

POST-EMERGENCE MOVEMENT AND OVERWINTERING STRATEGIES OF
DIAMONDBACK TERRAPIN (*MALACLEMYS TERRAPIN*) HATCHLINGS

THESIS

Presented in Partial Fulfillment of the Requirements of the Degree of Master of Science


By

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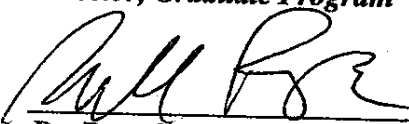
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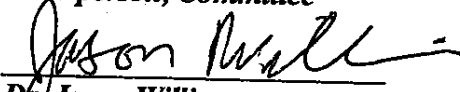
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Abstract

As with most turtle species, the life histories of hatchling diamondback terrapins (*Malaclemys terrapin*) are poorly known. Most hatchling literature focuses on emergence, whereas post-emergent movement and survivorship are largely unknown. Only a few short term studies and anecdotal notes exist regarding terrapin hatchling movements, salinity tolerance, microhabitat use or overwintering locations. Hatchlings turtles may overwinter in the nest, or in water, or on land outside the nest. Anecdotal evidence indicates terrapins overwintering in each of these locations; however no general overwintering pattern has been documented. I installed drift fences and pitfall traps in six locations at Ruler's Bar, Jamaica Bay, New York, in fall 2006-spring 2008. I investigated terrapin hatchling movements for as long as nine months after emergence, identified environmental factors associated with hatchling movements and documented predation. I captured 324 live hatchlings, 95 of these were recaptured at least once, and I found 42 dead hatchlings. More than 80% of dead hatchlings were found on nights with less than 50% lunar illumination. Over 50% of fall hatchlings were moving away from the water, at least 18 hatchlings overwintered terrestrially outside of the nest, and 62% decreased in length while overwintering. The length of time between fall capture and spring recapture ranged from 183 - 276 days. Over 50% of spring hatchlings moved towards water. I found a significant relationship between the number of hatchlings captured and high air temperatures and a significant relationship between hatchling movement and precipitation. Hatchling terrapins move further away from the water after fall emergence and back towards the water in the spring. Future work should include management plans that identify and protect terrestrial overwintering habitat.

Introduction

Target Species: Diamondback terrapins (*Malaclemys terrapin terrapin*, Schoepff, 1793) belong to the freshwater turtle family Emydidae, which consists of two subfamilies, Emydinae and Deirochelyinae (Stephens and Wiens 2003). Emydinae consists of the genera *Emydoidea*, *Emys*, *Actinemys*, *Clemmys*, *Glyptemys*, and *Terrapene*; Deirochelyinae consists of the genera *Chrysemys*, *Deirochelys*, *Graptemys*, *Malaclemys*, *Pseudemys*, and *Trachemys*. Some species of Emydidae sometimes inhabit brackish water (e.g., *Pseudemys nelsoni* and *Trachemys decussata*) but diamondback terrapins are the only fully brackish-water species Emydidae (Ernst and Lovich 2009).

Diamondback terrapins are small to medium-sized turtles; females reach about 22 cm long, males reach about 14 cm long. Seven subspecies of terrapins range along the east coast of the United States from Cape Cod, Massachusetts through the Gulf of Mexico to Corpus Christi, Texas (Ernst et. al 1994). Terrapins primarily inhabit *Spartina* marshes, which provide shelter and feeding habitat. The diet of adult terrapins include invertebrates such as snails, crabs, mussels, barnacles, annelids, and plants (Marganoff 1970, Bishop 1983, Tucker et al. 1995); hatchlings consume insects, snails, grass shrimp, green crabs and amphipods (King 2007). King (2007) found that terrapin hatchlings forage in the intertidal high marsh zone, a transitional zone which supports both aquatic and terrestrial prey, and noted that adult terrapins feed in low salt marsh habitats (*Spartina alterniflora* patches, mud flats). This suggests a dietary change related to habitat utilization, perhaps as hatchlings mature, salt tolerance increases and habitat utilization changes (Dunson 1986).

Female terrapins nest from April – August depending on geographical location (Feinberg and Burke 2003, Ernst and Lovich 2009). Nests are generally laid in sandy areas and on vegetated dunes (Scholz 2007). Nest and hatchling survivorship varies through their geographical range (Burger 1976, 1977, Auger and Giovannone 1979, Roosenburg 1992, Scholz 2007).

Terrapin hatchling life histories, like that of nearly all turtles, are poorly known, primarily because turtle hatchlings typically occur in low densities and are inconspicuous. Anecdotal reports indicate that hatchlings are consumed by praying mantids (species unknown but probably *Tenodera aridifolia*, D. Reipe, unpub. data), raccoons (*Procyon lotor*, Rulison 2009), Norway rats (*Rattus norvegicus*, Draud et al. 2004), ghost crabs (*Ocypode quadrata*, Arndt 1991, 1994; Zimmerman 1992; Butler 2004), laughing gulls (*Larus atricilla*, Burger 1976), and black-crowned night herons (*Nycticorax nycticorax*, Burger 1976).

In addition to survivorship, most other aspects of turtle hatchling movements and habitat use are also poorly known (Burger 1976, Iverson 1991, Morafka 1994, Tom 1994, Aresco 1999, Tucker 1999, Tucker 2000a, 2000b). Most hatchling literature focuses on emergence, not subsequent movement, and this may be due to the difficulty of locating and tracking hatchlings after they leave the immediate nest vicinity. Nevertheless, post-emergent movement may be influenced by time of day (Plummer 2007, *Apalone mutica*; Tucker 1997, *Trachemys scripta elegans*), precipitation (DePari 1996, *Chrysemys picta*; Tucker 1999, *Trachemys scripta elegans*; Nagle 2004, *Graptemys geographica*) and soil temperature (Bleakney 1963, Hartweg 1944, as cited in Tucker 1999, *Trachemys scripta elegans*). Tucker (2000a) suggested that hatchling movement is timed to minimize water loss. Hatchling behavior may therefore minimize

predation, excessive solar exposure, or water loss. Terrapin hatchling movement is generally towards the closest vegetation, regardless of direction (Burger 1976, Aresco 1999).

Hatchling and juvenile terrapins have been found in *Spartina* marshes, within tidal wrack, under boards, or under low growing vegetation (Figure 1) (Pitler 1985, Lovitch et al. 1991).

Methods for capturing and locating terrapin hatchlings include using nest enclosures (Roosenburg et al. 2003, Roosenburg et al. 2004, Roosenburg et al. 2005, Roosenburg et al. 2007, Roosenburg et al. 2009), drift fences/traps (Roosenburg et al. 2003), following crawl trails (Butler et al. 2004), hand captures (Draud et al. 2004, Roosenburg et al. 2005, Roosenburg and Sullivan 2006, Roosenburg et al. 2007, Roosenburg et al. 2009, King 2007), and telemetry (Draud et al. 2004). Other work on terrapin hatchlings include movement studies (Burger 1976, Lovitch et al. 1991, Butler et al. 2004), diet (Lovitch et al. 1991, King 2007, Kinneary 2008), survivorship (Burger 1977, Roosenburg 1992, Draud et al. 2004), freeze tolerance (Dinkelacker et al. 2005, Baker et al. 2006), salinity tolerance (Dunson 1985, Dunson and Mazzotti 1989) microhabitat (Hay 1917, Pitler 1985, Lovitch et al. 1991, Roosenburg 1991, Burger 1976) and predation (Burger 1977, Butler et al. 2004, Draud et al. 2004). These studies have been limited mostly by small sample sizes, short study durations and/or their incidental nature, which can bias interpretations of hatchling behavior. None of these studies have involved hatchling tracking and monitoring for multiple consecutive seasons.

Turtle Hatchling Overwintering Locations: The general overwintering locations of adults of many temperate northern American turtle species are reasonably well known (Ultsch 1989, 2006). However, overwintering locations of hatchlings are poorly known. Hatchlings of most aquatic turtle species emerge from their nests in the fall and move immediately to water (e.g., Anderson 1958, Ehrenfeld 1979, Moll 1984, Palmer and Cordes 1988, Butler and Graham 1995).

This pattern is not ubiquitous; some hatchlings overwinter in the nest (e.g., *Chrysemys picta*, *Deirochelys reticularia*, *Graptemys geographica*, *Terrapene ornata* (suspected), *Trachemys scripta*) (reviewed by Nagle et al. 2004), and others emerge in the fall but move away from or avoid water after fall emergence (e.g., *Emydoidea blandingii*, Standing et al. 1997, McNeil et al. 2000, Linck and Gillette 2009). There are no generally satisfying explanations for the variation in post-hatching behavior. Costanzo et al. (1995) summarized turtle hatchling overwintering location options as (i) terrestrial hibernation in shallow nests (ii) terrestrial hibernation deep under ground, and (iii) aquatic hibernation. For example, some emydid hatchlings may overwinter in unfrozen depths of ponds or rivers as do adults, while some hatchlings overwinter on land (Ultsch 2006). The specific location of hatchlings overwintering in water is unknown for any species. Other emydid hatchlings spend their first winters terrestrially either in their nests (*Chrysemys picta*, *Deirochelys reticularia*, *Graptemys geographica*, *Trachemys scripta*, reviewed Nagle et al. 2004), or in refuges they dig below their nests (*Terrapene ornata*, Converse et al. 2002). However, these three options do not include terrestrial hibernation at or near the ground surface outside the nest, as occurs in some *Terrapene carolina* (Capitano 2005) and *Gopherus polyphemus* (e.g., Pike 2006). Variation in overwintering patterns exists both among and within Emydidae species; overwintering patterns can even vary within a clutch (i.e., *Emys orbicularis* Mitrus and Zemanek 2000, 2003, and Mitrus 2005; *Trachemys scripta* Costanzo et al. 2001c; and *Graptemys geographica* Nagel et al. 2004).

Overwintering in the Nest (OWN): The phenomenon of turtle hatchlings overwintering in the nest (OWN) has received considerable attention, mostly addressing the possible adaptive function(s) of this behavior and assessing how hatchlings survive freezing temperatures. Most OWN hatchling work has focused on *Chrysemys picta* (reviewed by DePari 1996). OWN occurs

more often in high-latitude hatchlings (Carr 1952, Congdon and Gibbons 1985), with the exception of *Clemmys guttata* (Costanzo et al. 2008), *Glyptemys insculpta* (Costanzo et al. 2008) and *Emydoidea blandingii* (Congdon et al. 2000) hatchlings which have never been reported to OWN. Conversely, some lower-latitude species OWN (i.e., *Chrysemys picta* Cagle 1950, *Trachemys scripta* Jackson 1994, *Deirochelys reticularia* Buhlmann 1998, *Trachemys scripta gaigeae* and Stuart 2001, *Trachemys scripta scripta* Aresco 2004, *Pseudemys rubriventris* Swarth 2004).

Explanations as to why hatchlings overwinter in the nest include both proximate (mechanistic) and ultimate (evolutionary) causes. Proximate reasons to OWN include inability to leave the nest due to a physical barrier (Tinkle et al. 1981, DePari 1996), reduction in fall temperatures reducing locomotor ability (Bleakney 1963, Tucker 1999) and poor incubation conditions which result in a retardation of development (Bleakney 1963, Costanzo et al. 2004). Ultimate reasons to OWN include reduced predation (if fall emergers experience heavier predation rates, Costanzo et al 2008); larger food reserves (if more resources, warmer temperatures, and more sunlight are available to spring emergers (Burger 1977, Ultsch 1989) and additional developmental time in a safe environment (Costanzo et al. 2008). Gibbons and Nelson (1978) predicted that it would be adaptive for turtle hatchlings to overwinter in the nest: (i) when the terrain (environment) between the nest and aquatic environment changes between seasons (fall vs. spring), (ii) when nesting season is extended such that females can continue laying clutches until very late in the season and therefore some clutches have too little time to develop fully, (iii) when food availability is low after fall emergence but higher in the spring and/or, (iv) when survivorship of hatchlings that remain in the nest is greater than the survivorship of hatchlings that leave the nest. Clearly the last prediction encompasses the previous three. None

of these explanations have been fully addressed experimentally (Finkler et al. 2002, Reese et al. 2004, Dinkelacker et al. 2005) and the available data do not strongly support any available explanation (DePari 1996). DePari (1996) found that under both laboratory and field conditions *Chrysemys picta* hatchlings that were incubated in substrates with high water potential tended to OWN while hatchlings incubated in substrates with low water potential were more likely to emerge in the fall. More investigation into the advantages and mechanisms of OWN are needed.

Overwintering Aquatically (OWA): Possible benefits from overwintering aquatically (OWA) include protection from freezing, desiccation, and predation (Costanzo et al. 2008). Hatchlings that OWA are not at risk of extreme cold temperatures (Ultsch 1989, 2006) if they remain in water that does not freeze. Most temperate adult turtles as well as some hatchlings overwinter aquatically. Low oxygen levels (anoxia) could be dangerous for these turtles; and hatchlings may reduce the risk of anoxia by overwintering in lentic systems, up-wells, air pockets, under ice caps, or near the edges of banks (Costanzo et al. 2008).

Overwintering Terrestrially (OWT): Possible benefits from emerging in the fall and overwintering terrestrially outside the nest (OWT) are even less clear than for OWN or OWA. In almost every circumstance, it appears less favorable for a hatchling to emerge from the nest and overwinter near the substrate surface instead of OWN or OWA. Terrestrially overwintering hatchlings can experience freezing conditions, flooding, predation, desiccation, and energy depletion (Costanzo et al. 2008), and for each of these risks, overwintering on the surface is probably more dangerous than overwintering in the nest. OWT may be favored over OWN if nests flood and/or OWT hatchlings are able to feed either before hibernation or earlier in the spring. However, there are no data regarding these possibilities. Although OWT probably occurs throughout tortoises, among Emydidae OWT is known only in some populations of *Terrapene*

carolina (Capitano 2005), *Malaclemys terrapin* (Draud et al. 2004), and *Emydoidea blandingii* (Linck and Gillette 2009), although hatchling behavior is not well known in all Emydidae (e.g., *Terrapene coahuila*).

