The number of surveys I carried out per day varied according to weather conditions. When terrapins were encountered on shore they were observed as inconspicuously as possible until they nested, unless they were either already disturbed or already done nesting. Park roads were regularly patrolled for live, injured, and dead terrapins. In the evenings the beaches of the important nesting areas were raked with a leaf rake, leaving a clear set of trails parallel to the water line. Each morning these trails were checked for terrapin and predator tracks to determine the relative amount of terrapins nesting at night vs. during the day.

Samples of randomly chosen nests were protected from predators, using buried wire screening (Feinberg 2000). These nests were monitored until hatchling emergence, so that I could collect data on hatching success rate for unpredated nests, determine clutch size and to serve as an indication of the normal time from oviposition to emergence.

All nests observed were marked and checked daily until either predation occurred or, the end of the nesting season arrived (i.e., early August). After early August nests were checked approximately weekly until either hatching occurred or cold weather arrived. Nests that have not hatched by the onset of cold weather were excavated. Predated, hatched, and unhatched nests were excavated to determine whether or not any eggs or hatchlings remained, and to make eggshell counts when possible. Any hatchlings found live when nests were excavated were released nearby in the water.

Jamaica Bay Unit Secondary Study Areas

In 2000, I visited CP only once, in the beginning of August. During that visit I discovered one adult turtle trail. In 2001 I went to CP twice each week in June and July to find possible nesting beaches, turtle trails, predated nests, or nesting females. In 2001 I also monitored Pumpkin Patch and Elder's Point only occasionally (once or twice each 1-2 weeks).

In 2000 I surveyed two mainland sites bordering JB within GNRA for signs of terrapin nesting. One of the sites was Dubos Point, a small peninsula bounded by Grass Hassock Channel and Somerville Basin (Fig. 2). It consisted of undeveloped

parkland owned and maintained by New York City Department of Parks and Recreation. Bands of low marsh border the shoreline of this peninsula (Pickman et al. 2000). During surveying this area I set up drift fences and cover boards to trap small mammals and reptiles. During nesting season (June and July of 2000) I observed three females laying their nests at this site. I marked two of these nests with orange flags.

The second mainland site I surveyed in 2000 was Spring Creek (SC). SC is a tidal creek that, in part, has retained its meandering pattern and separates Kings and Queens counties (Fig. 2). Property adjacent to the creek includes low marsh and high marsh and filled upland (Pickman et al. 2000). I put up drift fences and pitfall traps on this site. I did not observe any nesting at SC, but I captured two gravid females and one hatchling in my pitfall traps.

In 2000 I surveyed SI five times between late August and October. In 2001 I visited SI only twice, in August and September. During these visits I searched the island for predated nests, turtle tracks, hatchlings, and post-emergence holes.

In August of 2000 I also visited GK Park and MF located in SIU once (Acronyms in Table 1). I searched these areas for signs of nesting terrapins.

Predated Nests Counts

I searched each of the units, and especially the shorelines, on foot in 2000 and 2001. In 2002 I studied another area of GNRA: SHU, New Jersey. For both units, I determined nest predation by finding scattered terrapin eggshells near nest holes. Each time a predated nest was found, I recorded the way in which the nest was predated. I also looked for predator tracks and scat in the vicinity. Then I collected the eggshells

and counted them to estimate the clutch size. Afterwards the nest hole was covered, and eggshells were collected, so it would not be counted again.

Capturing and Processing Nesting Females

I surveyed nesting beaches in the six-hour time period centered by high tide because previous researchers noted that terrapins prefer to nest near high tide (Burger and Montevecchi 1975, Auger and Giovannone 1979, Feinberg 2000). Each time I captured a terrapin I recorded the date, time, and location of capture.

The plastron length of captured females was measured to the nearest tenth of a millimeter, from the anterior juncture of the gular scutes to the posterior juncture of the anal scutes. I used calipers or measuring tape to take the measurements. Each captured female was palpated in the abdomen anterior to the hind limbs to determine if they were gravid, and I noted any abnormalities.

Each adult terrapin was marked with a unique notch number (Cagle 1939), which continued the terrapin numbering system begun by Feinberg (2000). Additionally, nesting females received an internally injected passive integrated transponder (PIT) tag, which have been shown to successfully monitor populations (Buhlmann and Turberville 1998), especially for long-term studies. Terrapins were released in the area of their capture within 24 hours.

Measuring Clutch Size and Hatchling Size

Clutch size was determined three ways: 1) from counts of eggshells of predated nests, 2) from counts of eggshells excavated from protected nests after emergence and

3) from counts of eggshells found in nests after emergence when the nest was not protected. In all three cases, nests were thoroughly excavated. The remaining eggshells were counted each time a predated nest was found. In cases wherein some hatchlings remained in the nest, I counted and measured the remaining hatchlings. I excavated post-emergence nests right after they were discovered, and reconstructed eggshells.

Hatchling plastron length was measured as described for females above. Plastron width was measured between the junctures of the left and right pectoral and humeral scutes. Hatchling carapace length was measured from the anterior center edge of the nuchal scute to the juncture of the rear marginals. Hatchling carapace width was measured across the widest part of the carapace. Hatchlings were measured to the nearest tenth of a millimeter with a vernier caliper.

Nesting Beach Study

During 2000 and 2001, I walked transects on nesting beaches on LEM, RB, CP, and I surveyed SHU in 2002, from early September to late October for emergence holes and hatchling crawl trails. This method enabled me to locate evidence of terrapin nesting beaches, nests, and hatchlings making their way to the water. Sometimes when sand was sufficiently dry, I could determine whether or not any adult terrapins had come on shore during my absence, and if they were heading toward or away from the water.

Mammal Surveys at LEM and RB

In addition to casual observations of mammals made during all visits to terrapin nesting areas, I surveyed LEM and RB more intensively for basic information on which mammal species known to be potential predators on terrapin eggs, hatchlings or adults. From September 3rd to 17th, 2001, I set live mammal traps on these two islands. I used Tomahawk live traps (80 x 30 x 30 cm) baited with marshmallows, donuts, and cat food, to capture mammals such as rats, raccoons, and opossums. Three Tomahawk traps were placed on LEM (three traps per 18.3 hectares) and five Tomahawk traps were placed on RB (five traps per 56.8 hectares). I used Sherman traps baited with a peanut butter and seed mixture to trap smaller mammals, such mice, meadow voles and shrews. I set forty Sherman traps on LEM and twenty traps were set on RB.

Bird Surveys at Each Island

At each visit to LEM, RB, and CP, I made observations of any bird species that might be predators on terrapin eggs, hatchlings, or adults, such as gulls (*Larus* spp.) (Watkins-Colwell and Black 1997), and crows (*Corvus* sp.) (Seigel 1980a).

RESULTS

Nesting Areas Identified by GIS

Based on GIS analysis of the vegetation maps and surveys of the LEM, RB, and SHU (primary nesting areas), CP, EP, PP, SC, DP, Subway Island, Great Kills Park and Millers Field (secondary nesting areas; Figs. 3 and 4), I determined that all appeared to have at least some suitable nesting habitat (Table 2). However, PP and EP had very little nesting area (0.3% of JBU's islands). CP had more than twice as much as RBH (21%).

Using GIS I determined that LEM has 18.3 ha of suitable nesting habitat, but terrapins only make use of 12.1 ha (Table 2). I established that RB has 56.9 ha of habitat, but terrapins only utilize 19.7 ha. At Sandy Hook terrapins use only 7% of the total of 792 ha (Fig. 6).

Results of Field Surveys for Evidence of Nesting

1. Primary Study Areas – LEM, RB, and SHU

I observed that terrapins were nesting in large numbers on the primary nesting areas: LEM, RB, and SHU. In 2000 and 2001, I found 41 nests on LEM and RB (in 2000 $n = 23$, and in 2001 $n = 18$). Twenty nests were post-emergence holes, seven unprotected nests for which I observed oviposition, and 14 nests I found after predation.

In 2002 in the Sandy Hook Unit, I found 202 nests, all either predated or protected nests for which I observed oviposition, or post-emergence holes. I determined that SHU has eight important terrapin nesting areas (Fig. 5, Table 2): Battery Zone, Critical Zone, Holly Forest, Plum Island, Skeleton Hill Island, Horseshoe

Cove, Sandy Spit #1, and Sandy Spit #2. I determined that the most important nesting areas were the Battery Zone, Critical Zone, and Holly Forest.

2. Secondary Study Areas

I found that terrapins also nested at CP, DP, and SC, which were secondary nesting areas. I did not find predated nests at CP, PP, or EP (Fig. 2). However, on CP I found evidence of two nesting terrapins. In 2000 I found one crawl trail leading to a nearby sandy patch and back to the water. In 2001 at the same location I observed one terrapin crawl trail that extended out of the water to a sandy patch and back to the water. I was unable to locate a nest hole in either year. On the two smaller islands, PP and EP, I did not find any nesting turtles or evidence of nesting. However I observed nine turtles swimming in the nearby marsh.

In 2000, I captured five females at DP in pitfall traps, all of which were gravid. During the hatching period (between August and October), I found 90 hatchlings in pitfall traps, and additionally I found numerous raccoon-predated nests.

In 2000 in Spring Creek I caught two gravid females in the pitfall traps and one hatchling during the hatching period. During visits to SC I did not observe nesting activity, predated nests or adult crawls. In Great Kills and Miller's Field I also did not find any evidence of nesting females. However, in Great Kills, during summer 2002, one hatchling terrapin was found walking on the parking lot, near the visitor center (Cook, pers. comm.).

Capturing Nesting Females

In 2001, at JBU females nested from at least June 6th to August 2nd, a 55-day nesting season. However, it is possible that I missed at least one week of nesting before June 6th.

1. LEM

On LEM, the highest nesting activity occurred on June 18th, 2001(Fig.9). During that day, I found 17 turtle tracks on LEM, indicating that possibly eight or nine turtles came to nest. In 2001 seven female terrapins were captured on LEM and RB on land and uniquely marked with PIT tags (behind right hind limb), return tags, and shell notch. Three of the seven nesting females were caught on LEM. The first female was captured on June 18th, 2001. The female laid her nest behind a large tree, on a sandy patch with sparse vegetation. The second female was captured on June 28th, while nesting on the sandy dune, with a sparse beach grass. The female laid her nest approximately 20 cm away from a patch of beach grass. The third female was captured on June 30th, during low tide; while she was heading back to water after nesting (Table 4). Her tracks were clearly visible on the mud flat, therefore her nest location was discovered post-facto.

2. RB

On RB, four nesting turtles were caught in 2001 (Table 4). I captured the first female while she was covering her nest on June 28th, in a sandy patch with sparse vegetation. The other three females were captured on July 3rd; after they were done nesting and heading back to the water. They nested near where the first female nested, in a sandy area with sparse vegetation around it.

3. SHU

At SHU in 2002 I captured 49 females that came on shore to nest. These females received unique shell notch marks and return tags. Females were picked up after they were done nesting or as they were heading back to the water after nesting.

Female Sizes

The mean plastron length (PL) of females captured at LEM and RB was 171.9 ± 11.1 mm ($n = 7$, range = 159-187 mm) (Table 4). Using a two-tailed t-test I compared these data to Feinberg's (2000) data from RBH ($n = 126$, mean = 172.9 ± 8.7 , range = 145-198), and determined that there was no significant difference in PL ($t = 0.25$, d.f. = 6, $p = 0.81$). The mean (PL) of females captured at SHU (2002) was 178.1 ± 11.0 ($n = 48$, range 151-222 mm). Using a two-tailed t-test I compared these data to Feinberg's (2000) data from RBH. A significant difference was detected ($t = 2.9$, d.f. = 71, $p < 0.004$).

Clutch Size Data

1. LEM and RB

On LEM and RB, I collected clutch size data from nests located by directly observing nesting females, and by excavating post-emergence holes. Most post-emergence nests were found in sandy dunes after hatchlings emerged. Post-emergence holes looked like a small slit in the ground. Sometimes hatchling trails were located all around the opening in the ground. In these nests, I always found eggshells of emerged hatchlings, hatchlings, and/or undeveloped eggs.

The average clutch size for 2000 and 2001 was 12.86 ± 2.66 eggs ($n = 29$, range = 9-21) (Table 10,11). I compared LEM and RB combined data to clutch size from RBH (11.8 ± 3.1 , $n = 68$) (Giambanco's [2003] 2000 and 2001 data). The average clutch size was significantly different between the LEM & RB combined data and RBH ($t = 1.667$, d.f. = 62, $p = 0.100$).

2. SHU

In SHU the average clutch size, as determined from the emergence holes, was 9.14 ± 2.8 ($n = 128$ eggs, $n = 14$ nests, range 5-13). The average clutch size from predated nests was 10.62 ± 3.6 ($n = 2039$ eggs, $n = 192$ nests, range 3-19). The average clutch size from protected nests was 13.27 ± 3.7 ($n = 146$ eggs, $n = 11$ nests, range 9-19). There is a significant difference between clutch size estimated using predated nests vs. nests directly observed ($t = 2.3$, d.f. = 11, $p = 0.04$). The difference between clutch sizes using predated nests vs. emergence holes was not significant ($t = 1.85$, d.f. = 17, $p = 0.08$). The difference between clutch sizes estimated from protected nests vs. that of emergence holes was significant ($t = 3.1$, d.f. = 18, $p = 0.006$).

The most reliable mean clutch size comes from counting eggs in the protected nests; therefore I used those data for further comparisons. The difference in mean clutch size between SHU and RBH ($n = 68$, mean = 11.8) (Giambanco [2003] 2000 and 2001) was not significant: $t = 1.24$, d.f. = 12, $p = 0.24$.

Hatchling Size Data

I observed substantial variation in skin color, shell color, and patterning among hatchling terrapins. The carapaces appeared gray, light brown, and orange with dark

grooves. Their plastrons were yellowish or greenish, and marked with black spots and blotches. Some hatchlings were missing scutes on their carapace, and some of them had additional scutes.

In 2001, I found 48 hatchlings from 12 nests located on LEM and RB. The mean plastron length of 40 of these hatchlings was 25.3 ± 1.63 mm ($n = 40$, range = 22-28), the mean plastron width was 18.3 ± 1.32 mm ($n = 40$, range = 15.5-22), the mean carapace length was 28.8 ± 1.79 mm ($n = 40$, range = 24-31), and the mean carapace width was 26.4 ± 1.78 mm ($n = 40$, range = 23-29). In 2002 at SHU I found 69 hatchlings from 11 nests. The mean plastron length of these hatchlings was 25.6 ± 2.21 mm (range = 23.2-30.3), the mean plastron width was 21.5 ± 1.53 mm (range = 18.6-24.4), the mean carapace length was 29.28 ± 2.5 mm (range = 25.0-31.9), and the mean carapace width was 25.53 ± 1.85 mm (range = 20.8-27.8).

There was no significant difference in hatchling plastron length between the LEM and RB, and SHU ($t = 1.75$, d.f. = 72, $p = 0.085$). There was a significant difference in plastron size between hatchlings captured by Feinberg (2000) at RBH and hatchlings from LEM and RB ($t = 5.82$, d.f. = 35, $p < 0.01$).

Nest Mortality Rates

1. LEM and RB

During the nesting seasons of 2000 and 2001 nest mortality rates on LEM and RB were low. A total of 43 nests were found through emergence holes, and direct observation of nesting females. Mammalian and avian predation accounted for the loss

of 32.6% of these nests, whereas flooding accounted for the loss of 7.8% of eggs (Table 6).

Mortality among non-predated nests on LEM (n = 12) was 23.6% and on RB (n = 5) was 4.6% in 2000, because terrapin eggs failed to develop, were eaten by maggots or were flooded (Table 6). In 2001, mortality of non-predated nests on LEM (n = 7) was 14.1%, and on RB (n = 5), was 5.0%, because terrapin eggs failed to develop, were eaten by maggots or were flooded (Table 6). Overall, egg mortality of unpredated nests on LEM and RB was 14.7%.

On LEM, I found two predated nests in 2000 and no predated nests in 2001. On RB, I found 10 predated nests in 2000 and 2 predated nests in 2001. All predation events were discovered post facto; I did not directly observe any predation on terrapins or their nests. Predated eggshells were scattered 3-4 meters from the nests; the eggshells were not in a neat pile near the nest. The nests' scars looked different from those left by raccoons at nests on RBH.

In 2000 one nest on RB was predated in the same manner as the nests on RBH, which would indicate of presence of raccoons. The rest of the predated nests did not resemble raccoon predation. Rat tracks were found around the other predated nests.

2. Egg, Hatchling, and Nest Mortality Rates

At SHU a total of 192 raccoon-predated nests were found. In addition, 19 nests were protected and monitored from the time of oviposition until predation or hatching during nesting season of 2002. Wire mesh predator excluders were successful in keeping raccoons away from freshly laid nests during incubation. Excluders were removed 63 days after oviposition so that hatchlings would not be trapped or obstructed

as they emerged. After removal of excluders raccoons predated 42.1% (8/19) of the protected nests. Root predation accounted for the loss of 20.5% of protected nests. All the eggs ($n = 30$) in two of the remaining 11 nests were root predated.

Additionally, 14 emergence holes were discovered in those various SHU nesting locations. These emergence holes led to nests that survived raccoon predation and successfully produced hatchlings.

Egg Viability

Egg viability of diamondback terrapin eggs was determined by excluding eggs that were predated, flooded, died while hatching, undeveloped or eaten by maggots (Table 6). In 2000, on LEM egg viability was 95.8% (115/120), on RB the percentage of eggs that hatched was 96.9% (63/65). In 2001, on LEM egg viability was 91.6% (87/95), and on RB the percentage of eggs that hatched was 95% (57/60). Combining 2000 and 2001 data shows egg viability of 94.7% (322/340).

At SHU in 2002 egg viability was 73.3% (85/116, 11 nests). This was partially due to the fact that one female laid two clutches ($n = 15, 16$) that had 0% survivorship. If nests from this female are excluded from the egg viability calculations, viability at SHU was 100% (85/85). Only two hatchlings died after hatching.

Adult Predation

In 2001 I found one turtle carcass (unidentified sex) at RB, which appeared to have died due to natural causes, not raccoon predation. At SHU, it appears that raccoons killed seven adult females that came ashore to nest. Five turtles appeared to be killed during the 2002 nesting season, and two were possibly from the previous

years. Their carcasses were discovered laying upside down on the ground or on pieces of wood. Raccoon scat was found near the killed females.

Casual Observations

Although raccoon and muskrat were never captured in the traps, their tracks were observed. In 2000 I observed raccoon tracks twice on RB and once on LEM. In 2001, I found a raccoon skull on RB. I also found one terrapin nest on RB that appeared to have been predated by a raccoon, because eggshells were piled neatly near the nest. Otherwise, a lack of footprints throughout the area and bite patterns in the eggshells suggested that raccoons were not the main predators on LEM and RB.

At SHU raccoons were observed at dusk searching the terrapin nesting areas. I did not directly observe predation on terrapin nests at SHU, but abundant evidence of raccoon predation was common. Eggshells were piled neatly right next to nest holes, raccoon tracks were observed all around the area, and eggshells were punctured. I also observed foxes and their prints in the area, but none of the nests showed evidence of fox predation.

Nesting occurs primarily in the daytime on sandy dunes with low vegetation cover (Feinberg 2000). On LEM and RB I was not able to observe directly whether or not terrapins mostly nested during nighttime or daytime. However, at SHU I observed five night-nesting females. The sun already set when I observed nesting turtles on the beach located near water.

Mammal and Bird Surveys

Results of bird surveys during this study are summarized in Table 9. Nesting colonies of breeding greater black-backed gulls (*Larus marinus*) and herring gulls (*Larus argentatus*) were found on LEM. RB had a large breeding colony of herring gulls on the opposite side of the island from where the terrapins nested.

Mammal Trap Results

Results of the mammal trapping are summarized in Table 8. Meadow voles (*Microtus pennsylvanicus*) and Norway rats (*Rattus norvegicus*) were captured on LEM and RB. A total of 11 voles and rats were captured in 14 trap-nights, an overall rate of three captures per 980 trap-nights (0.003 captures/trap night) using Sherman traps, and an overall rate of eight rats per 112 trap-nights (0.071 captures/trap night) using Tomahawk traps.

Norway rats were caught on both LEM and RB, and meadow voles were only found on RB. No raccoons were captured at either island. Human visitors to the islands tampered with the Tomahawk traps on LEM and RB. The donuts and marshmallows were missing from the trap and the door of the trap was placed on the top of the cage.

Invasive Mammals

From September 11th to September 22nd, I trapped mammals on LEM and RB. Trapping effort on LEM resulted in catch rate of 3 rats per 112 trap nights. Trapping effort on RB resulted in catch rate of 5 rats per 112 trap nights (Table 8).

Once I approached the traps the rats became extremely aggressive towards me. They squealed and bumped against the traps. Captured rats were large, and appeared well fed. Based on coloration, (grayish-brown) I identified these rats as Norway rats (*Rattus norvegicus*). I also noted that their tails were shorter than their bodies, another diagnostic characteristic of *R. norvegicus*.

Data Analyses

All data are presented as means plus/minus one standard deviation. I used two-tailed t-tests in all statistical comparisons.

DISCUSSION

Nesting Areas

I used GIS to locate all possible nesting habitats in GNRA. Nesting populations of terrapins were reported previously by Cook (1989b) and Feinberg (2000) at five locations in GNRA: Floyd Bennett Field, Great Kills, SHU, RBH, and LEM, by finding predated nests, hatchling trails, and dead females. I investigated nesting ecology and predation rates at these locations plus others (Table 3). I found two previously unreported nesting populations on RB and CP. LEM, RB, and CP were visited by Feinberg (2000) only once each. He determined that there is some nesting at LEM, but not CP and RB. It is not surprising he did not report finding any signs of nesting terrapins at these sites, because he spent little time there, and his survey technique could only find predated nests. LEM appears to be a much more important nesting site than Feinberg indicated in his study.

Feinberg (2000) determined that raccoons predated approximately 93% of the nests on RBH. I concentrated my work on LEM, RB, and CP because these islands were less accessible to raccoons, humans, and other predators. Because there were few predators, Feinberg (2000) was not able to determine whether or not LEM was an important nesting ground. LEM, RB, and CP had suitable nesting beaches on only some parts of each island. The rest of the islands appeared unsuitable for nesting because they had tall grass, thick shrubs and abundant poison ivy. Access to certain parts of the islands was limited, therefore more nesting areas may exist than are documented here.