Temperature Stress Associated with Overwintering: Adult and hatchling turtles may exhibit different cold-hardiness strategies because overwintering habitat changes with ontogeny (Bouchard et al. 2006, Rinehart et al. 2006). Whether hatchlings are in the nest or at the substrate surface, winter survival for high latitude may entail exposure to subzero temperatures, and therefore require a strategy for either tolerating or avoiding freezing. The overwintering strategy turtle hatchlings use depends on physiological and microenvironment conditions (Costanzo et al. 1995) and may change as winter progresses. Only three reports document survivorship and dispersal of high latitude turtles that overwinter terrestrially outside the nest (Draud et al. 2004, Capitano 2005 and Linck and Gillette 2009). None of these studies report cold-hardiness strategies. Capitano (2005) and Linck and Gillette (2009) document hatchling survivorship in the spring, despite repeated periods of low temperatures and without major snow cover.

Freeze tolerance is a process in which internal ice formation (ice inoculation) occurs and is tolerated as the body's water freezes in a gradual process (Lee and Costanzo 1998); moderate to high freeze tolerance has been seen in the hatchlings of several turtle species, primarily Emydidae (e.g., *Chrysemys picta*, *Terrapene ornata*, *Malaclemys terrapin*). Other Emydidae (e.g., *Trachemys scripta*, *Graptemys geographica*, sister taxon to *Malaclemys* (Spinks et al. 2009, Stephens and Wiens 2003) have low freeze tolerance (Costanzo et al. 1995, Packard et al. 1999a, Baker et al. 2003, Dinkelacker et al. 2005). Freeze tolerant hatchlings depend on ice inoculation at high subzero temperatures and the ability to cool at relatively slow rates to limit ice to extra-cellular spaces. Ice-nucleating agents (INA) are common in freeze tolerant animals;

when in the body INA are kept within the extra cellular body fluids to induce ice formation. During freezing, tissues can become distorted due to cell dehydration, and therefore cryoprotectants are necessary to prevent rupturing. Cryoprotectants are naturally produced antifreeze compounds, commonly synthesized before first winter freeze from glycogen reserves in the liver. Cryoprotectants can play an important role in freeze tolerance because they ease osmotic stress within the cells, increase osmolality, and stabilize the structure of the cell (Lee and Costanzo 1998, Willmer et al. 2005). Two forms of cryoprotectants exist: colligative cryoprotectants raise the osmotic concentration of body fluids, limiting the percentage of total body water that can turn into extracellular ice. Noncolligative cryoprotectants protect cell membranes from long term damage by binding in place of water (Willmer et al. 2005). During freezing, respiratory and cardiovascular functions are stopped and membrane potentials are maintained at low levels (Miller and Dinkelacker 2008).

Supercooling is a different strategy for survival of sub-zero conditions, in which animals persist in a low metabolic state, body fluids are liquid at temperatures below their equilibrium freezing/melting point, and yet resist freezing. During supercooling, cardiovascular and respiratory functions stop. Supercooling can enable turtle hatchlings to remain unfrozen while reaching temperatures as low as -20.0°C (Costanzo et al. 2000, 2001b), but it requires effective barriers to prevent penetration of ice and exogenous ice nucleating agents (i.e., bacteria or ice found around the hatchling) into the body. The nucleators' effectiveness often depends on soil moisture, temperature, and morphological considerations (Willmer et al. 2005). The ability to supercool instead of freezing depends on small body size, inhibition of both endogenous (i.e., bacteria found within the hatchling) and exogenous INA (i.e., bacteria or ice found around the hatchling), the quantity and distribution of water in the body, and the osmotic pressure of the

body fluids (Costanzo et al. 2001a, 2003). Dependence on supercooling can be dangerous, because if contact with ice is initiated, freezing can quickly become lethal as ice crystals cause extensive damage, puncturing cell membranes and disrupting subcellular structures (Schmidt – Nielsen 1997). Most terrestrial overwintering turtle hatchlings come in contact with INA, causing inoculative freezing (Costanzo et al. 2001a). INA may enter the body through any opening, such as the nares, eyes, mouth, cloaca, umbilicus, and wounds (Costanzo et al. 2001a, 2003); thus the presence of INA can limit supercooling ability (Lee and Costanzo, 1998, Zachariassen and Kristiansen, 2000). Inoculative freezing could occur at relatively high (but still subzero) temperatures if a supercooled hatchling comes in direct contact with ice or INA (Costanzo et al. 2000, Baker et al. 2003, 2006, Dinkelacker et al. 2004). To prevent such occurrence, hatchlings must resist inoculative freezing (i.e., inoculative resistance). Inoculative resistance has been studied in only a few species and is thought to be well developed in some turtle species whose hatchlings overwinter on land (Costanzo et al. 2001b).

There is an on-going debate among physiologists over the relative importance of freeze tolerance and freeze avoidance via supercooling in turtle hatchlings that OWN, and, by extension, OWT. While some workers have demonstrated that the hatchlings of some turtle species produce cryoprotectants and are freeze tolerant under laboratory conditions, heated discussions continue whether this is biologically relevant. For example, Packard and Packard (2003a) suggested that claims of natural freeze tolerance lack empirical field evidence and are spurious; instead they suggested that supercooling is more biologically important. For example, for freeze tolerance to be a successful survival strategy, hatchlings must not be exposed to temperatures below -3°C for more than one day (Costanzo et al. 1995, Packard et al. 1999b) or below -4°C for more than a few hours (Churchill and Storey 1992a, Packard and Packard

2003a). Such winter weather conditions may be unlikely in many places. Thus Packard and Packard (2003a) instead suggest that hatchlings remain supercooled, unfrozen at temperatures below the equilibrium freezing point. However, Storey et al. (1988) suggested that supercooling as an overwintering strategy will not allow turtles to avoid freezing in wet soils or sand, because the risk of inoculative freezing from environmental ice would be high. To date there is no definitive answer as to which overwintering mechanism is more common and/or successful for turtle hatchlings.

Two studies, Baker et al. (2006) and Graham (2009) addressed these issues in terrapins. Baker et al. (2006) concluded that terrapin hatchlings can either supercool or tolerate freezing, depending on specific conditions. While frozen, terrapin hatchlings tolerated exposure to -2.5°C for at least seven days, but none were able to survive after being frozen at -2.5°C for 12 days. Terrapin hatchlings could also supercool; in the absence of INA terrapin hatchlings could remain unfrozen to -15°C (Baker et al. 2004). If INA are present, they can reduce supercooling capability by $8-10^{\circ}\text{C}$, i.e., ice can start to form (Costanzo et al. 2000, 2003), furthermore terrapin hatchlings were highly susceptible to inoculation from ice or INA in the environment (Baker et al. 2006).

Further research is needed to understand the limits of terrapin freeze tolerance in the field. However, Graham (2009) compared INA in terrapin nests and reported that terrapin hatchlings with higher amounts of INA in the nest substrate emerged in the fall and may have avoided supercooling as an overwintering strategy, while spring emergers had lower amounts of INA and may have used supercooling. Thus overwintering strategy may be depend on characteristics of the nest cavity.

Moisture Stress via Desiccation: Hatchlings may experience dehydration stress while in the nest, after emergence from the nest, during overland movement, and, for hatchlings that do not OWA, while overwintering. Water can be lost through respiration or across the skin (cutaneously). If frozen, hatchlings can also lose water through sublimation. Costanzo et al. (2001b) reported that rates of evaporative water loss (EWL) of turtle hatchlings are low in strictly terrestrial and are high in highly aquatic species, suggesting that desiccation resistance correlates with habitat aridity. Evaporative water loss was associated with the amount of cutaneous surface at the limbs and nuchal pockets, which was in turn associated with body size and shell morphology within the same range of terrestrial and aquatic hatchling species. The rate of EWL serves as excellent predictor of inoculative resistance i.e., hatchlings with high EWL rates are less likely to be freeze tolerant and are likely to overwinter underwater. Costanzo et al (2001) showed turtle hatchlings with high rates of EWL (*C. serpentina*, *S. odoratus* and *S. carinatus*) may not OWT, are not freeze tolerant and resist desiccation and inoculative freezing by being underwater. EWL has not been assessed in terrapins.

Little is known about desiccation tolerance and how it impacts hatchling's fitness (Kolbe and Janzen 2002). Hatchlings that OWN face dehydration stress which limits opportunities for survivorship, early feeding, and growth (Costanzo et al, 2008). Dehydration can also affect hatchlings outside the nest; Kolbe and Janzen (2002) discovered that dehydration in *Chelydra serpentina* caused locomotive impairment and death. However, Costanzo et al. (1995) found that dehydration can enhance supercooling capability of hatchling *Chrysemys picta* in laboratory settings. Partial dehydration may also benefit freeze tolerant species because it can concentrate osmolytes internally, lowering the ice concentration and limiting potential damage to sensitive body structures (Costanzo et al. 2008).

Salinity Stress: Turtles evolved roughly 220 MYA, sea turtles (superfamily Chelonioidea) evolved approximately 100 MYA, and terrapins (*Malaclemys*) evolved from freshwater ancestors only 7-11 MYA (Chan et al. 2006). Unlike their close extant relatives, but like sea turtles, terrapins have (non-homologous) orbital salt glands that excrete salts (Dunson 1985). Dunson (1976, 1985) showed that terrapin salt glands are similar in function to sea turtles (Cheloniidae and Dermochelyidae) but excrete salt at lower rates. Adult terrapins can tolerate full strength sea water (36 ppt) for extended periods of time (Dunson 1976), but Dunson (1985) concluded that salt tolerance of hatchling/subadult terrapins was lower; juveniles less than 50 grams were incapable of growing in 36ppt salt water, and even up to 80g, juveniles needed a source of freshwater to survive (Dunson 1976, Dunson and Mazzotti 1989). Peterson and Burke (unpub. data) found that hatchling terrapins have even poorer salt tolerance than the juveniles such as those tested by Dunson. Newly-hatched terrapins could not survive 18 ppt salinity for more than 14 days. These results suggest that hatchling terrapins cannot spend much time in salt water.

Hatchling Overwintering vs. Adult Overwintering: Anoxia tolerance may also influence hatchling turtle overwintering behavior. Hibernation physiology of adult turtles of many species has been well studied (Ultsch 1989, 2006, Jackson 2002, Jackson et al. 2007) and while there have been laboratory studies of hatchling overwintering that model OWN (Costanzo et al. 2000, Packard and Packard 2003a, Baker et al. 2006, Dinkelacker et al. 2004), little is known about the physiological challenges of aquatic hibernation of hatchling turtles (Finkler et al. 2002, Reese et al. 2004, Dinkelacker et al. 2005a, b). One potentially important risk associated with aquatic overwintering is anoxia; anoxia tolerance is important for overwintering habitat choice in adult turtles. Turtle species (*Chrysemys picta* and *Chelydra serpentina*) that typically overwinter in

anoxic substrates (i.e., mud) are able to tolerate low oxygen levels and species that are anoxia intolerant (i.e., *Graptemys geographica* and *Apalone spinifera*) often hibernate in oxygen-rich water such as streams and large lakes (Ultsch 2006). Much less is known about anoxia tolerance in hatchling turtles, but generally hatchling turtles are less anoxia tolerant than adults (Ultsch 2006), suggesting that hatchlings overwinter in higher oxygen environments than adults. Hypoxia tolerance may increase ontogenetically (Dinkelacker et al. 2005). For instance, adult *Chrysemys picta* are anoxia tolerant and can overwinter in ponds that become hypoxic or anoxic during winter months (Crawford 1991); yet *Chrysemys picta* hatchlings are less tolerant of anoxic conditions and typically spend their first winter in the nest (Thacker 1924, Woolverton 1963).

Shell composition also influences the ability of adult turtles to overwinter aquatically. In general, adult shells are completely ossified, and therefore can serve as pH buffer reserves improving the odds of tolerating hypoxia and anoxia (Reese et al. 2004, Dinkelacker et al. 2005a, b, Ultsch 2006). Turtles can overcome lactacidosis by mobilizing calcium carbonate and magnesium carbonate from the skeleton (mainly the shell), which buffers protons, and by removing lactate from the shell (Jackson 2000). Adults also accumulate, buffer, and store large concentrations of lactate within the shell during winter months (Jackson 1997, Jackson et al. 2002). Hatchling shells are not fully ossified and are less able to buffer acidosis (Ultsch 2006). Little is known regarding the aquatic overwintering locations of adult terrapins but they probably overwinter in hypoxic or anoxic mud (Yearicks et al. 1981). Nothing is known about anoxia tolerance of hatchling terrapins.

Purpose: The purpose of my research was to (i) investigate terrapin hatchling movements after emergence, especially over their first winter (ii) identify environmental factors associated with

hatchling movements, (iii) identify important hatchling predators. I tested the hypothesis that *Malaclemys* hatchlings regularly overwinter terrestrially after emerging from their nests in the fall, as indicated in previous anecdotal observations. I hypothesized that recaptured overwintered hatchlings would have larger carapace and plastron length in the spring because they may have additional time to feed and absorb nutrients (water or yolk) while overwintering. Post-emergence movement of hatchling turtles have been associated with environmental factors (Hartweg 1944, as cited in Tucker 1999, Bleakney 1963, DePari 1996, Tucker 1997, Tucker 1999, Nagle 2004 Plummer 2007), therefore I hypothesized that I would capture more hatchlings on days with higher air temperatures because warmer temperatures may stimulate and promote high levels of hatchling activity as seen in high capture rates. I hypothesized that I would capture more hatchlings on days with less precipitation based on low capture rates on days in which it rained. I hypothesized that I would capture more hatchlings on nights with brighter lunar illumination because I found two unmarked nests emerge on nights with a full moon, but I also hypothesized that based on rat predation I would experience lower predation rats on nights with greater lunar illumination. Terrapin hatchling movement patterns, overwintering locations, and mortality risks during this terrestrial phase are essentially unknown, and thus constitute an important gap in our knowledge of the life history of this species.