Feinberg (2000) reported that Miller's Field and Great Kills Park did not appear to support significant nesting terrapin populations anymore. I also did not observe any evidence indicating that terrapins use these areas. However, in the past Cook (1989b) reported some nesting activity at Miller's Field.

MF Field and GK Park did not appear to support terrapin populations when Feinberg (2000) visited these areas in 1999, but in 1980, Cook reported that these areas once supported healthy populations. Miller Field located in SIU was built after World War I to serve as a landing field for military biplanes. Today this 78.4-hectare open area now serves thousands of Staten Island residents.

SHU supports a large population of nesting terrapins. When I visited this unit in 2000 and 2002, I found more than 60 and 170 predated terrapin nests, respectively. Sandy Hook's turtle population appears to include at least 200 females and males. I observed roughly 150-180 turtles basking on the edge of the Sandy Spit #1 on numerous occasions.

There are other areas in Jamaica Bay where I observed populations of nesting terrapins. One turtle population is located in Spring Creek, where nesting females have to walk 30-50 meters on land to get to the nesting grounds (pers. obs.). SC has not reported previously as a terrapin nesting site. This area needs to be studied in the future to determine the importance of this nesting beach.

Also, I observed a nesting population at Dubos Point, a site that is difficult to access, because much of it is flooded twice per month during the highest tides. Sadove et al. (1996) surveyed Dubos Wetlands Sanctuary from mid-May through September of 1995. He counted 123 individual diamondback terrapins, 104 through capture and 19

through observation. In 2000 I found approximately 90 hatchlings in drift-fence traps. Also, I found evidence of high rates of raccoon predation of terrapin nests on this site. More study needs to be done to determine actual nesting and predation rates at this location.

Nesting Areas Identified by GIS

From my GIS analysis I learned that at RBH nesting turtles utilize only ca. 7% of the total suitable nesting habitat. At LEM 66% of the island's nesting habitat is utilized for nesting. On RB 35% of the total land is used for nesting. According to GIS on Canarsie Pol 49% of area has suitable nesting habitat, but only 1% is utilized for nesting. Therefore, large numbers of terrapins nest together on small patches of suitable habitat.

Terrapins at JBU use a variety of habitats for nesting. On LEM they mainly use the extensive sandy dunes to lay their eggs. The nests seem to be clumped in one area close to the shore, whereas the middle of the island was not being used. On RB the nesting habitat was only located on small patches of sand close to the shore, so the distribution of the nests also appeared to be clumped.

At Sandy Hook, terrapins seemed to nest in sandy areas with sparse vegetation or in areas with abundant beach grass. Only 7% of all available land is being used for nesting. Terrapins seemed only to be nesting at eight small sandy beaches, resulting in high densities of nests in each area.

Nest Predators at the Jamaica Bay Unit

I found raccoons, and possibly rats and birds, to be important predators of terrapin eggs. Natural predators on terrapin eggs and hatchlings elsewhere include foxes, raccoons, crows, and gulls (Burger 1977).

Nothing is known about past numbers of raccoons at most locations in and around Jamaica Bay, although only 20 years ago there were no raccoons observed on RBH (O'Connell 1980). Currently raccoons are considered as a major threat to the terrapin population at RBH. Feinberg (2000) found 23 terrapins dead due to raccoon attack. I only found one turtle carcass on RB, which probably died due to natural causes, not raccoon predation. It is unlikely that raccoons inhabit LEM and RB for long periods, because to reach these islands, raccoons would have to swim deep channels against strong currents, and also, all of the islands except RBH lack a fresh-water source, probably necessary for raccoons to stay alive. However, I found raccoon tracks on LEM and RB and one raccoon skull on RB. My experience on RBH indicates that raccoons have a specific egg-consumption technique. They usually eat the inside of the terrapin egg and leave a neat pile of eggshells nearby. I found two nests predated in this manner on RB in 2000, which enabled me to speculate that at least one raccoon was present there. It is possible that raccoons could get there during wintertime, when the channels are partially frozen.

It appears that on RB and LEM rats and/or birds (probably gulls) were responsible for most of the predation of most terrapin nests, as evidence by their tracks around the area of predated nests, and eggshells scattered nearby. I suspect nest holes without any adjacent eggshells were the result of bird predation on the nest while

the female was nesting. The only previously reported avian predators of terrapin nests that occur on LEM are laughing gulls. I did not directly witness any avian predation on terrapins, perhaps because the colony of gulls flew away whenever volunteers and I surveyed LEM and RB. In 2000 I did not find any predated nests on LEM. However, Feinberg (2000) found 34 predated terrapin nests on LEM, all of which appeared to have been predated by birds, based on the same evidence reported here. Burger (1977) reported that gulls predated eggs while turtles were depositing them into the nest. In contrast, crows waited for each turtle to nest; then they dug up the eggs.

Invasive Mammals

Introduced commensal rats (*Rattus* spp.) are major contributors to extinction of island plants and animals (Donlan 2003). The two *Rattus* spp. known to occur in the JB are the Norway rat (*Rattus norvegicus*) and Black rat (*Rattus rattus*). Norway rats (also known as brown rat and house rat) are much larger than any other rats, and are predominantly terrestrial, rarely climbing heights greater than three meters (Thorsen et al. 2000).

In contrast Black rats (also known as roof rat and house rat) have a uniformly colored dorsal side, usually black to tawny brown. The underbody is paler, lighter brown or slate colored (Hall 1959). The tail is longer than the head and body, sparsely haired and scaled. They are adapted for climbing and living in high places.

The invasion of exotic species, of which rats are one example, into native ecosystem is considered second most important cause for diversity loss, after habitat destruction and fragmentation (Courchamp et al. 2003). As for habitat destruction and

fragmentation, humans are responsible for transporting invasive species onto islands. According to Courchamp et al. (2003), introduced mammals have caused more problems than any other vertebrate group. These rats may be threats to the native species of mice (i.e., meadow voles, *Microtus pennsylvanicus*) present on the Jamaica Bay islands. Norway rats are predators of large insects, reptiles, birds, crustaceans, and plants. They have also been implicated globally in the decline or extinction of a number of bird species (Atkinson 1985). Introduction of rats has also led to breeding failure of seabirds and significant reduction of their populations, particularly petrel and tern species (Prieto 2003). Rats are also known to predate on gulls. For instance, on some Danish islands Norway Rats preyed on eggs, chicks and adults of the common gull, *Larus sp.* (Prieto 2003).

I observed indirect evidence of rat predation upon terrapin eggs and hatchlings. On RB and LEM I observed that some nests were predated in different manner than on RBH, where raccoons are the major nest predators. The RB and LEM nests had no eggshells remaining in the vicinity of the predated nest, and I observed only rat footprints around the nest. I also found evidence that rats may have predated hatchlings. I found the nest of a Norway rat with remains of terrapin hatchlings under a cover board. I not only directly observed the rat present under the board, but I also found a terrapin hatchling carapace. I assume the rat consumed the flesh of the hatchling leaving the carapace pieces scattered in the rat's nest. O'Connell 1980 caught Norway rats on RBH (East and West Pond), JFK Airport, and CP.

No evidence of Black rats was observed on LEM, and RB. There is a record from 1980 that black rat used to live in JBU (O'Connell 1980). One specimen was

captured at Breezy Point. Before, one specimen was captured on the north shore of Queens County in 1921. These introduced species probably are present on Long Island, but in low numbers. They most likely came to New York Harbor on ships and occasionally are released onto Long Island.

Rat Management

On LEM and RB, Sherman and box traps and direct observation revealed that Norway rats and Meadow Voles are living on these islands. Norway rats were found on both of the islands. The rats were large in size and appeared to be in good health. The traps were set in September, during the hatchling emergence period. Rat predation on hatchlings has not been reported previously at GNRA, but has been observed elsewhere on Long Island (M. Draud, pers. comm.). There is also no previous evidence that rats prey on terrapin eggs at GNRA, but there is evidence that it occurs in Florida (B. Mealey, pers. comm.). Presumably the rats on the islands of JB predate not only on terrapin nests and hatchlings, but also the eggs of the nesting shorebirds. I determined that numerous bird species (oystercatchers, terns and others) are using islands for their nesting grounds.

Long-term predator control will be required to reduce the risk to endemic island species, such meadow voles, shorebirds and terrapins. Efforts to control rat populations should be made. Baited traps should be used to capture rats. In my attempts to capture mammals, raccoon traps, baited with marshmallows, donuts and cat food were used successfully. Before eradication efforts are undertaken a study of

predation of endemic fauna could be done. Some fake nests could be set throughout the islands to determine the ability of rats to predate eggs.

Since LEM and RB are relatively small islands, trapping, instead of rodenticides should be used to eradicate rats. Trapping has historically been used for medium-sized mammals, and large rodents. Also by using the larger traps, only the large mammals, such as rats or raccoons (if present) will be targeted, not small native species,

Nest Predators at SHU

At SHU, raccoons appeared to be the only terrapin nest predators. I did not observe evidence of predation by any other mammalian or avian predators. I did observe foxes around the nesting areas, but I did not see any evidence of predation by them.

Raccoons appeared to have killed five adult females at SHU. Females were found dead in the nesting areas. These carcasses were usually found lying upside down on the ground or on pieces of wood. The neck appeared to be broken, and the turtle was eviscerated. Since, terrapins do not possess hinged plastron they are unable to retreat into their shell, and are susceptible to raccoon predation.

Based on my estimate of 300 adult terrapins in SHU's population, this predation rate amounts to a loss of females of 1.7% per year. This rate of loss may not be sustainable if recruitment is low, as it appears. Predation on nesting females can have a severe impact on populations of typically long-lived species such as turtles, and such predation has been shown to drive terrapin populations to extinction elsewhere. For example, in Florida an entire population of terrapins was eliminated due to raccoon

predation on adults (Seigel 1993). On Merritt Island, FL, it is estimated that raccoons killed 10% of the female diamondback terrapins that nested there over several years (Seigel 1980b).

Female Sizes

I determined that the females from LEM and RB were similar in PL to RBH females, but the females nesting on LEM and RB appeared to have larger clutches. Females from Sandy Hook were significantly larger from the females from RBH. The significance of these patterns is not clear. According to Congdon and van Loben Sels (1991), the body size of an adult turtle depends on size at birth, growth rate, age of maturity, and growth rate as an adult. Furthermore, in many turtle species it is common to observe sexual dimorphism. Female terrapins attain larger body sizes than males. Larger body size has numerous advantages for female turtles. These females can produce larger eggs, and therefore produce larger hatchlings, perhaps with higher survivorship.

Clutch Size and Nesting Data

Clutch size and the number of clutches per year are important to population recruitment. During this study I found evidence of 40 nests on CP, LEM, and RB (2000 n = 23, 2001 n = 17) by observing nesting events, emergence holes, and predated nests. I determined clutch size from LEM and RB using data from nests located by their emergence holes.

The terrapins nesting on RB and LEM had significantly larger clutches than those at nearby RBH. Feinberg (2000) found the mean clutch size at RBH in 1999 to be 10.9, Giambanco (2003) found mean clutch size to be 11.8 for the same population in 2000. The significant difference between clutch sizes from RB and LEM, (Giambanco 2003, Feinberg 2000) could be due to the fact that most of my data from RB and LEM came from emergence holes. Feinberg (2000) obtained his data from predated nests.

My data from SHU indicate that examination of protected nests is the most reliable way to estimate average clutch size, and that estimations based on predated nests underestimate clutch size. Giambanco's (2003) data is reliable, because it came from freshly oviposited nests.

According to Roosenburg (1994) average terrapin clutch size ranges range-wide from 4 to 18 eggs, and also changes with latitude, such that northern clutches are bigger. He reviewed data showing that females in southern regions tend to produce larger and fewer eggs, whereas females from northern regions produce smaller and more eggs. In contrast, females at SHU were considerably larger than females at JBU and laid larger clutches.

The average clutch size for protected nests at SHU was 13.27 eggs/clutch. The average clutch size from post-emergence holes was significantly smaller, which differed from protected nests. I speculate that the data from the emergence holes were less accurate, because it is possible that some hatchlings dragged eggshells out of the nest while emerging and that wind removed the empty shells. The predated nests' average clutch size was 10.51 eggs/clutch, which was significantly different from the protected nests' average clutch size, but not different from the emergence-hole data. It is possible

that this is due to the same factors as in emergence holes. Additionally, in predated nests I tried to reconstruct the eggshells from pieces, which could lead to miscounts. Therefore, I considered the data from the protected nests to be the most accurate

According to Congdon and van Loben Sels (1991), the body size of an adult turtle depends on size at birth, growth rate, age of maturity, and growth rate as an adult. Furthermore, in many turtle species it is common to observe sexual dimorphism. Female terrapins attain larger body sizes than males. Larger body size has numerous advantages for female turtles. These females can produce larger eggs, and therefore produce larger hatchlings, perhaps with higher survivorship.

Unfortunately, I was unable to determine if terrapins on LEM or RB laid multiple clutches, due to the low female re-capture rates. Cook (1989a) suggested that because of short, well-defined periods of nesting and hatching, RBH terrapins lay only a single clutch. However, Feinberg (2000) documented multiple clutches for three females at RBH, which suggests that some females produce two or three clutches/year in Jamaica Bay. Much larger egg production was reported in terrapin farm hybrids (Hildebrand 1932), where some females laid five clutches per year, producing an average of 35 eggs/year. Because farmers fed the females large quantities of food the turtles were able to commit a great deal of energy into egg production. This phenomenon is unlikely to occur in the wild population, but indicates that reproduction in the wild may be limited by resource availability.

Nest Mortality Rates

High nest mortality is common to turtle species (Wilbur and Morin 1988). Turtles typically live 30 – 40+ adult life spans, lay multiple clutches, and require a long time to reach sexual maturity. High nest mortality might be relatively unimportant to most turtle populations, but in combination with other factors (raccoon predation, destruction of nesting and feeding habitats, and commercial harvesting), it is possible that the loss of the eggs may seriously impact the viability of a population. Diamondback terrapin nests on LEM and RB experienced 4% (21/526) egg failure due to inviability. On LEM and RB, I observed that 2% (8/526) of hatchlings died while they were emerging from their eggs. On LEM 5% (29/526) of the terrapin eggs were flooded and maggots infested 2% (11/526) of the eggs. These two factors alone contributed to 13% egg mortality. In 2000 and 2001, mammalian and avian predation on LEM and RB was 36%. Therefore, about 49% of the eggs laid on LEM and RB failed to produce viable hatchlings due maggots and flooding.

Nevertheless egg mortality was much lower on LEM and RB than on RBH, where raccoons alone eliminated 93% of the terrapin eggs during Feinberg's (2000) study. Cook (1989a) believed that raccoons would not be able to colonize the human-created uplands of Jamaica Bay because they are separated from the main island by deep channels and strong currents. However, I did find evidence of raccoon presence on these two islands. However, I do not think they are able to live there for prolonged time due to lack fresh water and all year round food source. The only island where a large raccoon population is found presently is RBH, mainly because it is connected by the two

bridges to the mainland and people commonly release trapped raccoons there (Riepe pers. comm.).

On RB and LEM, nest predation rates were moderate in 2000 (36%), and lower in 2001 (9%) (Table 6). It is plausible that detected predation rates were much higher in 2000 because I was not present on the island throughout the nesting season. In 2001 volunteers and I may have distracted predators (gulls) present on LEM and RB, and thus reduced predation rates. On CP I only observed two trails of nesting females, which indicates that the island is not very important for nesting. I did not find any evidence of predated nests there.

Egg Viability

The egg viability rate I found at LEM and RB, for the field incubated, unprotected terrapin nests in this study (95%) was similar to those found on RBH (88.8%) by Giambanco (2003), and much higher than Feinberg's (2000) study at RBH. As Giambanco (2003) discussed, the Feinberg's method of determining egg viability was less accurate. It appears that the egg viability of field incubated eggs is much higher than previously thought. These high egg viability values suggest that these populations could have high recruitment levels if predation levels were low.

Hatching rate for non-predated, non-flooded, non-root predated, non-maggot attacked field incubated eggs at SHU was 73%. This egg viability rate was much lower than that found on LEM and RB, due to the fact that a particular female nested twice. Just by chance I protected her two nests, where clutch size was 15 and 16 eggs. It turned out that all the eggs from both of the nests laid by this female were inviable.

After, removing this single female from calculations the SHU egg viability rate rose to 100%.

Nesting behavior

Burger and Montevicchi (1975) and Feinberg (2000) reported that most nesting occurs during high tide. In contrast, on LEM and RB I captured five females during low tide as they walked a great distance across considerable mud flats before they were able to get to dry sand. At SHU, females were found to nest mostly during high tide, but also occasionally during low tide.

I was not able to observe night nesting at LEM and RB, but I found turtle trails indicating overnight activity. At SHU I observed five females that nested after the sun set. They came on shore before the sunset but nested when it was dark. These females did not walk far from the shore, I found them within 3-5 meters from the water. I do not think that night nesting is a common behavior, but occasionally happens. More studies need to be done to determine the frequency of night nesting.

Characteristics of Hatchlings

Roosenburg (1994) noted that clutches are larger, and eggs smaller, in north of range. In contrast I found that SHU (south) had larger females and larger clutch size than JB (north), and no significant difference in hatchling size.

Nest Emergence Surveys

Incubation periods (time from oviposition to emergence) on LEM and RB lasted from 53 to 76 days (Table 7). Most of the hatchlings emerged in September, but I also

observed hatchlings trails in October. Some hatchlings stayed in their nests and emerged the next spring. I found hatchling trails before and during the nesting season, which indicates that they are capable of over-wintering in terrestrial environments. As hatchlings emerged, I was able to locate their nests by finding their crawl marks in the area. The emergence holes appeared as star shapes. Hatchling trails seemed to go in every direction as they emerged from the nests, but would finally all turn and head towards the water. In the cases of 15 hatchlings for which I followed tracks, I was able to find them walking towards the water. Upon release, almost all hatchlings dug into tidal wrack, as was observed by Lovich et al. (1991).

Coast Guard officers reported that they have seen baby terrapins sitting on top of floating seaweed. In August of 2001, during a high tide a volunteer spotted a baby turtle swimming in Jamaica Bay near the shore. It was a recently emerged hatchling that was looking for cover.

Mammal and Bird Surveys at Each Island

Surveys of RB and LEM for terrapins also yielded useful information about different species of birds and mammals present on these islands. Norway rats (*Rattus norvegicus*) appeared to be the most abundant mammal found on LEM and RB (Table 8). As reported by O'Connell (1980), rats were widely distributed in GNRA. *R. norvegicus* are an introduced species, usually associated with man. This species adapts readily to a variety of different habitats. Conditions on these islands were fairly harsh. There is no source of fresh water readily available, and not many mammal species would be able to survive there.

From bird surveys I discovered that laughing gulls, which are terrapin egg and hatchling predators, are present on CP, LEM, and RB (Table 9). They pose some threat to the turtle population, but not as much the raccoons.

Comparison of Nesting Islands

Within the JBU, the vast majority of terrapin nests were found at Ruler's Bar Hassock. In 1999, Feinberg (2000) found many fewer terrapins nesting on LEM and elsewhere in Jamaica Bay. No previous studies of terrapins on LEM, RB, and CP had been conducted. Based on my studies, these three islands contain suitable nesting grounds for diamondback terrapins. Additionally, they provide breeding habitat for terns, gulls, and oystercatchers. These islands also have few raccoons, which are very important predators on RBH.

It is possible that the JBU's terrapin population is one big population wherein the females nest freely on all islands. Another possibility is that the terrapins inhabit isolated patches of resources, and each individual turtle nests only where it hatched. The third scenario could be proposed that terrapins live as a metapopulation. Each distinct population in a metapopulation may be referred to as subpopulation, a local population, or simply as a population. Jamaica Bay terrapins may constitute a metapopulation if they move between nesting sites. Metapopulations are important because raccoons appear to be severely limiting terrapin recruitment on RBH. Migration of terrapins hatched on LEM and RB may be able to sustain terrapin populations on RBH. It seems that RBH may be a sink population, whereas the LEM and RB are source populations. So, the nesting females might occasionally switch

between the nesting beaches. Therefore, these females could exist in a number of populations that are only partially isolated from one another. Prior to the introduction of raccoons, RBH probably produced the vast majority of Jamaica Bay hatchlings, currently LEM and RB produce more hatchlings. LEM and RB have much lower predation rates than the mainland, where most of the nests are raccoon predated. I speculate that the dynamics of this metapopulation were altered by human actions. This patchy distribution might be detrimental to their future survival.

However, in my 2000-2001 studies I was not able to determine if individual females nested on more than one island. Throughout my study of Jamaica Bay terrapins, I did not recapture any females twice. To fully understand how sink-source population concept works in the ecosystem, long-term terrapin studies are needed. From the results of my study, I conclude that LEM, RB, and CP are relatively safe nesting places for terrapins. Although RBH has many terrapin nests, approximately 2000/year (Feinberg 2000), my work suggests LEM and RB also produce a significant number of hatchlings. A conservative estimate is that 93 terrapin nests were laid on these three islands in 2001 (Figs. 5, 6, 7). Ninety-three nests probably contained about 1367 eggs, based on my mean clutch size data. My data suggests that about 66% of the eggs laid on RB and LEM hatch, resulting in 526 hatchlings. This number of hatchlings is similar to the number eggs hatched at RBH (ca. 630, Feinberg 2000).

Future Implications

In the future, more extensive studies of RB, LEM, and CP are needed to determine female nest fidelity. To find out if the same female terrapins repeatedly utilize

these islands, more researchers must be posted on these islands during the nesting season.

These islands differed in the type of the nesting habitat, which may affect hatchling sex ratio. For example, LEM consisted of sandy dunes without much vegetation, with the exception of one area with large trees. Most of the turtles seemed to nest on the sandy dunes, a good distance away from any vegetation. Few females nested in the area of the large trees, which provides substantial cover from the sun. In contrast, CP and RB had much thicker vegetation, mostly large trees, shrubs, and poison ivy. It is possible that different islands are biased towards either female hatchlings or male hatchlings. More studies are needed to determine if hatchling sex-ratio differences occur.

These islands should be closed to the public during the nesting period, because humans and their water activities disturb nesting females. On several occasions, there were large groups of people docking their boats there, using Jet Skis, and digging holes on the nesting beaches. While these activities occurred, no terrapin nesting activity was observed.