Material and Methods

Field Site: Rulers Bar Hassock (RBH) is a 458 ha island in the mainly estuarine Jamaica Bay Wildlife Refuge (JBWR), which in turn is part of Gateway National Recreation Area (Figure 2). JBWR is within the border of Queens and Brooklyn, New York. It consists of ca. 3662 ha hectares of federally protected property with a diverse range of habitats, including sandy shorelines, forested areas, salt marshes, two freshwater ponds, and a wide variety of native and

nonnative plants and animals. JBRW has the largest terrapin population in New York State; nearly 2000 nests are laid annually (Feinberg and Burke 2003). Over 95% of JBWR terrapin nests are laid on RBH (Ner and Burke 2008). JBWR is located near the center of the range of the northern terrapin subspecies, *Malaclemys terrapin terrapin*.

Drift Fence: In fall 2006, spring and fall 2007, and spring 2008 I installed 11 drift fence lines parallel to the shoreline using 13 cm high aluminum flashing strips with metal stakes to anchor below the ground (Figure 3). I labeled each side of the 11 fences; the side facing the water was waterside and the opposite side was landside. I distributed the drift fences among six field locations (Goose Trail (GT), Terrapin Trail (TT), Dunes, Far Side Dunes (FSD), Cactus Patch (CP) and Bench 9 (B9)) in RBH (Figure 2). Habitat type differed among areas, but high levels of terrapin nesting activity had occurred in all areas in previous years (Burke, unpub. data). Fence line length varied according to habitat size (Table 1). Dates of fence establishment varied between seasons and years, but for each season all fence lines were installed before the first hatchling was captured at any fence (Table 2). I changed the number of fence lines and traps each season to add new sites or make adjustments because of erosion and storm damage. I removed drift fences between seasons except between spring 2007 and fall 2007.

Pitfall Traps: I buried pairs of pitfall traps, made from plastic liter-sized milk containers, along each side of each fence at one meter space intervals, and one pair at each end of the fence. Each field location had two styles of pitfall traps. I made the vertical style of trap by cutting milk containers in half transversely and using only the bottom half of the container. This trap style had a large opening for hatchlings to fall into. I made the horizontal style of trap by placing the container on its side and cutting a 5cm X 7cm rectangular hole on the top of the container. I cut four holes in the bottom of traps for water drainage. I buried the traps into sand or dirt, with the

lip of the trap opening flush with the substrate surface (Figure 4). All traps contained a layer of sand and a small amount of dried plant material for refuge. I maintained fence lines and traps daily, removing sand that accumulated along the fences and in traps, trimming vegetation that abutted the fence by hand, and repositioning traps exposed due to erosion.

Documenting Hatchlings: I checked all pitfall traps daily, generally between 1200 - 2000 hours. In fall 2007 I checked more commonly between 1730 – 2300 hours. I checked each trap by removing sand, dirt, or dried plant material from each trap and probing the debris in the bottom of the trap. I used a small mirror to see into the back of horizontal traps. I marked, measured, and photographed hatchlings and released them under nearby vegetation on the opposite side of the fence. Hatchlings that I found walking along the fence line, but not in a trap, were processed and replaced at site of capture. I marked each hatchling with a unique identification number using a marker (Sharpie permanent marker ®) on its carapace and plastron. I measured carapace and plastron lengths and widths with digital calipers and recorded locations (site, fence line, trap number, and side of the fence). I re-measured and re-marked hatchlings that I recaptured.

Predators: I made daily surveys for predator tracks while checking traps and walking on the beach (Figure 3). I placed track plates and motion sensor cameras at irregular intervals alongside fence lines (Figure 5).

Tracking Technique: I used colored fluorescent powder (Day-Glo Color Corporation) on some hatchlings in fall 2007 and spring 2008 to track their movements (Butler and Graham 1995; Tuttle and Carroll 2005). Hatchlings were tracked only on nights with high hatchling activity and little precipitation. I dipped the posterior half of each hatchling's shell in fluorescent powder and released it where captured (Figure 6). After sunset I used a small portable battery-operated

ultraviolet light to scan the ground and detect fluorescent powder until I could no longer see the powder. I tracked hatchlings until the powder trail was not visible.

Photograph Comparison: Because my marking system was not permanent, I used records of plastron patterns as a second method to identify recaptures. I compared plastron photographs from all hatchlings for all four field seasons to each other to test whether I failed to identify a previously caught hatchling as a recapture, i.e., if it lost its identification number. For each hatchling photograph, I found an unusual pattern or design on its plastron and looked for the same pattern on all other photographs. I repeated the photograph comparison more than once to ensure I accounted for all hatchlings captured.

Statistical Analysis: Levels of significance were set at $\alpha=0.05$. I compared hatchling carapace and plastron lengths and widths between seasons using two-tailed t-tests assuming unequal variance. I used two-tailed paired t-tests to analyze hatchling overwinter growth and to analyze for growth between recaptures.

Hatchlings that fell into pitfall traps were categorized by field site location, fence line, and trap number. The number of hatchlings that fell into traps per day per fence line was calculated using the total number of hatchlings that fell into each trap per day per individual fence line divided by the number of traps per fence line and the number of days traps were open. Each trap line and season was analyzed separately.

I used online weather data (daily low, average, and high air temperature, daily rainfall, and lunar phase) recorded at a weather station located at JFK Airport (ca. four km NE from study site) collected by the National Weather Service and reported by wunderground.com.

I compared the number of hatchlings captured each season using two-tailed t-tests. To test whether air temperatures (daily minimum, daily average and daily maximum air

temperatures) affected hatchling capture rate I compared the temperature data to the number of hatchlings captured per day. I sorted the air temperatures per degree in ascending order with respect to the number of hatchlings captured per day. I added the number of hatchlings captured within the same temperature degree and determined the number of hatchlings captured at each temperature. I used regression analysis to compare the number of hatchlings captured per day with the daily low, daily average, and daily high air temperature for each seasons. I did the same regression analysis comparing daily low, daily average, and daily high air temperature for all seasons combined.

To test whether precipitation affected hatchling movement I compared daily precipitation from online data (wunderground.com), grouped into 0.5mm precipitation intervals, with daily hatchling capture rates, using a chi square test. I whether percent lunar illumination affected hatchling movement using a regression analysis comparing percent lunar illumination vs. number of hatchlings captured per day.

I recorded the date, location and postmortem condition of each hatchling found dead. I used regression analysis to determine whether there was a relationship between percent lunar illumination and the number of hatchlings found dead per day per season and for all four seasons combined.

I used two methods of analyzing hatchling captures; by trapping season and by active season (Table 3). Each trapping season began as the first day I installed the first fence line and trap and ended the day I dissembled the last fence line and trap. Each active season began as the first day I captured the first hatchling of that season and ended the last day I captured or recaptured a hatchling that season. All weather analyses were conducted using the trapping season data.

Results

Capture/Recapture Rates: I captured 324 different hatchlings (dead and alive) and had 428 recaptures (dead or alive) in the four field seasons (fall 2006, spring 2007, fall 2008, and spring 2008, Table 4 and Table 5); 95 of these were recaptured at least once during a subsequent season. I caught significantly more hatchlings in pitfall traps in the fall seasons than spring ($\chi^2 = 35.2$, $p < 0.001$, d.f. = 1); 49 hatchlings in fall 2006, 185 hatchlings in fall 2007; 23 hatchlings in spring 2007, and 99 hatchlings in spring 2008 (Table 6). The number of hatchlings captured varied among seasons (Table 7) and months, August and October had the most fall recaptures: 21 hatchlings in August and 25 hatchlings in October (Table 8), while May had the most spring recaptures: 3 hatchlings in 2007 and 14 hatchlings in 2008 (Table 9). I found 42 dead hatchlings in all four seasons combined.

Trapping Season: The number of hatchlings captured in pitfall traps per day varied each season within the trapping season, fall 2006 $\bar{x} = 0.62$ hatchlings per day (n=47), spring 2007 $\bar{x} = 0.39$ hatchlings per day (n=19), fall 2007 $\bar{x} = 1.99$ hatchlings per day (n=138), and in spring 2008 $\bar{x} = 1.8$ hatchlings per day (n=67) (Table 10). There was no significant difference in the number of hatchlings captured per day per trap during either fall or spring months in the trapping season ($\chi^2 = 0.34$, $p = 0.85$, d.f. = 1)

The number of hatchlings captured in pitfall traps during the trapping season varied per location. In fall 2006 and spring 2007 I caught the most hatchlings in pitfall traps at G.T. fence line #1, 17 hatchlings in fall 2006 (Table 11) and nine hatchlings in spring 2007 (Table 12). In fall 2007 I caught the most hatchlings in pitfall traps per season, 110 hatchlings at Dunes fence line #1 (Table 13) and I caught more hatchlings at Dunes fence line #1 than any other fence line.

In spring 2008 I caught the most hatchlings in pitfall traps at Dunes fence line #3, 26 hatchlings (Table 14).

Active Seasons: The number of hatchlings captured in pitfall traps per day varied within the length of the active season, fall 2006 $\bar{x} = 0.71$ hatchlings captured per day (n=47), spring 2007 $\bar{x} = 0.68$ hatchlings captured per day (n=19), fall 2007 $\bar{x} = 2.15$ hatchlings captured per day (n=138), and spring 2008 $\bar{x} = 1.87$ hatchlings captured per day (n=67) (Table 15). There was no significant difference in the number of hatchlings captured per day per trap during either fall or spring months in the active season ($\chi^2=0.08$, $p = 0.78$, d.f. =1)

Hatchling Size Differences: Hatchlings captured in fall 2006 had significantly larger carapace lengths than those captured in fall 2007 (Table 16) ($t=2.29$, $p=0.02$; d.f. = 74) but there was no corresponding difference in hatchling plastron lengths ($t=1.55$, $p=0.123$, d.f. = 142). In contrast, hatchlings captured in spring 2007 had significantly larger plastron lengths than those captured in spring 2008 ($t=2.71$, $p=0.01$, d.f. = 37) but there was no difference in hatchling carapace lengths ($t=1.00$, $p=0.33$, d.f. = 28). A regression analysis showed a highly significant and positive relationship between initial carapace lengths and plastron lengths for data from all four seasons combined ($r^2 = 0.61$, $F_{1,270} = 422.02$, $p < 0.001$).

Hatchlings captured in fall 2006 were not significantly different in carapace length than those captured in spring 2007 ($t=1.89$ $p=0.06$, d.f. =38), but fall 2007 hatchlings were significantly larger in carapace length than those captured in spring 2008 ($t=2.81$ $p=0.006$ d.f. =124). Hatchlings captured in fall 2006 were significantly larger in plastron length than spring 2007 hatchlings ($t=4.15$ $p= 0.0001$, d.f. = 58), but fall 2007 hatchlings were not significantly different in plastron length than those captured in spring 2008 ($t=1.59$ $p=0.11$ d.f. =145).

I captured 18 hatchlings in fall (between 2006 or 2007) and recaptured them in the subsequent spring; five hatchlings were not measured. Eight of these hatchlings decreased in carapace size from fall to spring, losing 0.35% - 3.6% of their fall length. Four were unchanged in carapace size, and one grew 1.4% in carapace length (Table 17). Ten hatchlings decreased in plastron size, losing 0.4% - 10% of their fall length (Table 18). Three hatchlings grew, gaining 0.85% - 8.6% of their fall length. Overall, the fall-spring recaptures had significantly smaller carapace lengths (paired $t = 2.52$, d.f. = 12, $p = 0.027$) but no significant difference in plastron length (paired $t = 1.35$, d.f. = 12, $p = 0.201$).

Hatchling Activity patterns & Environmental Conditions: I found no significant difference in the number of hatchling captures in fall or spring and combined fall seasonal and spring seasonal data ($\chi^2 = 0.34$, $p = 0.85$, d.f. = 1). In each fall there were extended periods between the first capture of the season and the last capture of the season during which no hatchlings were captured. In fall 2006 the longest gap was 31 days; in fall 2007 the longest gap was 11 days. Neither spring seasons had similar periods without hatchling captures (Tables 3 and 5).

The longest time a hatchling remained on land between recaptures within a fall season was 61 days (Table 19). The longest time a hatchling was recorded to remain on land within either spring season was 17 days (Table 19). The longest time between recaptures of the same hatchling from fall to spring was 276 days (Table 20).

Minimum Air Temperature: With fall 2006 and 2007 data combined, there was a significant but weak positive relationship between the number of hatchlings captured per day and the minimum air temperature ($r^2 = 0.03$, $F_{1,182} = 4.68$, $p = 0.032$). In the spring 2007 and 2008 data combined, there was no relationship between the number of hatchlings captured per day and the minimum air temperature ($r^2 = 0.014$, $F_{1,112} = 1.63$, $p = 0.20$). When all four seasons data of minimum air

temperature were combined, there was no relationship between the number of hatchlings captured per day and the minimum air temperatures ($r^2 = 0.007$, $F_{1,296} = 2.16$, $p=0.14$).