It is not plausible to control predators on RBH, because eventually raccoons would return to the area, because there is urban area all around it. I suspect that removing rats from the other islands, particularly LEM and RB would be feasible, because it would probably take a long time before they could repopulate the islands.

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Table 1-Table of acronyms used throughout this thesis.

Acronym	Name	Unit
CP	Canarsie Pol	JBU
DP	Dubos Point	JBU
EP	Elder's Point	JBU
GK	Great Kills	SIU
GNRA	Gateway National Recreation Area	
JB	Jamaica Bay	
JBU	Jamaica Bay Unit	
LEM	Little Egg Marsh	JBU
MF	Miller's Field	SIU
PP	Pumpkin Patch	JBU
RB	Ruffle Bar	JBU
RBH	Ruler's Bar Hassock	JBU
SC	Spring Creek	JBU
SHU	Sandy Hook Unit	
SI	Subway Island	JBU
SIU	Staten Island Unit	

Table 2-Study sites in Jamaica Bay Unit, Staten Island Unit, and Sandy Hook Unit of GNRA. "Potential" nesting-area size identified through GIS, actual nesting size through location of terrapin nests.

Unit	Site	Size (ha)	GIS Potential Suitable Nesting Areas Size (ha)	Actual Nesting Areas Size (ha)
JBU (Total = 7,517 ha) (Land = 2,508 ha)	Canarsie Pol	117.6	58.1	0.2
	Dubos Point	Unavailable		
	Pumpkin Patch	5.1	0.7	0
	Little Egg Marsh	18.3	12.1	0.5
	Elder's Point	7.1	1.3	0
	Ruffle Bar	56.9	19.7	0.2
	Ruler's Bar Hassock	361.5	26.5	1.5
	Spring Creek	Park		
Subway Island	19.9	11.7		
Total		586.4	60.3	2.3
SIU (Total = 836 ha) (Land=382 ha)	Great Kills Park	78.4 hectares		
	Miller's Field	-	-	-
SHU (Total = 1,905 ha) (Land = 792 ha)	Battery Zone	Not an Island		0.4
	Critical Zone			0.3
	Holly Forest			0.1
	Horseshoe Cove			0.2
	Plum Island			0.1
	Sandy Spit #1			0.2
	Sandy Spit #2			0.2
	Skeleton Hill Island			0.2
Total		36.9	1.7	

Table 3-Surveys of different nesting beaches at Gateway National Recreation Area. Ten sites were surveyed for nesting activity and compared to Cook (1989b) and Feinberg (2000). PRESENT = terrapin nesting activity detected; ABSENT = terrapin nesting activity not detected. CP, LEM, RB, RBH, SI, GK, MF are islands or parts of islands, the rest are mainland sites.

Site Name	Cook (1989b)	Feinberg (2000)	Nests found in this study
Canarsie Pol (JBU)	Absent	Absent	Present
Dubos Point (JBU)	not surveyed	not surveyed	Present
Little Egg Marsh (JBU)	Absent	Present	Present
Ruffle Bar (JBU)	Absent	Absent	Present
Ruler's Bar Hassock(JBU)	Present	Present	Present
Sandy Hook Unit (SHU)	not surveyed	Present	Present
Spring Creek (JBU)	not surveyed	not surveyed	Present
Subway Island (JBU)	Absent	Absent	Present
Great Kills Park (SIU)	Present	Absent	Absent
Miller Field (SIU)	Absent	Absent	Absent

Table 4-Female terrapins captured in the 2001 nesting season from LEM and RB. These turtles were captured in uplands, away from the water. For turtles listed as “missed nesting,” nesting was not observed, but they were palpated and did not appear to contain any eggs and were heading back to water during low tide. No female terrapins were captured in the 2000 nesting season.

Identification Number	Date of Capture	Status of Terrapin Capture	Island Name	Plastron Length (mm)
JB 029	6/18/2001	Nesting Observed	Little Egg Marsh	182
JB 034 (ACN)	6/28/2001	Nesting Observed	Ruffle Bar	187
JB 036	6/28/2001	Missed Nesting	Little Egg Marsh	177
JB 037	6/30/2001	Missed Nesting	Little Egg Marsh	165
JB 038	7/3/2001	Nesting Observed	Ruffle Bar	159
JB 039	7/3/2001	Nesting Observed	Ruffle Bar	159
JB 040	7/3/2001	Nesting Observed	Ruffle Bar	174

Table 5-Clutch size data from LEM and RB in 2000 and 2001. Data come only from non-predated nests after emergence (n = 24). Data reported as mean \pm s.d. (n).

Year	LEM	RB	Total
2000	12.42 \pm 3.06 (n = 12)	13.00 \pm 1.58 (n = 5)	12.59 \pm 2.67 (n = 17)
2001	14.14 \pm 2.54 (n = 7)	12.00 \pm 2.65 (n = 5)	13.25 \pm 2.70 (n = 12)
Total	13.05 \pm 2.93 (n = 19)	12.50 \pm 2.12 (n = 10)	12.86 \pm 2.66 (n = 29)

Table 6-Results of nests viability on Ruffle Bar and Little Egg Marsh. In total 38 nests (n = 315 eggs) were observed during 2000 and 2001 nesting season. Mammals and birds predated 36.8% of these nests. All nests were found through direct observation of nesting females, following tracks from the water, discovery of predated nests, and post-emergence holes.

	2000				2001				Total	
	LEM		RB		LEM		RB		Number	Percent
	Number	Percent	Number	Percent	Number	Percent	Number	Percent		
Number of Nests Found	14		15		7		7		43	
Predated Nests	2	14.3%	10	66.7%	0	0.0%	2	28.6%	14	32.6%
Number of Eggs Counted	149		65		99		60		373	
Mean Clutch Size	12.42		13.00		14.14		12.00		12.86	
Number of Nests in which Eggs Hatched	12	85.7%	5	33.3%	7	100.0%	5	71.4%	29	67.4%
Fate of Unpredated Eggs:										
Hatched	114	76.5%	62	95.4%	85	85.9%	57	95.0%	318	85.3%
Undeveloped	5	3.4%	2	3.1%	8	8.1%	3	5.0%	18	4.8%
Died while Hatching	1	0.7%	1	1.5%	2	2.0%	0	0.0%	4	1.1%
Flooded	29	19.5%	0	0.0%	0	0.0%	0	0.0%	29	7.8%
Fly Maggots	0	0.0%	0	0.0%	4	4.0%	0	0.0%	4	1.1%
Egg Mortality (unpredated)	23.5%		4.6%		14.1%		5.0%		14.7%	

Table 7-Incubation and emergence periods for diamondback terrapin nests, from time the nest was deposited to the time the hatchlings emerged.

Nest #	Island Name	Date of Nesting	Date of Emergence	Incubation Period (days)
1	LEM	6/18/2001	8/18/2001	60
2	RB	6/28/2001	8/22/2001	55
3	LEM	6/28/2001	8/22/2001	55
4	LEM	6/30/2001	8/22/2001	53
5	RB	7/3/2001	9/16/2001	75
6	RB	7/3/2001	9/17/2001	76
7	RB	7/3/2001	9/19/2001	76

* Average Incubation Period = 64.3 days

Table 8-Trap line capture rates for small and large mammals on each island – RB and LEM. Total capture rates are calculated as captures per 112 trap nights for Have-a-Heart traps, and 980 trap nights for Sherman traps (i.e., one trap set out for one night = one trap-night; five traps set out for one night = five trap-nights).

Type of Trap	Total Trap Nights	Total Captures	Capture Rates
Sherman	980	3	0.003
Tomahawk	112	8	0.071
Total	1092	11	0.074

Table 9-Results of bird surveys on the CP, LEM, and RB during 2001 nesting season.

A. LEM

Species	Nesting Colonies	Observed
American Oystercatcher (<i>Haematopus palliatus</i>)		√
Black Crowned Night Heron (<i>Nycticorax nycticorax</i>)		√
Black Skimmer (<i>Rynchops niger</i>)		√
Canada Goose (<i>Branta canadensis</i>)		√
Common Tern (<i>Sterna hirundo</i>)	√	
Double-crested Cormorant (<i>Phalacrocorax carbo</i>)		√
Glossy Ibis (<i>Plegadis falcinellus</i>)		√
Great Egret (<i>Casmerodius albus</i>)		√
Greater Black-backed Gull (<i>Larus marinus</i>)		√
Green Heron (<i>Butorides striatus</i>)		√
Herring Gull (<i>Larus argentatus</i>)		√
Laughing Gull (<i>Larus atricilla</i>)	√	
Snowy Egret (<i>Egretta thula</i>)		√
Yellow Crowned Night Heron (<i>Nyctsnassa violacea</i>)		√
Willet (<i>Catoptrophorus semipalmatus</i>)		√

B. RB

Species	Nesting Colonies	Observed
American Oystercatcher (<i>Haematopus palliatus</i>)	√	
Black Crowned Night Heron (<i>Nycticorax nycticorax</i>)		√
Black Skimmer (<i>Rynchops niger</i>)		√
Canada Goose (<i>Branta canadensis</i>)		√
Common Tern (<i>Sterna hirundo</i>)		√
Double-crested Cormorant (<i>Phalacrocorax carbo</i>)		√
Glossy Ibis (<i>Plegadis falcinellus</i>)		√
Great Egret (<i>Casmerodius albus</i>)		√
Greater Black-backed Gull (<i>Larus marinus</i>)	√	
Green Heron (<i>Butorides striatus</i>)		√
Herring Gull (<i>Larus argentatus</i>)	√	
Laughing Gull (<i>Larus atricilla</i>)	√	
Snowy Egret (<i>Egretta thula</i>)		√
Yellow Crowned Night Heron (<i>Nyctsnassa violacea</i>)	√	
Willet (<i>Catoptrophorus semipalmatus</i>)	√	

B. CP

Species	Nesting Colonies	Observed
American Oystercatcher (<i>Haematopus palliatus</i>)	√	
Black Crowned Night Heron (<i>Nycticorax nycticorax</i>)	√	
Black Skimmer (<i>Rynchops niger</i>)	√	
Canada Goose (<i>Branta canadensis</i>)		√
Common Tern (<i>Sterna hirundo</i>)		√
Double-crested Cormorant (<i>Phalacrocorax carbo</i>)		√
Glossy Ibis (<i>Plegadis falcinellus</i>)		√
Great Egret (<i>Casmerodius albus</i>)		√
Greater Black-backed Gull (<i>Larus marinus</i>)		√
Green Heron (<i>Butorides striatus</i>)		√
Herring Gull (<i>Larus argentatus</i>)	√	
Laughing Gull (<i>Larus atricilla</i>)	√	
Snowy Egret (<i>Egretta thula</i>)		√
Yellow Crowned Night Heron (<i>Nyctsnassa violacea</i>)	√	
Willet (<i>Catoptrophorus semipalmatus</i>)	√	

Table 10-Results of searches for emerged hatchling trails and post-emergence holes in 2000.

Survey Date	Little Egg Marsh			Ruffle Bar		
	Hatchling trails	Number of nests	Number of eggs in nest	Hatchling trails	Number of nests	Number of eggs in nest
4-Sep	41	4	12			
			14			
			17			
			10			
10-Oct	8	0	0			Did not visit
15-Oct			Did not visit	30	5	9
						11
						11
						16
						13
26-Oct	147	3	17			Did not visit
			15			
			14			
Total	196	7	99	30	5	60
Mean Clutch Size			14.14			12.00

Table 11-Results of searches on LEM and RB for emerged hatchling trails and post-emergence holes in 2001.