In fall 2006, 95% of hatchlings were captured on days with minimum air temperature $\geq 7^\circ\text{C}$ (n =56 hatchlings). In fall 2007, 98% of hatchlings were captured on days with minimum air temperature $\geq 6^\circ\text{C}$ (n= 208 hatchlings). In fall 2006 and fall 2007 combined, 97% of hatchlings were captured on days with minimum air temperature $\geq 6^\circ\text{C}$ (n=265 hatchlings). In spring 2007, 90% of hatchlings were captured on days with minimum air temperature $\geq 9^\circ\text{C}$ (n=26 hatchlings). In spring 2008, 90% of hatchlings were captured on days with minimum air temperature ranging $\geq 9^\circ\text{C}$ (n=111 hatchlings). In spring 2007 and 2008 combined, 90% of hatchlings were captured during minimum air temperature that ranged $\geq 9^\circ\text{C}$ (n= 137 hatchlings).

Average Air Temperature: In the fall 2006 and 2007 data combined there was a significant but weak positive relationship between the number of hatchlings captured per day and the average air temperature ($r^2=0.05$, $F_{1,169}=9.01$, $p=0.003$). In the spring 2007 and 2008 data combined there was no significant relationship in the number of hatchlings captured per day and the average air temperature ($r^2=0.013$, $F_{1,112}=1.46$, $p=0.23$). When all four seasons data of average air temperature were combined, there was a significant relationship with the number of hatchlings captured per day and the average air temperature ($r^2 = 0.014$, $F_{1,283} = 4.03$, $p=0.045$).

In fall 2006, 92% of hatchlings were captured on days with average air temperature from $11^\circ - 23^\circ\text{C}$ (n =54 hatchlings). In fall 2007, 99% of hatchlings were captured on days with average air temperature from $12^\circ - 26^\circ\text{C}$ (n=224 hatchlings). In fall 2006 and fall 2007 combined, 90% of hatchlings were captured on days with average air temperature from $11^\circ - 25^\circ\text{C}$ (n= 256 hatchlings).

In spring 2007, 96% of hatchlings were captured on days with average air temperature ranging from 13° – 23° C (n=28). In spring 2008, 92% of hatchlings were captured on days with average air temperature ranging from 11° - 24° C (n=115). In spring 2007 and 2008 combined, 90% of hatchlings were captured during average air temperature ranging from 12° - 26° C (n=144 hatchlings).

Maximum Air Temperature: In the fall 2006 and 2007 data combined there was a weak but significant positive relationship between the number of hatchlings captured per day and the maximum air temperature that day ($r^2=0.040$, $F_{1,176}=7.36$, $p=0.007$). In the spring 2007 and 2008 combined data, there was no significant relationship between the number of hatchlings captured per day and the maximum daily air temperature ($r^2=0.010$, $F_{1,112}=1.11$, $p=0.29$). When all four seasons data of maximum air temperature were combined, there was no relationship between the number of hatchlings captured per day and maximum air temperature ($r^2 = 0.009$, $F_{1,290}=2.86$, $p=0.09$).

In fall 2006, 90% of hatchlings were captured on days with maximum daily air temperature from 16° - 28°C (n =53 hatchlings). In fall 2007, 92% of hatchlings were captured on days with maximum daily air temperature from 17° – 29°C (n=208 hatchlings). In fall 2006 and fall 2007 combined, 91% of hatchlings were captured on days with the maximum daily air temperature from 17° - 29°C (n= 259 hatchlings).

In spring 2007, 93% of hatchlings were captured on days with maximum daily air temperatures was 16 – 28° C (n=28). In spring 2008, 91% of hatchlings were captured on days with maximum daily air temperature from 15° - 31° C (n=114). In spring 2007 and 2008 combined, more than 93% of hatchlings were captured with maximum daily air temperature from 15° - 31° C (n=144 hatchlings).

Lunar Phase: In fall 2006 and fall 2007 data combined there was no significant relationship between the number of hatchlings captured and lunar illumination as indicated by moon phase ($r^2 = 0.0001$, $F_{1,175} = 0.022$, $p=0.88$). One hundred fifty-five hatchlings (55%) were captured on nights with less than 50% lunar illumination (n=284 hatchlings). In spring 2007 and spring 2008 combined data, there was no significant relationship between the number of hatchlings captured and lunar illumination ($r^2 = 0.0002$, $F_{1,101} = 0.024$, $p=0.88$). Sixty-three hatchlings (41%) were captured on nights with less than 50% illumination (n=155 hatchlings). When all four seasons data of lunar phase were combined, there was no significant relationship between the number of hatchlings captured and lunar illumination ($r^2 = 0.0002$, $F_{1,278} = 0.56$, $p=0.81$). Two hundred eighteen hatchlings were captured on nights with less than 50% illuminations (n=439).

Rainfall: In fall 2006 and fall 2007 there was a highly significant relationship between the number of hatchlings captured per day and the amount of daily rainfall ($\chi^2 = 0.2$, $p < 0.001$, d.f. = 1). During fall 2006 and fall 2007, 92% of hatchlings were captured on days with less than 1mm of rainfall (n=284). The most hatchlings captured (n=249 hatchlings in fall 2006 and 2007) occurred when there was no rainfall (Table 21). During both fall seasons, 10% of hatchlings were active on days in which it rained (n=278).

In spring 2007 and spring 2008 there was a weak but highly significant relationship between the number of hatchlings captured per day and the amount of rainfall ($\chi^2 = 0.13$, $p < 0.001$, d.f. = 1). During spring 2007 and spring 2008, 81% of hatchlings were captured on days with less than 1 mm of rainfall (n=155). The most hatchlings captured (n= 97 hatchlings in spring 2007 and 2008) occurred when there was no rainfall (Table 22). When all four season precipitation data were combined, there was a highly significant relationship between the amount of hatchlings captured and the amount of rainfall ($\chi^2 = 0.15$, $p < 0.001$, d.f. = 1), hatchlings

moved in disproportionately high numbers under low rainfall conditions. In both spring seasons, 37% of hatchlings were captured on days in which it rained (n=155).

Hatchling Recaptures Between Seasons (Overwintering): I recaptured 18 hatchlings in spring that were originally captured in the previous fall. One hatchling was first captured in fall 2006 and was recaptured in spring 2007; the other 17 hatchlings were first captured in fall 2007. Four spring-captured hatchlings were found upland from their fall location, further away from the water. Nine spring captured hatchlings were found in the same location of their last known fall location. Five spring recapture hatchlings were found downhill than their fall location, closer to the water. All hatchlings except two were recaptured near their fall locations (Dunes). The two that moved were recaptured in another field location (one fall hatchling moved from FSD to its spring capture location at the Dunes and one fall hatchling moved from Dunes to its spring capture location at the Bench 9); both locations were further away from the water. The rest of the hatchlings, besides the two hatchlings that moved to a different field locations, only moved one fence line upland or towards the water. The length of time between fall captures and spring recaptures ranged from 183 days to 276 days, $\bar{x} = 226$ days, (8/27/2007 – 5/29/2008) (Table 20).

Hatchling Captures in Pitfall Traps: I captured/recaptured 356 live hatchlings in pitfall traps during four field seasons fall 2006 – spring 2008 (Table 6); I found 29 additional hatchlings outside traps. I hand captured and/or trapped 53 hatchlings that were either found dead (n=42) or were not used in analyses because of missing data (n=10).

Hatchling Directional Movement per Season: In fall 2006, 56% (26 of 47) of the hatchlings captured in pitfall traps were captured moving upland, away from the water ($\chi^2=0.53$, $p=0.46$ d.f. = 1). In fall 2007, 62% (85 of 138) of hatchlings captured in pitfall traps were captured moving upland, away from the water; these differences were significant ($\chi^2=12.58$, $p=0.0004$

d.f. = 1). In spring 2007, 84% (16 of 19 hatchlings captured in pitfall traps) of hatchlings were moving towards the water, away from the upland; these differences were significant ($\chi^2 = 7.2$, $p = 0.007$, d.f. = 1). In spring 2008, 67% (45 of 67 hatchlings captured in pitfall traps) of hatchlings were moving towards the water, away from the upland; these differences were significant ($\chi^2 = 8.4$, $p = 0.004$, d.f.=1) (Figure 7).

Tracking Technique: I tracked 39 hatchlings after sunset during fall 2007 and spring 2008 using different colored florescent powder and a black light. Powder tracks were not always easy to follow depending upon habitat type and powder color. Dense upland vegetation and aquatic vegetation always made tracking hatchlings more difficult. Neon pink was the easiest color to track. Only a few tracks were accurate enough to determining hatchling movement. One trail was followed into thick vegetation, two trails were followed into the wrack line, two more trails were followed into the wrack line and then into the water, and two trails went into the water. I found powder on several recaptured hatchlings and one hatchling that OWT, traces of powder were visible on its carapace 180 days after its fall capture.

Hatchling Predation & Predators: I found 42 dead hatchlings during the four field seasons combined (Figure 8). All dead hatchlings were less than 24 hours post-mortem, the time between my last trap check and my return the next day. I found 27 dead hatchlings in traps and 15 dead hatchlings on wrack lines or sand. I found more dead hatchlings ($n=27$) in fall 2007 than in any other season (Table 23).

I found ten hatchlings with missing heads and three hatchlings missing half of their bodies. I found seven hatchlings with missing heads and five with missing limbs. Five hatchlings had flattened shells, four hatchlings had blood visible, and eight hatchlings had inner organs exposed (Tables 23, 24, 25, & 26).

During all four seasons, both style of pitfall traps were occasionally excavated, flipped over or otherwise moved on an irregular basis at all locations. This occurred most frequently soon after traps were initially installed each season. Raccoons (*Procyon lotor*) were common in all trapping areas (Figure 9). I observed raccoons, mostly during the evening, while they were predated nests, swimming, foraging, and walking alongside active fence lines during every field season. I regularly observed raccoon tracks. Video recordings, pictures from motion-sensitive cameras, and track plates all showed that raccoons were present and active in known hatchling areas.

Norway rats (*Rattus norvegicus*) were also present. I never observed rats near any drift fences but I observed rat tracks on the nearby beach. In fall 2007 I found more predated hatchlings that may have been killed by rats (n=6) than in any other season. I found 17 dead hatchlings with missing limbs (see above); their appearances were similar to those descriptions by Draud et al. (2004) including “hatchlings completely eviscerated through either the carapace or plastron and had their limbs and head gnawed or completely consumed”. There was a very weak but significant relationship between the percent lunar illumination each night and the number of dead hatchlings found that night ($r^2 = 0.05$, $f_{1,184} = 0.398$, $p=0.05$) meaning that after nights with greater lunar illumination I found fewer dead hatchlings. In fall 2007, 26 hatchlings were found dead on nights with 3% - 33% moon illumination, while four dead hatchlings were found on three separate nights with higher than 50% moon illumination; 66%, 77%, 90 and 99% moon illumination (Table 27).

Ants (unknown sp.) were found in traps foraging on at least five dead hatchlings; in these cases hatchling shells were bare, with only bones remaining, or only some of the organs intact. Ants were also found in traps feeding on crickets, spiders, mice, crabs, and caterpillars.

I regularly saw birds that may have been hatchling terrapin predators (e.g., Herring Gulls (*Larus argentatus*), Laughing Gulls (*Larus atricilla*), Ring-Billed gulls (*Larus delawarensis*), Northern Harriers (*Circus cyaneus*), Great Blue Herons (*Andea herodias*), Yellow-Crown Night Herons (*Nycticorax violacea*), and Fish Crows (*Corvus ossifragus*)); however, I never witnessed avian predation on terrapin hatchlings.

Discussion

Hatchling Overwintering Locations: It has been previously documented that some terrapin hatchlings sometimes stay on land after fall emergence. Pitler (1985) incidentally found 12 juvenile terrapins (shell lengths ranging from 25 mm to 75 mm) in New Jersey from May – October hiding under surface debris on mudflats or surface debris and vegetation (low growing blueberry bush, *Vaccinium* spp., and *Spartina* spp.) as much as 91 meters from water's edge. Four terrapins were found in June and five in July, and based on their sizes, this suggests that terrapins may remain on land during a substantial part of their juvenile period. They may have been on land since emergence or may have returned to land after spending time in the water. I never found a hatchling on land other than during my spring and fall field seasons and I never found a juvenile. More terrapins could have easily been on land but been undetected.

Roosenburg et al. (2009) reported hatchlings captured from natural nests and released into the water in September and October returned to land and sought higher ground. Butler et al. (2004) found that 93% (n=172) of post-emergent hatchling crawls headed in the direction of vegetation or an adjacent salt marsh and not to the nearby open water. Draud et al. (2004) radio tracked eight terrapin hatchlings that remained on land after hatching at least through October. Roosenburg and Sullivan (2006), Roosenburg et al. (2007), Roosenburg et al. (2009) reported that some fall hatchlings headed to shore and away from water at the same field site over three

nesting seasons. Even laboratory hatchlings that were later released in the field followed the same pattern; Lovitch et al. (1991) released artificially incubated hatchlings offshore and all swam back to land, crawled up the beach, and took refuge under tidal debris. Therefore several reports indicate hatchling terrapins remain on land for an unknown period of time. However, none of these studies tracked a substantial number of naturally-incubated terrapin hatchlings over a significant period of time, therefore it has been unclear whether they were artifacts of manipulation or small samples. My study shows that terrapin hatchlings behave differently from their close relatives, *Graptemys geographica* or *Trachemys scripta*, which have only been reported to OWN. Terrapins are also different in that they overwinter outside of their nest and they can tolerate lower temperatures for longer durations (see below) (Baker et al. 2006).

Overwintering In the Nest (OWN): OWN is found in at least five species of Emydidae (*Chrysemys picta*, *Deirochelys reticularia*, *Graptemys geographica*, *Terrapene ornata*, *Trachemys scripta*, reviewed by Nagle et al. 2004). Based on anecdotal reports at RBH (Ultsch 2006) I suggest that some terrapin hatchlings may have overwintered in the nest. Ultsch (2006) reported that hatchlings overwinter in 10% of RBH nests, even within a single nest some hatchlings overwintered and others did not. Elsewhere in their range, terrapins have been reported to OWN (Hildebrand 1929 (NC), Lazell and Auger 1981(MA), Roosenburg et al. 2003 (MD), Baker et al. 2006 (NJ), Graham 2009 (MD)). In my study it was not possible to distinguish between fall emerging hatchlings which I did not capture from spring emerging hatchlings. In Spring 2007 and 2008 96% and 76% hatchlings, respectively, were unmarked, which may have OWN or may have emerged in the fall, overwintered on land, but not fallen into the pitfall traps in the fall. Thousands of nests are laid on Ruler's Bar, and many hatchlings could have evaded my traps.

Overwintering Aquatically (OWA): I found that 3.5% hatchlings in fall 2006 and fall 2007 and 1.02% of hatchlings in spring 2007 and spring 2008 moved towards open water from fence lines closest to the water line and then moved back upland, returning to the fence. These hatchlings either never entered the water or entered the water only temporarily. Standling et al. (1997) reported that *Emydoidea blandingii* hatchlings entered water then returned to land. Similarly, Linck and Gillette (2009) tracked three *Emydoidea blandingii* hatchlings into shallow water (wetland) for varying lengths of time before they returned to land to overwinter. This similar behavior in both terrapins and *Emydoidea* (a freshwater species) suggest that hatchlings may be entering freshwater to hydrate themselves before overwintering on land. Terrapin hatchlings may also be avoiding brackish water.

At RBH, OWT appears to be the most common form of overwintering, followed by OWA and OWN. In fall 2007 45% (n=47) and fall 2008 36% (n=154) hatchlings moved towards water, instead of upland, and these hatchlings may have OWA. At least three hatchlings moved towards and entered water after fall emergence and I suspect they may have OWA because I did not recapture them again. However, my fences did not stretch along the entire shoreline and they may have returned to land elsewhere. Hatchlings of other turtle species prefer shallow water-depths for feeding (Hart 1983, Congdon et al. 1992, Pappas and Brecke 1992) but it is unknown whether such locations are also used for OWA (Ultsch et al. 2008) because so little is known of any turtle species that OWA. In general, it is difficult to determine whether hatchlings OWA because of the difficulty of locating and tracking hatchlings underwater and underwater hibernacula locations are unknown. At present no technology is available that would solve this problem, which needs further attention (Ultsch et al. 2008).

Overwintering Terrestrially (OWT): I observed hatchlings moving upland in the fall, and I recaptured 18 hatchlings on land in spring that I had initially caught on land in the previous fall. It is likely that more hatchlings OWT in my study but were not found because they chose an overwintering location outside of my study area or they circumvented my drift fences. More direct evidence is needed (e.g., Capitano (2005) *Terrapene carolina* and Linck and Gillette (2009) for *Emydoidea blandingii*). However, this is the strongest evidence yet that *Malaclemys* regularly OWT for the entire winter in significant numbers. Draud et al. (2004) suggested terrapin hatchlings OWT because 24 terrapin hatchlings were radio tracked from their nests in the fall, eight survived rat predation and buried themselves “0.5 – 35m inland from the mean high tide line”, with the last known date of October 22, 2003. They did not report the further fate of these hatchlings, nor what percentage of the hatchling population they studied. It is also possible that their transmitters affected hatchling behavior; their transmitters were well above the generally accepted maximum of 5% of the mass of the tracked individual.

As Packard and Packard (2003a) suggested, for freeze tolerance to be a successful overwintering strategy, hatchlings must not be exposed to temperatures below -3°C for more than one day. During winter 2006 at RBH, I found the coldest air temperature was -13°C and average minimum air temperatures reached -6°C , -8°C , -9°C , and -10°C for periods of 2 – 6 days. Minimum air temperatures during winter 2007 were -8°C , -9°C , -10°C for two to three days, and the coldest temperature was -12°C . The relationship between air temperature and ground temperature is unknown, so I cannot estimate the thermal conditions to which hatchlings were exposed. However, temperatures in the shallow substrate may have approached the lower limit for successful freeze tolerance.

It is unclear what advantages OWT could have over OWN. I found that predation of hatchlings was common in the fall, but without robust estimates of the size of the hatchling population in each season I cannot compare predation rates seasonally. OWT also probably exposes hatchlings to greater temperature extremes, and colder temperatures overall than OWN (Nagle et al. 2004). Terrapins have been reported to be both freeze tolerant and to be able to supercool (Backer 2006, Graham 2009, see above). Baker (2006) found that terrapin hatchlings were freeze tolerant; hatchling survived exposure to cold temperatures of -2.5°C in the laboratory for up to seven days but could not tolerate being frozen for 12 days at -2.5°C . Similarly, terrapins recovered and survived from freezing cold temperatures between -3.0 and -3.5°C for three days. Some map turtles (*Graptemys geographica*) are known to OWN (Nagle et al. 2004), can tolerate subzero temperatures via supercooling and have a well developed resistance to inoculative freezing (Baker et al. 2003). *Graptemys* has been recorded to tolerate the lowest known temperature for a turtle species at (-8°C) (Nagle et al. 2004). In comparison, terrapins can tolerate low temperatures for longer durations than *Graptemys* (Baker et al. 2004). Thus this clade of turtles appears to have highly flexible hatchling overwintering strategies whose adaptive implications are not well understood.

It would be prudent to study terrapin terrestrial overwintering sites in greater detail, measuring hydric conditions and temperatures, and comparing these to other Emydidae. Linck and Gillette (2009) described different overwintering locations that were used by *Emydoidea blandingii* hatchlings i.e., in moist leaf litter, in or on the edge of potholes, under vegetation, or in uplands; terrapins may be utilizing similar locations. To better understand the evolutionary and ecological history of the trait, studies should compare and look for similarities between substrate depth, distance to closest vegetation, solar radiation, and include vegetated upland

habitats and damp terrestrial areas, such as those used by *Emydoidea blandingii* (Refsnider 2005).

Drift Fences: Drift fences are used commonly to survey and capture herpetofauna (e.g., Anderson 1958, Sexton 1959, Gibbons 1970, Gibbons and Nelson 1978, Gyuris 1993, Tucker 1997, Tucker 1999, Tucker 2000b, Janzen et al. 2000, Kolbe and Janzen 2002, Roosenburg et al. 2003). Drift fence sampling is known to be biased because climate affects activity, thus probability of capture and differences in animal mobility affect capture rates (Todd et al. 2007). These problems are not likely to be important in this study because it targeted a single life stage of one species.

Drift fences can also be costly, time and labor intensive (Sheppe 1967). Poor installation of a drift fence or traps, or a lack of maintenance and repair, can lead to low capture rates, resulting in misinterpretation of population size, desiccation, and high death rates (Dodd 1991, Todd et al. 2007). Drift fences can also become barriers to non-target animals (Charney et al. 2009). In 2007 I left drift fences in place from April until November. Some drift fences closest to the water line prevented gravid terrapins from moving to suitable nesting habitats, and I witnessed gravid terrapins unable to cross the drift fence and nesting alongside the drift fence. This can be avoided by either removing the drift fences before the nesting season or leaving openings in the fence.

Drift fences would be less reliable if target species could routinely climb over or under fences. Hay (1917) reported that hatchling terrapins are capable of climbing over a concrete wall 91 cm; I saw hatchlings attempt to climb my 13 cm aluminum flashing strips without success. I made sure that all drift fences were securely pushed into the sand to prevent hatchlings from crawling underneath.

There have been previous terrapin studies that involved the capture of tens (Draud et al. (2004), hundreds (Burger (1975), Burger (1976), Roosenburg et al. (2003), Roosenburg et al. (2004), Roosenburg et al. (2007), King (2007) and even thousands (Roosenburg et al (2005), Scholz (2007), Roosenburg and Sullivan (2006), Roosenburg et al. (2009) of post-emergent hatchlings, using hand capture, ringed nests, drift fences, nest predator excluders, and nest emergence from marked nest (Table 28). I did not use predator excluders in my study because I wanted to test behavior under natural field conditions without biasing initial dispersal. Hand capturing large numbers of terrapin hatchlings is not practical at RBH for several reasons, it would have been even more time demanding because hatchling overwintering habitat was unknown, hatchlings might be trampled during searches, and the vegetation may be too dense to conduct a successful search in many places. Radio tracking terrapin hatchlings is not feasible due to the small mass size of the hatchlings (as small as 3.7g) and the unavailability of transmitters that are under the usual 5% weight limit for telemetry packages, but Draud (2004) reported radio tracking of terrapin hatchlings.

Charney et al. (2009) suggested using Passive Integrated Transponder (PIT) stationary antennae for monitoring the movements of small terrestrial animals. Such a system would allow hatchlings to naturally move freely without being detained by a drift fence or falling into traps, decrease predation and desiccation while trapped, reduce detection and retention to the target species, and be less labor and time intensive. Equipment used for PIT is more expensive than drift fence equipment, but Charney et al. (2009) concluded that while the total costs (equipment + including manual labor) for PIT and drift fences are similar, PIT was less damaging to the studied animals allowing them to move freely with fewer disruptions. I suspect this technique

would be successful at RBH but problems could include damage to the antennae (i.e., rodents, raccoons, and curious people), cost, and supplying a remote power source for the antennae.

Growth While Overwintering on Land: It is not clear what selective advantages may accrue with OWT, but one possible advantage is the ability to feed and grow. I tested for this by comparing carapace and plastron lengths of hatchlings captured in fall and again in the subsequent spring. I hypothesized that spring recaptures would have larger carapace and plastron lengths, because of the opportunity to feed, drink, absorb water, and absorb their yolks while overwintering. Typically the yolk is fully internalized when hatchlings emerge from the nest, but they still contain substantial amounts of yolk. Tucker et al. (1998) and Filoramo and Janzen (1999) suggested that hatchlings with adequate yolk can use it for somatic growth. However, all but one of the hatchlings decreased in size. Fall hatchlings on average had larger carapace and plastron lengths than the same hatchlings in the following spring. Without presenting data, Hay (1917) also observed that terrapin hatchlings were lighter and smaller in size in the spring than they were when newly emerged in the fall. My results suggest that terrestrially overwintering hatchlings may undergo food and/or water stress while overwintering and that yolk may not make up for these stresses. However, Roosenburg and Sullivan (2006) found terrapin hatchlings that OWT did not differ in plastron length from fall emerged hatchlings. DePari (1996) reported *Chrysemys picta* hatchlings that emerged from the nests in the fall had significantly smaller plastron lengths than hatchlings that OWT. Packard and Packard (1989) found that yolk does not contain large amounts of calcium and phosphorus and they suggested that yolk is perhaps used for maintenance, and not hatchling growth. If yolk stores are insufficient to meet metabolic needs, then yolk may be catabolized thus decreasing body mass (Finkler et al. 2002).

Hatchling shrinkage may be due to desiccation, instead of or in addition to metabolism of food reserves. There have been reports of Testudines shrinking due to desiccation (see Desiccation, below) or other environmentally related stress. *Gopherus agassizzi* hatchlings shrank (carapace length) during droughts (K.J. Field personal communication; as cited in Field et al. 2007). The drought lasted 115 days and carapace lengths shrank an average of 0.8% (1.9 mm); however the shrinkage was reversed with access to water. Loehr et al. (2007) found that straight carapace length, shell height and shell volume, and shell width and plastron length of adult *Homopus signatus signatus* also occasionally shrank. Adults were more prone to shrinking than juveniles. Shrinking frequency of adult tortoises was not related to sexual differences. Although shrinking occurred in all four years of the study, the highest number of shrinking adults was found during a drought. Adult marine iguanas, *Amblyrhynchus cristatus*, also decrease in size due to environmental changes. Wikelski and Thom (2000) reported shrinkage in snout-to-vent length of as much as 20% (6.8 cm) in two years. This may be an adaptive response to low food availability and extreme energetic stress during El Niño events.

Hatchling Recaptures within Seasons and Between Seasons (Overwintering): I caught more hatchlings, both initial captures and recaptures, in fall 2006 and 2007 than in either spring. This is probably because most hatchlings emerged in the fall rather than the spring, and because of the placement of drift fences around nesting areas, so that I captured hatchlings as they emerged and moved away from nests. Terrapin hatchlings rarely overwinter in the nest at RBH (Ultsch 2006). In the springs, there may have been fewer hatchlings due to overwintering mortality, and/or they may have dispersed from the areas of the drift fences.

Based on capture rates per season (i.e., multiple recaptures in the fall or first capture in the spring) and recapture locations which indicate directional movement, this study provides

good evidence that a substantial fraction of terrapin hatchlings overwinter terrestrially. Half of the overwintering hatchlings stayed within the same fence line between fall and spring capture locations, indicating little movement between seasons. Fall recapture rates and recapture locations suggest that hatchlings overwinter further away from the water because their fall movements were moving further upland and spring recapture data was consistent with the last known fall capture location. Spring capture hatchlings that were closer to the water than their fall location may be misleading. Hatchlings could have been moving before I captured them at their spring locations, therefore their spring locations cannot be assumed to be their overwintering locations. No hatchling overwintering location was determined during this study but because half of the hatchlings did not move more than the length of one fence line, it could be assumed that their overwintering locations were close to their fall and spring capture locations. RBH hatchlings moved towards areas with upland vegetation; in contrast Draud et al. (2004) and Roosenburg (as referenced in Costanzo 2008) found that terrapin hatchlings overwintered terrestrially close to the water, either in tidal wrack lines, burrowed underneath sand, or in *Spartina patens* marsh grass. These differences suggest variation in hatchling behavior in different populations based on the availability of appropriate overwintering habitat. For terrapin hatchlings at RBH, upland habitats may be more favorable for overwintering than aquatic habitats or wrack lines, because of the lack of *Spartina patens* and consistent wrack lines. Wrack lines at RBH are often absent during the winter and aquatic habitats may be too osmotically stressful for hatchlings (See salinity tolerance, below). Either location (upland or closer to the water) could be valuable overwintering habitat for terrapins if hatchlings are protected from predators and adverse environmental conditions.