Data	Little Egg Marsh			Ruffle Bar		
	Hatchling trails	Number of nests	Number of eggs in nest	Hatchling trails	Number of nests	Number of eggs in nest
15-Aug	15			9		
18-Aug	69	1	14	9		
21-Aug	14	2	9 11			Did not visit
22-Aug	25	3	13 11 10			Did not visit
25-Aug			Did not visit	7	3	12 11 14
26-Aug	11	3	21 12 11 13			Did not visit
10-Sep	7					
11-Sep	0					
14-Sep	2					
16-Sep	5					
17-Sep	8	1	11	4	1	13
19-Sep	7	1	13	8	1	15
20-Sep	0					
22-Sep	0					
24-Sep	0					
Total	163	11	149	45	5	65
Mean Clutch Size			13.55			13.00

FIGURES

Figure 1 – Map of the three units of Gateway National Recreation Area. Jamaica Bay Unit (JBU) and Staten Island Unit (SIU) are located in NY, and the Sandy Hook Unit (SHU) is located in NJ.



Figure 2 – Map of the Jamaica Bay Unit, Long Island, New York. Six upland islands within the JB refuge; all were surveyed for *Malaclemys terrapin* nesting activity. Pumpkin Patch, Elder's Point, Canarsie Pol, Ruffle Bar, Little Egg Marsh, Subway Island, Ruler's Bar Hassock. Map adapted from National Park Service (1994).

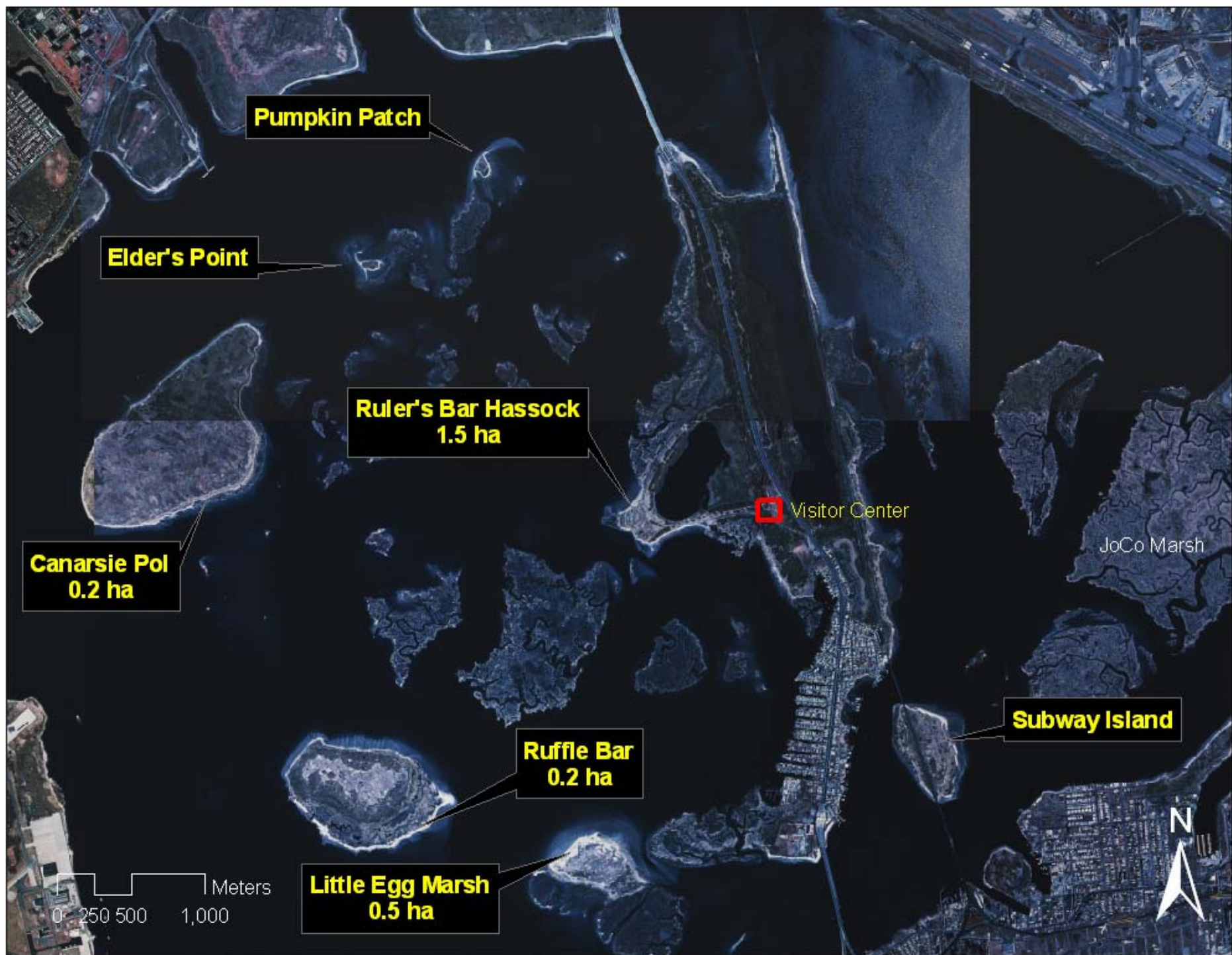
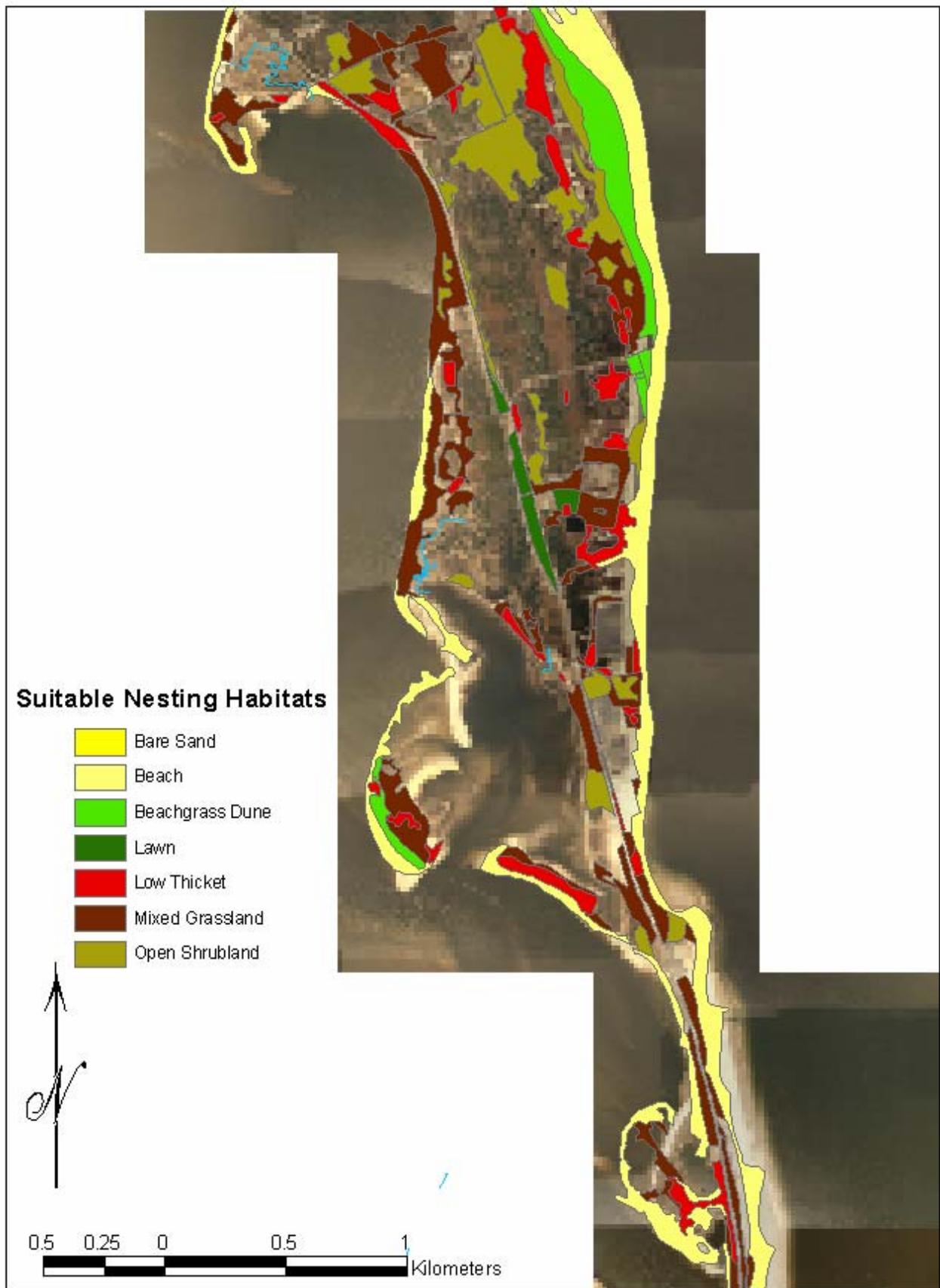


Figure 3 – Location of potential nesting beaches based on suitable nesting habitats (1994 aerial photography, 1976 land cover data), indicated by different colors, on the seven upland islands of the JBU, NY (Produced at Gateway NRA in 2003).

Figure 4 – Location of potential nesting beaches at SHU based on suitable nesting habitats (1997 aerial photography, 1976 land cover data), indicated by different colors, at the Sandy Hook Unit, NJ.



Data Source: 1977 aerial photography, 1976 land cover (NPS data)

Figure 5 – Location of actual nesting beaches based on my observations (1994 aerial photography, 1976 land cover data), indicated by yellow color, on the seven upland islands of the JBU, NY (Produced at Gateway NRA in 2003).