Hatchling Capture by Location: I found the greatest numbers of hatchlings in all four field seasons at the Dunes area of RBH, which had the highest density of terrapin nests at RBH (R.Burke, unpub. data). I captured the most hatchlings of any season at drift fence #1 in fall 2007. This is probably because the drift fence acted as a barrier for gravid females, increasing the number of nests near the fence. This technique could be deliberately exploited to increase the number of hatchlings captured in future studies.

Hatchling capture rates per day per trap were higher at Dunes drift fence #3 in the spring for both years than in the fall. There were no hatchlings captured at Dunes drift fence #3 in fall 2006 and eight in fall 2007. This may have been because more hatchlings moved towards and/or overwintered near drift fence #3, perhaps because the habitat there provided more heavily vegetated habitat than either drift fence #1 and #2.

Hatchling Activity Patterns: I found relatively long periods of hatchling inactivity during the fall, as long as 31 days in fall 2006 and 11 days in fall 2007, which may have been due to severe environmental conditions, i.e., extreme temperatures or moisture, for hatchling movement (Tucker 2000a, Filoramo and Janzen 1999). However, gaps in hatchling activity in the fall may also have been affected by patterns of hatchling emergence from nests. It is still unknown what environmental cues cause hatchlings to emerge, but these may include changes in nest temperature, soil moisture, soil characteristics, or other causes of hatchling stress (Costanzo et al. 2008). More data are needed on temperature and moisture patterns at various soil depths to better understand the relationship between ground temperature and hatchling emergence.

Air Temperature: The weather data I used were collected at nearby JFK airport where temperature sensors were mounted approximately 154cm above the ground. This is not ideal for analyzing hatchlings at ground level but no more relevant data were available. As generalist

ectotherms, I hypothesized that high air temperatures would be associated with high hatchling activity levels, as reflected in high capture rates, in both fall and spring. However, daily air temperature (minimum, average, maximum) had only weak relationships with hatchling capture rates (per trap-day) in fall 2006 or 2007, and no relationship in spring 2007 or 2008. The effects of air temperature may be modified by moisture and sunlight, so single factor analysis may show no relationship. Also, it is not always reasonable to expect a linear relationship between temperature and ectotherm activity, because high temperatures can instead inhibit activity.

Future examination of these relationships should include on-site and more detailed weather data collection. There are no field or laboratory data available on the preferred temperatures of hatchling turtles or on the relationship between temperature (air temperature or substrate temperature) and hatchling activity. I suggest placing temperature loggers at four locations: above nests, in wrack lines, in vegetated areas, and randomly submerged through a highly trafficked hatchling area, to test for relationships between temperature and hatchling activity in a more rigorous way.

Lunar Phase: Low levels of lunar illumination are associated with reduced predation from nocturnal predators in some turtle species (*Chelonia mydas*, Bustard 1967, and *Caretta caretta*, Hays et al. 1992) and apparently aid foraging in others (*Cuora amboinensis*, *Cyclemys dentate*, and *Heosemys spinosa* Jensen and Das 2008). I hypothesized that hatchlings would be more active and I would capture more hatchlings on nights with higher levels of illumination. However I found that lunar phase had no effect on hatchling capture rates. This may suggest that hatchling terrapin movement patterns are neither responsive to nocturnal predators nor use lunar illumination for foraging or navigating. Also, RBH often is well illuminated even without lunar illumination because of light reflected from New York City.

Rain: Rainfall increases moisture and softens soil within turtle nests (Nagle et al. 2004), reduces carbon dioxide and increases oxygen within the nest (Costanzo et al. 2008) and allows hatchlings to minimize desiccation during movement. In general turtle hatchlings are more active during precipitation events (*Chelydra serpentina*, Finkler 1999, Kolbe and Janzen 2002, *Trachemys scripta*, Moll and Lanler 1971, Mitchell 1988, Tucker 1997, 1999, 2000a, *Chrysemys picta*, DePari 1996; *Podocnemis expansa*, Alho and Padua 1982; *Dermatemys mawii*, Polisar 1996). In my study I found hatchlings were less active during rainfall events because I captured the most hatchlings on days with no rainfall. Terrapin hatchlings may have a higher desiccation tolerance compared to other freshwater hatchlings species therefore not relying on rainfall for movement. However, spring hatchlings were captured more often than fall hatchlings on days in which it rained. Spring rain may have stimulated nest emergence after overwintering and hatchlings would be more apt to be captured as rain acts as a cue for nest emergence.

Unlike other Emydidae species, terrapin hatchlings are less active during precipitation events. To understand their response to precipitation and use of microhabitat in greater detail I suggest using a larger sample size and conducting laboratory tests comparing hatchling movement and substrate choice with different precipitation levels and then comparing that to several other Emydidae hatchling species that are known to be active during precipitation. Hatchlings should be placed in identical artificial environmental substrates (wrack, vegetation, soil substrate) and subjected to a set of varying levels of precipitation to identify the relationship between precipitation and hatchling movement per species. The results of these tests may be influenced by each species' typical rates of evaporative water loss.

Moisture Stress via Desiccation: Desiccation can be a major cause of turtle hatchling mortality (Gregory 1982, Finkler 1999, 2001, Janzen et al. 2000a). Hatchlings that overwinter OVN or

OWT may not be able to obtain moisture from the surrounding environment (Costanzo et al. 2001b), and hatchlings may lose mass during migration to water (Janzen et al. 2000b, Tucker 2000a). Some species are highly resistant to evaporative water loss (*Graptemys geographica*, Baker et al. 2003), whereas others are prone to desiccation (*Chelydra serpentina*, Ernst 1968). Costanzo et al. (2001b) suggested that the ability to tolerate desiccation may be an adaptation to terrestrial hibernation.

I found six hatchlings dead in pit fall traps and I suspect these died of desiccation. After these deaths, I placed pieces of dead plant material in the trap to provide a source of shade and shelter.

One way hatchlings might minimize desiccation is to select an appropriate microhabitat that helps conserve water (Finkler et al. 2000). For terrapins this may include microhabitats beneath wrack lines or in vegetated areas. I searched wrack lines when I saw a hatchling's crawl trail, and I found numerous hatchlings resting within the wrack during all four field seasons. Wrack lines can retain moisture during the day and maintain heat during evening, provide food resources, and offer predator protection (Lovich 1991). Vegetated areas can provide shade and predator protection, and leaf litter is probably moister than sand, unlike shoreline habitat that can have higher salinities than upland locations. Temperature and moisture levels in these microhabitats should be measured to better evaluate their potential value to hatchlings.

The desiccation and water loss rates of terrestrial and aquatic turtle hatchlings of different species could be manipulated in laboratory conditions as demonstrated by Finkler (1999), Costanzo et al. (2001b), and Kolbe and Janzen (2002). This would help to understand overwintering conditions hatchlings may be likely to endure. To identify the relationship between hatchling desiccation tolerance and habitat choice per species, hatchlings should be

given identical environmental substrates (source of water, wrack, vegetation, brackish sand substrate, and saline air quality) and be subjected to a set of varying levels of aridity.

Salinity Stress: Hatchling terrapins are generally intolerant of water at ocean-level salinities (32-37 ppt), and can be stressed even under brackish water conditions (3-17 ppt) (Dunson 1985, Dunson and Mazzotti 1989, Peterson and Burke, unpub. data). Dunson (1986) suggested that terrapin hatchlings mature as their salinity tolerance increases. This may cause hatchlings to limit exposure to water until salinity tolerance develops. Fall hatchlings moving away from the water may have been seeking overwintering locations further away from a saline environment, i.e., salty substrates and saline air conditions. Further studies of ontogenetic change in salt tolerance would help clarify the importance of salt avoidance to young terrapins.

Hatchling Movement per Season: Hatchlings from each season showed the same overall movement pattern: in the fall, substantial numbers of hatchlings (55-64%) moved away from the shoreline, while in spring, most (68-80%) moved towards the shoreline. This pattern is in contrast to other aquatic turtles, in which hatchlings proceed to the water immediately after emerging (Anderson 1958, Mittermeier 1978, Ehrenfeld 1979, Moll 1984, Palmer and Cordes 1988, Butler and Graham 1995). It is usually assumed that hatchlings and adults in high latitude populations specifically benefit from overwintering in the water (Butler and Graham 1995, Standing et al. 1997). It is unknown why terrapin hatchlings behave in this unusual way, but I consider several hypotheses below.

Tracking Technique: Tracking hatchlings using florescent powder did not prove to be very useful for detecting hatchling movements due to *i.*) environmental factors, i.e., wind erosion and wave actions distorting sand movement and covered tracks, *ii.*) dense vegetation or damp wrack lines easily wore off the powder *iii.*) powder on the hatchling's shell (specifically its plastron)

eventually wearing off while moving across the sand. It is unknown whether the presence of the powder affected hatchling predation rates. However, I recaptured powdered hatchlings within a season and one hatchling powdered in the fall was recaptured the following spring with small traces of powder still on its carapace. It was unknown, until this study, how long the powder can remain on a hatchlings shell, but this may be dependent on hatchling movement, amount of rainfall, or habitat choice; as all three can easily wear off excess powder.

Terrestrial Refuges: Burger (1976) found that terrapin hatchlings, both in laboratory and field conditions, moved to vegetation as a refuge, and headed towards the closest vegetation, regardless of direction. Burger observed that hatchlings turned around, walked up unvegetated slopes, or walked along slopes to reach vegetation. Vegetation refuges may reduce risks of desiccation and predation. Most of my drift fences were near vegetation except for the first drift fence at each location on the beach. Vegetation refuges may reduce risks of desiccation and predation. I tested hatchling habitat choice in a series of controlled semi-natural experiments not described here and found that hatchlings significantly preferred two types of refuge, wrack and vegetation, as opposed to plastic-covered refuges or no refuge at all (Muldoon, unpub. data). Hatchlings moved quickly and directly towards cover after release. In my similar experiments with released hatchlings in the field, they followed the same pattern, traveling towards vegetation or wrack lines (Muldoon, unpub. data).

Predator Avoidance: The neonate life history stage for turtles is characterized by high egg and hatchling mortality (Wilbur and Morin 1988, but see Pike et al. 2008). Predation is likely to be an important source of neonate mortality in many turtle species. However, far less is known about mortality of hatchlings than egg and nest mortality probably because hatchlings are rarely encountered in the wild in significant numbers. It is difficult to determine the cause of death of

turtle hatchlings found in the field, as many predators leave similar signs, or no signs at all, and one animal may kill a hatchling and another may scavenge it later. Also, predation itself is likely to occur inconspicuously. DNA scatology (Dalen et al. 2004, Gompper et al. 2006, Valentini et al. 2008) will probably be necessary to confirm other predators of diamondback terrapin hatchlings. Of the confirmed terrapin hatchling predators, all but ghost crabs are present at RHB.

Raccoons: Raccoons (*Procyon lotor*) are major predators of terrapin nests at RBH and elsewhere through their range (Mitchell and Klemens 2000). Raccoons are very common at RBH and active year round throughout the terrapin nesting area (Rulison 2009, pers. obs.). Approximately 1000-2000 nests are laid each year at RBH and 93-98% of nests are predated by raccoons annually (Feinberg and Burke 2003, Burke unpub. data). Raccoons also predate nesting adult terrapins (Seigel 1980, Feinberg and Burke 2002). I did not observe raccoons consuming hatchlings at RBH but I frequently observed raccoon tracks close to drift fences, especially in the Dunes. Also, Rulison (2009) found terrapin hatchling remains in the scats of RBH raccoons. One scat indicated that a hatchling was predated on land in July (Rulison 2009).

Rats: Norway rats (*Rattus norvegicus*) are terrestrial predators of hatchling terrapins (Draud et al. 2004). Rats were trapped at the Dunes by Rulison (2010). Draud et al. (2004) found eviscerated terrapin hatchlings and hatchlings with their heads and limbs gnawed off on the north shore of Long Island, 52 km northeast of RBH. Descriptions by Draud et al. (2004) match 17 (40%) of the dead terrapin hatchlings I found. Draud et al. (2004) also found fragments of terrapin egg shells in the stomach of four dissected rats, but Rulison (2009) did not find any terrapin remains in the stomachs of 15 dissected rats from RBH.

Rats are generally nocturnal, and they are less active during full moon nights, presumably because of increased risk of predation by visual predators (O'Farrell 1974, Price et al. 1984,

Álvarez Castañeda et al. 2004). Therefore I hypothesized that if terrapin hatchlings were predated by rats, then they would experience lower predation rates during greater lunar illumination; this prediction was supported by my data. This finding supports my hypothesis that rat predation is an important source of mortality of terrapin hatchlings at RBH.

Ants: There are no indications that any ant species predate terrapin hatchlings. Butler et al. (2004) reported that ants (*Solenopsis invicta* and *Conomyrma* species) feed on terrapin hatchling carcasses, and stated it is likely that ants were scavengers and not the primary predator; but neither ant species occur in New York. I found dead hatchlings in the field covered in ants and suspected ants to be scavengers. Ants may be capable of injuring hatchlings that are confined in a trap.

Avian Predators: Burger (1976) reported that Laughing Gulls and Black-crowned Night Herons predate hatchling terrapins. Red-wing blackbirds (*Agelaius phoeniceus*) and common grackles (*Quiscalus quiscula*) readily attack and kill young turtles (Janzen et al. 2000a). All four species occur at RBH but I never saw any birds close to my drift fences or traps or foraging in areas where I knew hatchlings to be present. However, I observed small bird tracks, species unknown, along drift fences in the Dunes.

Conclusions

I conducted a mark and recapture study of terrapin hatchlings over two consecutive field seasons, in which I attempted to fill in gaps in our knowledge of hatchling terrapin life history. Drift fences proved to be a successful measure for capturing hatchlings but more recent methodologies (pit tagging and scanning) may prove even better for capturing more hatchlings without interrupting hatchling movement. Fluorescent powder did not work well for tracking hatchlings. My research shows that a large fraction of hatchling terrapins move further away from

the water after fall emergence and in the spring move back towards the water. I document that terrapins can overwinter terrestrially outside the nest and survive to remerge in the spring. I suspect more hatchlings did OWT but were not captured. The shells of hatchlings that OWT shrank in size, probably due to desiccation. More hatchlings were captured on days with less rainfall and higher air temperatures. There was no relationship between the number of hatchlings captured and lunar phase but I found fewer dead hatchlings on nights with higher lunar illumination. Future work should include improved hatchling capture and recapture methodology and result in a management plan that identifies and protects terrapin hatchling overwintering habitats.

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Table 1: Description of drift fences at each site. TT had two fence lines in fall 2006 and one fence line for all other seasons. CP had two fence lines in fall 2006 and spring 2007 and one fence line for all other seasons. The B9 fence line was first installed in fall 2007.

Site Name (Location)	Number of Fence Lines	Average Number of Traps in all four Seasons	Length of Longest Fence Line (meters)	Primary Vegetation Cover Species
Goose Trail (GT)	2	34	5.5	<i>Rosa rugosa</i>
Terrapin Trail (TT)	2, 1	126	3.9	<i>Aralia spinosa</i> <i>Rhus sp.</i>
Dunes	3	154	12.8	<i>Parthenocissus quinquefolia</i> , <i>Ammophila breviligulata</i>
Far Side Dunes (FSD)	2	54	5.2	<i>Ammophila breviligulata</i>
Cactus Patch (CP)	2, 1	48	6.1	<i>Opuntia humifusa</i>
Bench 9 (B9)	1	36	13.4	Open Field

Table 2: Dates of fence use, number of fence lines, and number of traps for all four seasons

Season	Dates Fences In Use	Average Number of Days Traps Were Open	Number of Fences	Number of Traps
Fall 06	August 12– October 30	79	11	242
Spring 07	April 23 – June 21	59	10	258
Fall 07	August 5 – November 6	93	11	294
Spring 08	April 19 - June 13	55	10	288

Table 3. Beginning and ending dates of hatchling trapping season and active season for all four seasons

	Trapping Season Begin	Active Season Begin	Active Season End	Trapping Season End
Fall 2006	8/12/2006	8/15/2006	10/22/2006	10/30/2006
Spring 2007	4/23/2007	5/7/2007	6/9/2007	6/21/2007
Fall 2007	8/5/2007	8/9/2007	10/30/2007	11/6/2007
Spring 2008	4/19/2008	4/21/2008	6/10/2008	6/13/2008

Table 4: Number of hatchlings captured and recaptured per week in fall 2006 and fall 2007

Dates	Fall 2006			Fall 2007			Fall 2006 + 2007
	Number Captured/ Week	New Captures	Recaptures	Number Captured/ Week	New Captures	Recaptures	Number Captured/ Week
8/5 – 8/11	0	0	0	5	4	1	5
8/12 -8/18	5	5	0	31	31	0	36
8/19- 8/25	0	0	0	11	7	4	11
8/26 – 9/1	0	0	0	45	44	1	45
9/2- 9/8	0	0	0	18	17	1	18
9/9 – 9/15	11	11	0	18	17	1	29
9/16 – 9/22	14	12	2	5	2	3	19
9/23- 9/29	18	14	4	11	11	0	29
9/30 – 10/6	1	1	0	13	11	2	14
10/7 – 13	5	4	1	28	21	7	33
10/14- 20	2	1	1	12	5	7	14
10/21 – 27	6	5	1	6	1	5	12
10/28 - 11/3	0	0	0	7	5	3	8
11/4 – 10	0	0	0	0	0	0	0

Table 5. Number of hatchlings captured and recaptured per season in spring 2007 and spring 2008

Dates	Spring 2007			Spring 2008			Spring 2007 + Spring 2008
	Number Captured/ Week	New Captures	Recaptures	Number Captured/ Week	New Captures	Recaptures	Number Captured/ Week
4/19 – 4/22	0	0	0	8	5	3	8
4/23 – 4/29	0	0	0	26	16	10	26
4/30 – 5/6	0	0	0	17	15	2	17
5/7 – 5/13	3	3	0	20	11	9	23
5/14 – 5/20	8	6	2	16	12	4	24
5/21 – 5/27	5	4	1	19	9	10	24
5/28 – 6/3	7	5	2	11	3	8	18
6/4 – 6/10	7	5	2	7	5	2	14
6/11 – 6/17	0	0	0	1	0	1	1
6/18 – 6/21	0	0	0	0	0	0	0

Table 6. Total number of all hatchlings captured or recaptured alive in traps

Fence Location	Fall 2006	Spring 2007	Fall 2007	Spring 2008
GT fl 1	17	9	12	5
GT fl 2	0	0	3	2
Dunes fl 1	12	1	110	15
Dunes fl 2	10	5	28	12
Dunes fl 3	0	3	7	26
CP fl 1	0	1	6	0
CP fl 2	7	3	0	0
TT fl 1	2	NA	0	0
TT fl 2	1	1	1	1
FSD fl 1	0	NA	17	7
FSD fl 2	0	NA	1	6
Bench 9	NA	NA	0	25
Total	49	23	185	99

Table 7. Dates of first and last hatchling capture per season

Season	Date First Hatchling Captured	Date Last Hatchling Captured
Fall 2006	8/15/2006	10/22/2006
Spring 2007	5/7/2007	6/9/2007
Fall 2007	8/9/2007	10/30/2007
Spring 2008	4/21/2008	6/10/2008

Table 8. Total number of hatchling recaptures per month in fall 2006 and fall 2007 and the number of hatchlings percent recaptured per month

	Total Number of Recaptures	August	September	October
Fall 2006	8	0	4	4
Fall 2006 % Recap/month		0	0.5	0.5
Fall 2007	59	21	13	25
Fall 2007 % Recap/month		0.36	0.22	0.42

Table 9. Total number of hatchling recaptures per month in spring 2007 and spring 2008 with the number of hatchling percent recapture per month

	Total Number of Recaptures	April	May	June
Spring 2007	3	0	3	0
2007 percent Recap/month		0	1	0
Spring 2008	19	2	14	3
2008 percent Recap/month		0.11	0.74	0.16

Table 10. The number of hatchlings captured in pitfall traps and the average number of hatchlings captured per day during each trapping season

	Fall 06	Spring 07	Fall 07	Spring 08
Days	79	59	93	55
Hatchlings	49	23	185	99
Average Number Hatchling Captured per Day	0.62	0.39	1.99	1.8

Table 11. Fall 2006 total average number of hatchlings captured per day in each trap per fence line location and average number of hatchlings found on the landside and the waterside of the drift fence at each fence line location during the trapping season

Fence Line Location	Number Traps/Line	Number Days Open	Number Hatchlings Found	Number Hatchlings Found on Waterside	Number Hatchlings Found on Landside	x per line, includes both waterside + landside
GT fl 1	12	78	17	8	9	0.0182
GT fl 2	5	78	0	0	0	0.0000
Dunes fl 1	24	79	12	3	9	0.0063
Dunes fl 2	17	79	10	8	2	0.0074
Dunes fl 3	16	77	0	0	0	0.0000
CP fl 1	9	78	0	0	0	0.0000
CP fl 2	12	78	7	5	2	0.0075
TT fl 1	5	78	2	0	2	0.0051
TT fl 2	6	78	1	1	0	0.0021
FSD fl 1	7	77	0	0	0	0.0000
FSD fl 2	8	78	0	0	0	0.0000

Table 12. Spring 2007 total average number of hatchlings captured per day in each trap per fence line location and average number of hatchlings found on the landside and the waterside of the drift fence at each fence line location during the trapping season

Fence Line Location	Number Traps/Line	Number Days Open	Number Hatchlings Found	Number Hatchlings Found on Waterside	Number Hatchlings Found on Landside	x per line, Includes Both Waterside + Landside
GT fl 1	10	59	9	2	7	0.015
GT fl 2	5	59	0	0	0	0.000
Dunes fl 1	24	28	1	0	1	0.001
Dunes fl 2	17	58	5	0	5	0.005
Dunes fl 3	16	47	3	1	2	0.004
CP fl 1	15	49	1	0	1	0.001
CP fl 2	9	49	3	1	2	0.007
TT fl 2	6	47	1	0	1	0.004

Table 13. Fall 2007 total average number of hatchlings captured per day in each trap per fence line location and average number of hatchlings found on the landside and the waterside of the drift fence at each fence line location during the trapping season. Terrapin Trail (TT) fence line number 1 (fl 1) was not installed this season.

Fence Line Location	Number Traps/Line	Number Days Open	Number Hatchlings Found	Number Hatchlings Found on Waterside	Number Hatchlings Found on Landside	x per line, Includes Both Waterside + Landside
GT fl 1	10	93	12	4	8	0.013
GT fl 2	5	93	3	3	0	0.006
Dunes fl 1	24	93	110	61	49	0.049
Dunes fl 2	17	93	28	12	16	0.018
Dunes fl 3	19	93	7	1	6	0.004
CP fl 1	15	92	6	6	0	0.004
CP fl 2	9	92	0	0	0	0.000
TT fl 2	6	92	1	1	0	0.002
FSD fl 1	13	80	17	11	6	0.016
FSD fl 2	14	80	1	1	0	0.001
B9	18	69	0	0	0	0.000

Table 14. Spring 2008 total average number of hatchlings captured per day in each trap per fence line location and average number of hatchlings found on the landside and the waterside of the drift fence at each fence line location during the trapping season. Cactus Patch (CP) fence line number 1 (fl1) and Terrapin Trail (TT) fence line number 1 (fl 1) were not installed this season, N.A.

Fence Line Location	Number Traps/Line	Number Days Open	Number Hatchlings Found	Number Hatchlings Found on Waterside	Number Hatchlings Found on Landside	x per line, Includes Both Waterside + Landside
GT fl 1	11	51	5	1	4	0.009
GT fl 2	5	55	2	0	2	0.007
Dunes fl 1	32	51	15	2	13	0.009
Dunes fl 2	17	49	12	1	11	0.014
Dunes fl 3	20	55	26	10	16	0.024
CP fl 2	9	50	0	0	0	0.000
TT fl 2	6	50	1	0	1	0.003
FSD fl 1	13	51	7	1	6	0.011
FSD fl 2	13	54	6	1	5	0.009
B9	18	54	25	17	8	0.026

Table 15. The number of hatchlings captured in pitfall traps and the average number of hatchlings captured per day during each active season

	Fall 06	Spring 07	Fall 07	Spring 08
Days	69	34	86	53
Hatchlings	49	23	185	99
Average Number Hatchlings Captured per Day	0.71	0.68	2.15	1.87

Table 16. Hatchling carapace and plastron lengths for all four seasons, live and dead hatchlings combined

	Parameter Status	<i>n</i>	Mean (mm)	SD	SE	Range (mm)
Fall 06	Carapace Length	50	29.6	2.49	0.35	18.6 - 33.0
	Plastron Length	50	26.92	2.58	0.36	17.0 - 31.7
Spring 07	Carapace Length	20	28.43	2.29	0.51	21.4 - 31.9
	Plastron Length	20	24.85	1.52	0.34	22.4 - 28.3
Fall 07	Carapace Length	140	28.71	2.04	0.17	23.0 - 33.4
	Plastron Length	140	26.26	2.48	0.21	10.9 - 29.7
Spring 08	Carapace Length	61	27.75	1.9	0.24	22.5 - 31.4
	Plastron Length	61	23.61	1.69	0.22	19.5 - 27.0

Table 17. Growth of carapace lengths (C.L.) of overwintering hatchlings from first capture to last recapture

Hatchling Number	C.L. First Recap (mm)	First Capture Date	C.L. Last Recap (mm)	Last Recapture Date	Number Days between Capture	Last - First Recap	Amount Grown/Day
69	30.0	8/11/2007	29.5	4/21/2008	254	-0.5	-0.00197
83	31.2	8/23/2007	30.3	4/26/2008	247	-0.9	-0.00364
94	31.2	8/26/2007	30.8	5/21/2008	269	-0.4	-0.00149
126	30.0	8/30/2007	30	5/10/2008	254	0	0.00000
174	27.7	10/4/2007	26.7	4/24/2008	203	-1	-0.00493
176	27.6	10/4/2007	27.2	5/4/2008	213	-0.4	-0.00188
180	26.5	10/6/2007	26.2	4/21/2008	198	-0.3	-0.00152
181	25.7	10/6/2007	25.7	4/22/2008	199	0	0.00000
184	29.0	10/7/2007	28.9	5/8/2008	214	-0.1	-0.00047
185	27.6	10/7/2007	28	5/26/2008	232	0.4	0.00172
186	27.0	10/7/2007	27	5/8/2008	214	0	0.00000
199	28.5	10/10/2007	28.5	4/26/2008	199	0	0.00000
212	29.7	10/29/2007	29.4	4/29/2008	183	-0.3	-0.00164

Table 18. Growth of plastron lengths (P.L.) of overwintering hatchlings from first recapture to last recapture