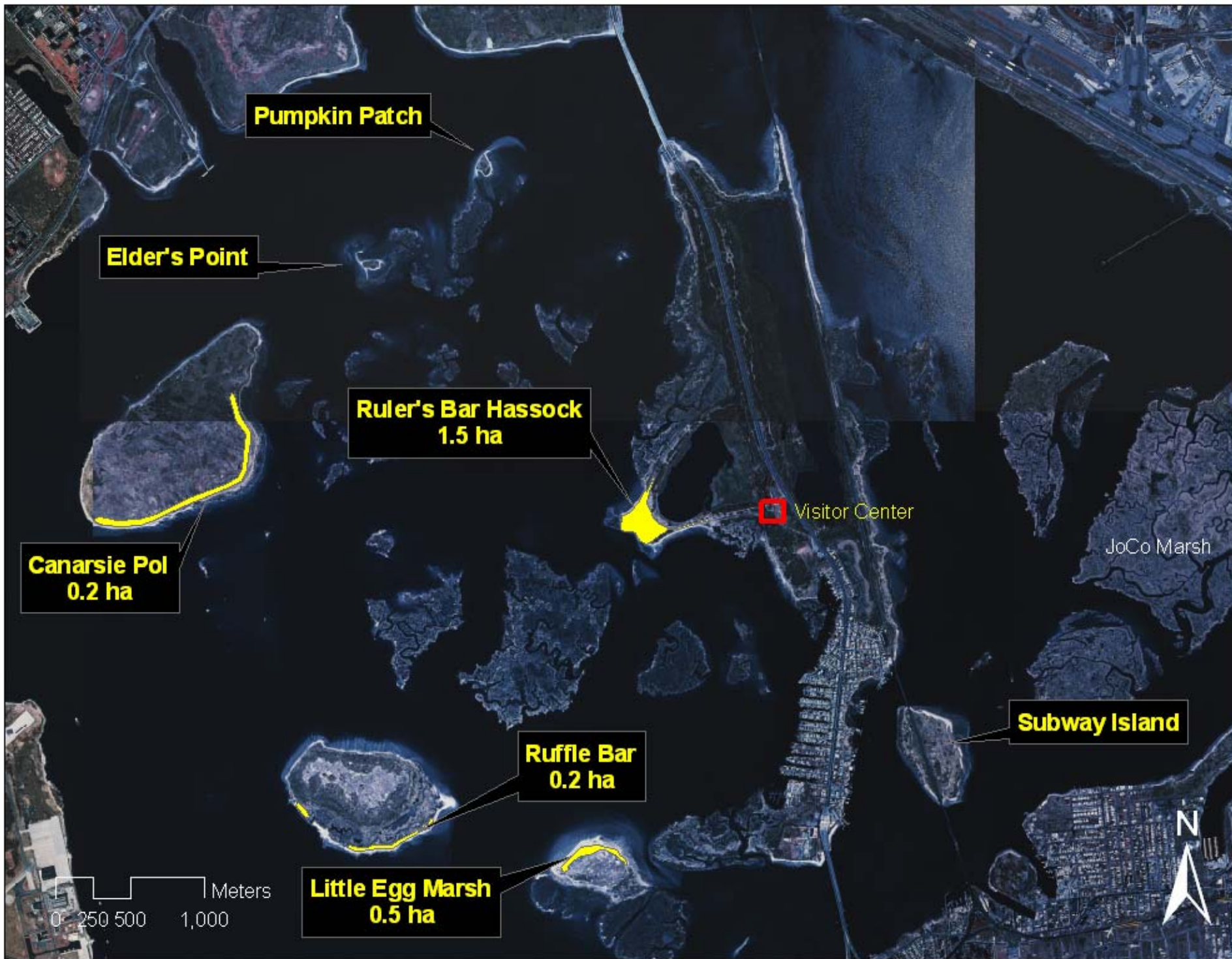
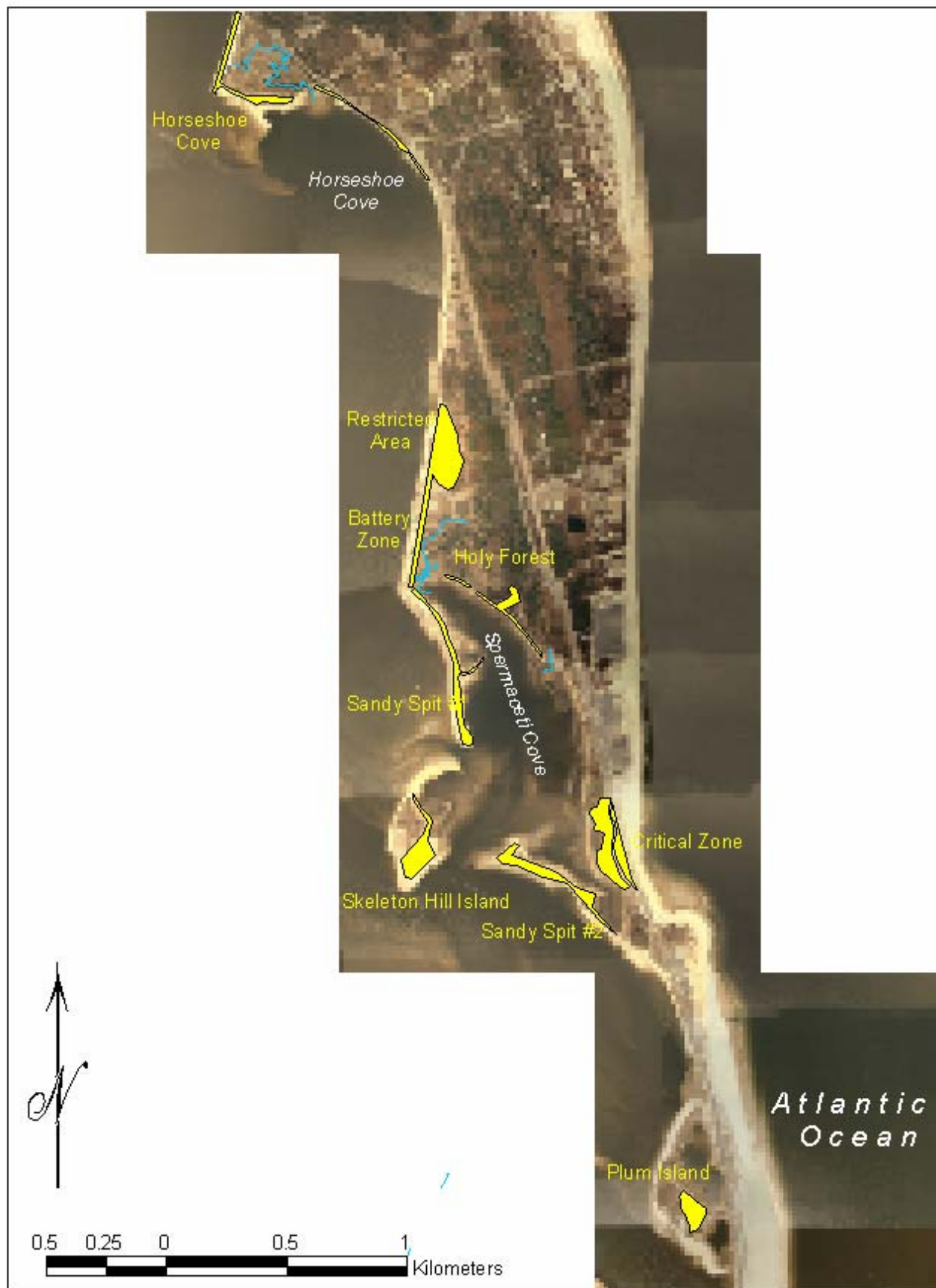


Figure 6 – Location of actual nesting beaches based on 2002 study (1997 aerial photography, 1976 land cover data), indicated by yellow color, at the Sandy Hook Unit, NJ (Produced at Gateway NRA in 2003).



Data Source: 1977 aerial photography, 1976 land cover (NPS data)

Figure 7 – Distribution of clutch sizes on LEM and RB in 2000 and 2001 (n = 29) of JBU.

Distribution of clutch sizes
n = 29 nest (373 eggs)

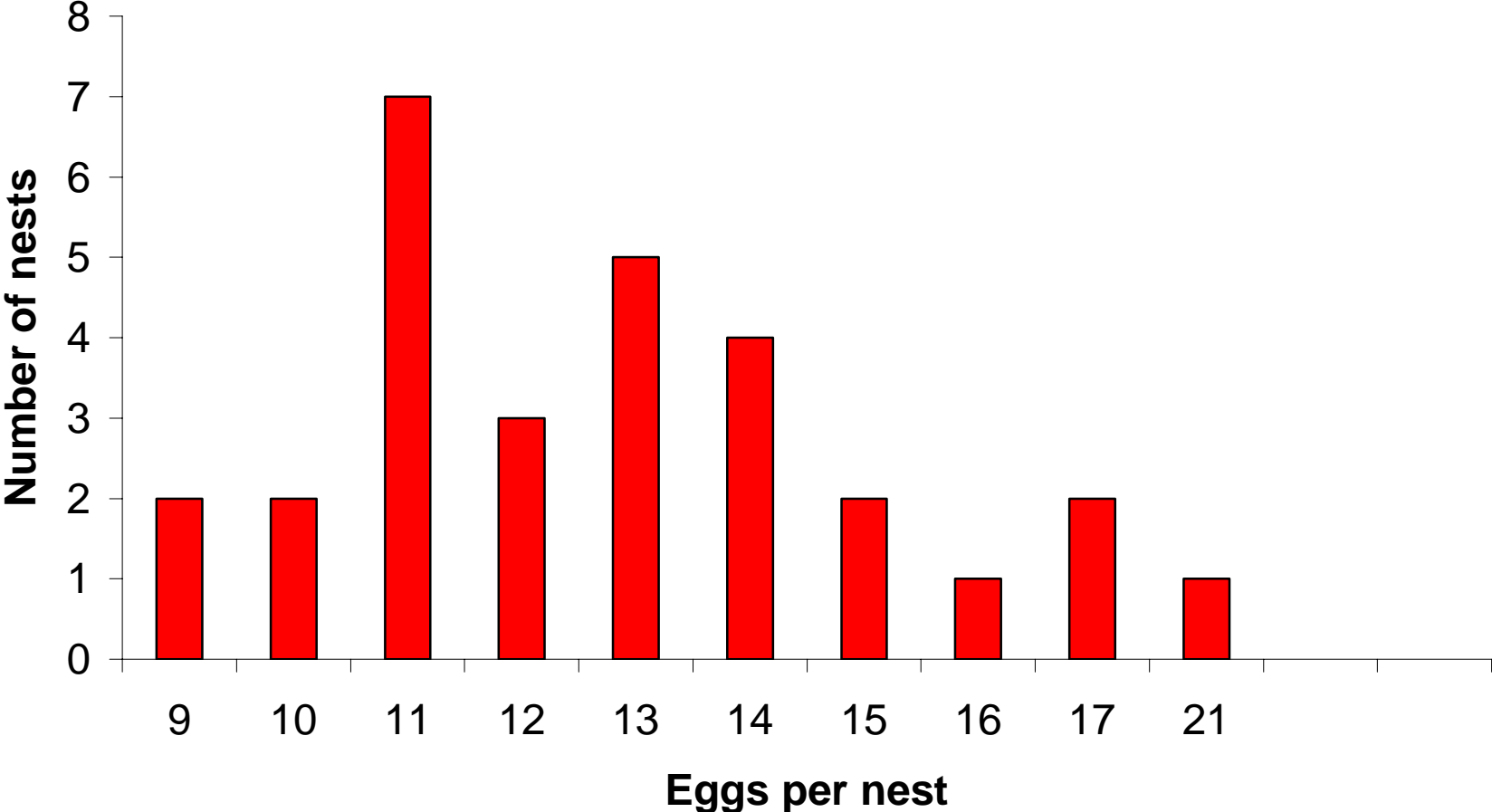


Figure 8 – Histogram depicting distribution of clutch sizes collected from predated, protected nests and emergence holes at SHU (n = 170).