Hatchling Number	P.L. First Recap (mm)	First Capture Date	P.L. Last Recap (mm)	Last Recapture Date	Number Days between Capture	Last - First Recap
83	28	8/23/2007	25.2	4/26/2008	247	-2.8
199	24.6	10/10/2007	23	4/26/2008	199	-1.6
174	24.4	10/4/2007	23.5	4/24/2008	203	-0.9
184	25.7	10/7/2007	25	5/8/2008	214	-0.7
94	28.3	8/26/2007	27.7	5/21/2008	269	-0.6
212	25.5	10/29/2007	25	4/29/2008	183	-0.5
180	22.5	10/6/2007	22.2	4/21/2008	198	-0.3
126	25.9	8/30/2007	25.7	5/10/2008	254	-0.2
176	24.3	10/4/2007	24.1	5/4/2008	213	-0.2
185	25	10/7/2007	24.9	5/26/2008	232	-0.1
181	21.2	10/6/2007	21.4	4/22/2008	199	0.2
186	23.3	10/7/2007	23.5	5/8/2008	214	0.2
69	24.2	8/11/2007	26.3	4/21/2008	254	2.1

Table 19. The five longest durations hatchlings recorded on land within either a fall or spring season

Hatchling ID Number	First Captured Date	Recaptured Date	Number Days Suspected on Land
91	8/26/2007	10/26/2007	61
195	10/8/2007	11/28/2007	51
206	10/20/2007	11/23/2007	34
248	5/8/2008	5/25/2008	17
249	5/8/2008	5/25/2008	17

Table 20. Capture dates for all hatchlings that are suspected to have overwintered on land

Hatchling ID Number	First Captured Date	Recaptured Date	Number Days Suspected on Land
103	8/27/2007	5/29/2008	276
94	8/26/2007	5/21/2008	269
71	8/9/2007	4/21/2008	256
69	8/11/2007	4/21/2008	254
126	8/30/2007	5/10/2008	254
83	8/23/2007	4/26/2008	247
185	10/7/2007	5/26/2008	232
154	9/10/2007	4/24/2008	227
213	10/30/2007	6/2/2008	216
184	10/7/2007	5/8/2008	214
186	10/7/2007	5/8/2008	214
176 D	10/4/2007	5/4/2008	213
45	10/21/2006	5/17/2007	208
174	10/4/2007	4/24/2008	203
199	10/10/2007	4/26/2008	199
181	10/6/2007	4/22/2008	199
180	10/6/2007	4/21/2008	198
212	10/29/2007	4/29/2008	183

Table 21. Fall 2006 and fall 2007 data combined, showing the total average number of hatchlings captured during rainfall events

Amount of Rainfall (mm)	Number of Hatchlings Captured	Number of Days with Amount of Rainfall
0	249	116
0.01-0.51	9	14
0.52-1.0	2	7
1.1-1.59	2	6
1.6-2.0	0	2
2.1-2.5	0	2
2.6-3.0	0	2
3.1-5.0	6	4
5.1-7.0	5	2
7.1-13.0	6	4
20.0-90.0	5	5

Table 22. Spring 2007 and spring 2008 data combined, showing the total average number of hatchlings captured during rainfall events

Amount of Rainfall (mm)	Number of Hatchlings Captured	Number of Days with Amount of Rainfall
0	97	75
0.1-0.5	17	3
0.51-1.0	21	4
1.1-1.5	0	4
1.6-2.0	8	3
2.1-2.5	0	2
2.6-3.0	6	3
3.1-5.0	0	4
5.1-7.0	0	3
7.1-9.0	0	1
9.1-13.0	6	4
13.1-15.0	0	0
15.1-17.0	0	1
17.1-19.0	0	0
19.1-21.0	0	2
21.1-23.0	0	0
23.1-25.0	0	2
25.1-44.96	0	3

Table 23. Fall 2007: total number of dead hatchlings found, location, and post-mortem condition

Fall 2007	Field Site	Number Hatchlings Found Dead	Found in Trap	Found in Sand or Wrack	Missing Head	Missing Limb	Flat	Ants or Spider	Eviscerated	Blood
8/15	GT	6	X							
8/16	D	4	X							
8/16	CP	3			X	X		X	X	X
8/25	D	1	X							
8/30	GT	1		X	X	X				
9/1	D	1	X		X	X	X			
9/2	D	1	X				X			
9/5	D	1	X					X		
9/6	GT	2		X	X		X		X	
9/7	D	1		X			X		X	
9/9	FSD	6		X					X	

Table 24. Fall 2006: total number of dead hatchlings found, location, and post-mortem condition

Fall 2006	Field Site	Number Hatchlings Found Dead	Found in trap	Found in Sand/Wrack	Bloated
8/15	GT	1		X	X
8/16	GT	2	X		X
9/13	D	3		X	X

Table 25: Spring 2007: Total number of dead hatchlings found, location and post-mortem condition

Spring 2007	Field Site	Number Hatchlings Found Dead	Found in trap	Found in Sand/Wrack	Missing Head	Missing Limb	Blood
5/23	GT	1	X				
5/28	GT	1		X	X	X	X
5/29	GT	1	x				
5/31	D	1	X		X	X	
6/8	D	1	X				

Table 26: Spring 2008, Total number of dead hatchlings found, location, and post-mortem condition

Spring 2008	Number of Hatchlings Found Dead	Field Site	Found in Trap	Missing Head	Ants Present
4/23	1	FSD	X		
5/18	1	D	X		X
5/25	1	D	X	X	
5/28	1	B9	X		

Table 27. Fall 2007, total number of hatchlings found compared to the percent lunar illumination

Fall 2007	Number Hatchlings Found	Predation Event: Number Dead Hatchlings Found	Percent Illumination
8/15	13	6	7
8/16	16	7	13
8/25	4	1	90
8/30	6	1	93
9/1	2	1	77
9/2	7	1	66
9/5	2	1	33
9/6	3	2	23
9/7	4	1	15
9/8	1	0	8
9/9	9	6	3

Table 28: Published reports of hatchling terrapins studies and methods of capturing

Years Work was Conducted	Number Hatchling Terrapins Captured	Method of Capture	Source
1974	157	Nest discovered by emergence hatchlings from marked nests	Burger 1976
1973-1974	207	Nest discovered by emergence hatchlings from marked nests	Burger 1977
2002	565	Hand capture, ringed nests, drift fence, nests discovered by emerging hatchling	Roosenburg et al. 2003
2003	565	Hand capture, ringed nest, anti-predator cages, drift fence	Roosenburg and Allman 2003
2003	387	Hand capture, ringed nests, anti-predator cages, nests discovered by emerging hatchlings	Roosenburg et al. 2004
2003	21	Hand capture	Draud et al. 2004
2004	1,337	Hand capture, ringed nests, nests discovered by emerging hatchlings	Roosenburg et al. 2005
2004	1306	Emerged from ringed nests	Scholz 2007
2005	1,526	Hand capture, ringed nests, anti-predator cages, nests discovered by emerging hatchlings	Roosenburg and Sullivan 2006
2005	1086	Emerged from ringed nests	Scholz 2007
2006	855	Hand capture, ringed nests, anti-predator cages, nests discovered by emerging hatchlings	Roosenburg et. al. 2007
2007	1,616	Hand capture, anti-predator cages, nests discovered by emerging hatchlings	Roosenburg et. al. 2009
2008	116	Hand capture	King 2007

Figure 1: Arrow points to a hatchling terrapin seeking refuge under vegetation



Figure 2. Study site: Jamaica Bay Wildlife Refuge, showing study areas, fence lines, and number of hatchlings captured per field location. Blue lines and red lines indicate drift fence and trap locations.

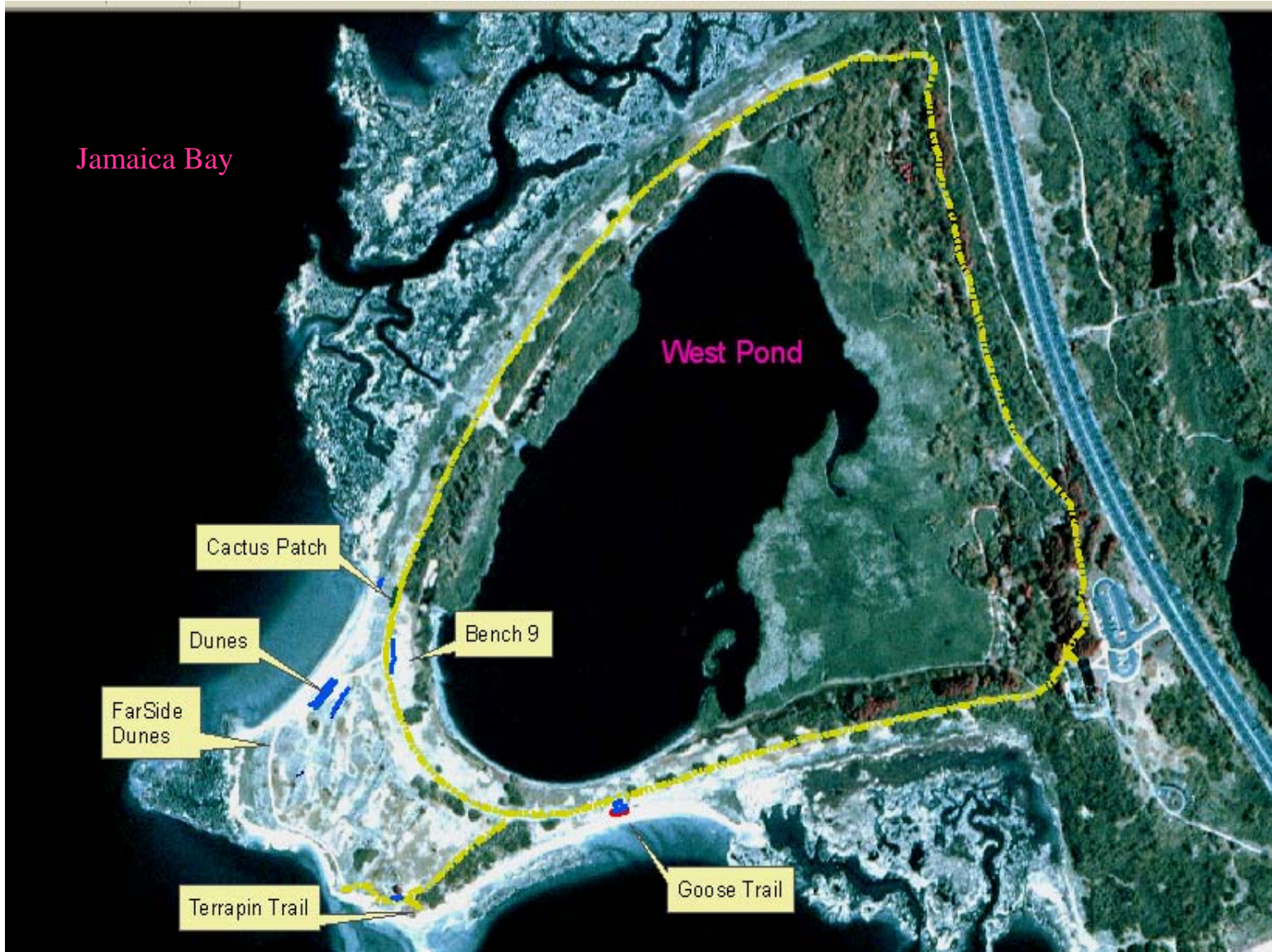


Figure 3: Red arrows indicate drift fence setup. Field location (Dunes) shows habitat type, wrack line, and water line



Figure 4: Three hatchlings terrapins captured together in a horizontal style trap with the drift fence showing in the background



Figure 5. Track plate showing raccoon track and a fence line with two traps



Figure 6. Hatchling with fluorescent powder moving towards shelter



Figure 7. Hatchling movement directionality per season

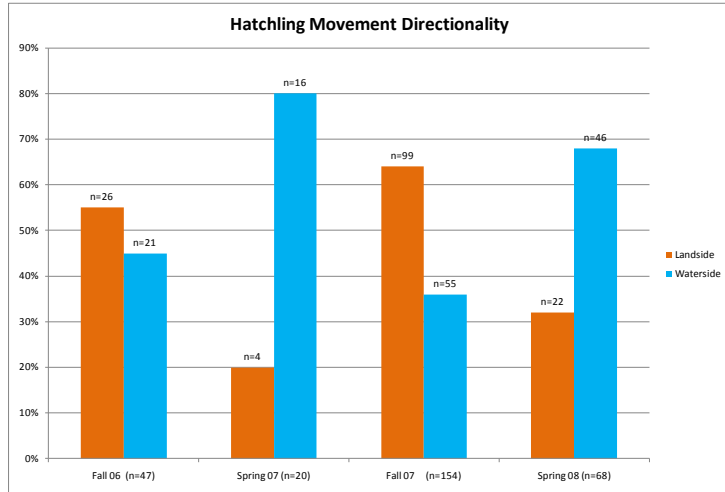


Figure 8. Examples of predated hatchlings a) missing limbs, b) eviscerated, c) flat

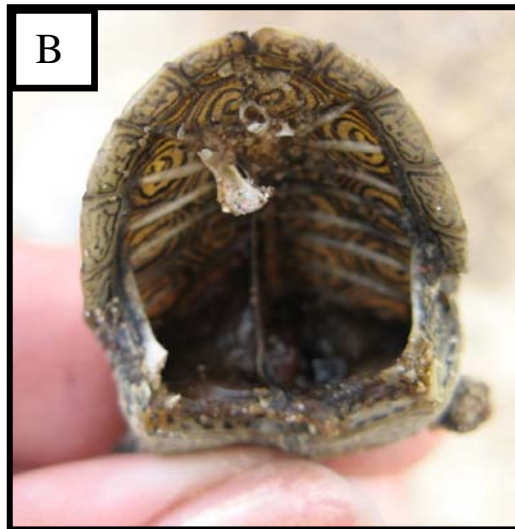


Figure 9. Raccoon tracks on both sides of a drift fence