Number of Eggshells in Each Depredated Nest
n = 170 nests

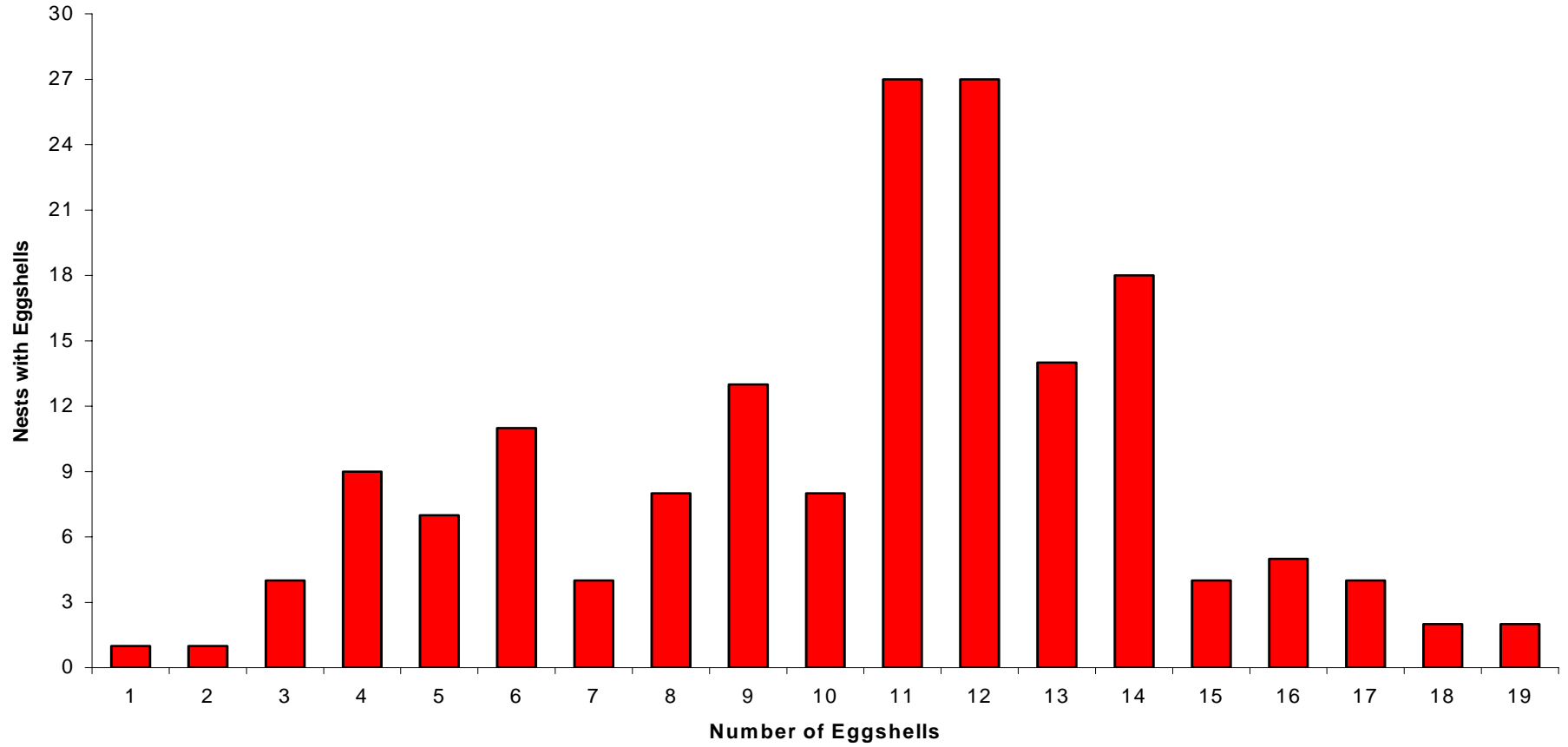


Figure 9 – Number of female terrapins determined nesting on Little Egg Marsh per day in 2001. The bars represent the number of females that were determined by counting turtle trails and observing nesting females (n=61).

Number of Nesting Females on LEM in 2001
n = 61

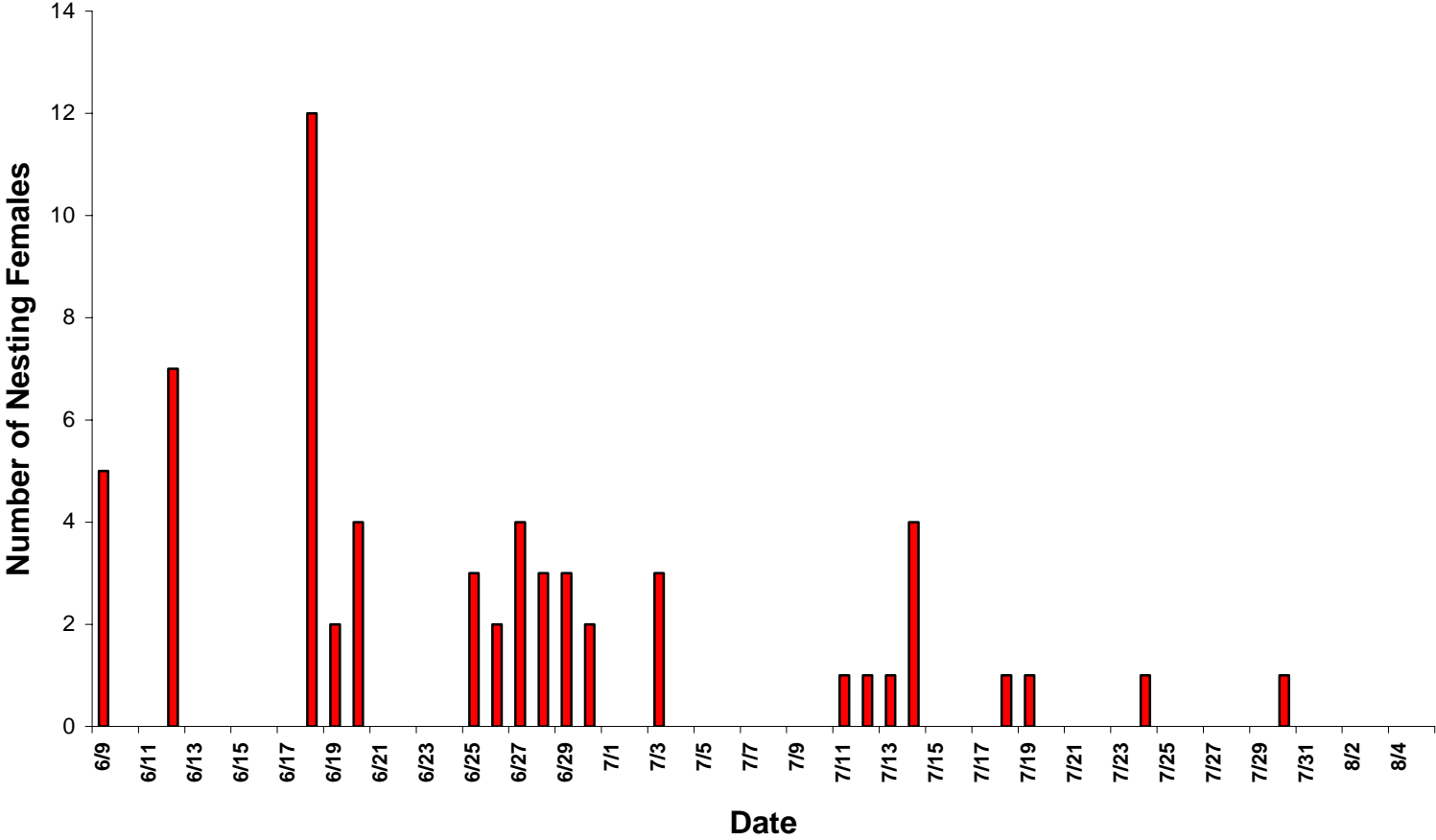


Figure 10 – Number of female terrapins determined nesting on Ruffle Bar per day in 2001. The bars represent the number of females that were determined by counting turtle trails and observing nesting females (n=31).

Number of Nesting Females on RB in 2001
n = 31

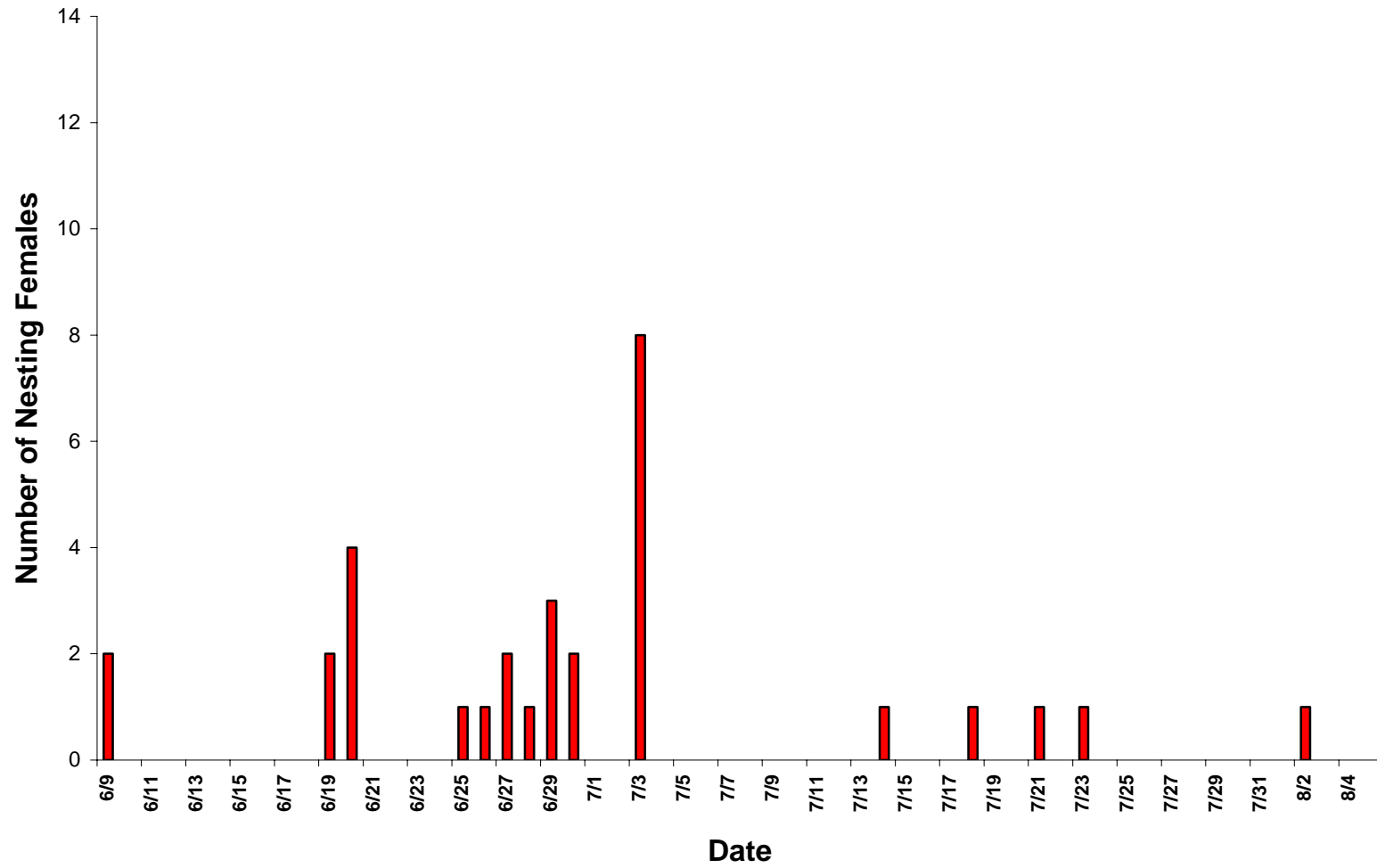


Figure 11 – 2002 season chronology of captured nesting females at SHU (n = 49).

Chronology of captured females

