ROAD ECOLOGY OF THE NORTHERN DIAMONDBACK TERRAPIN

(MALACLEMYS TERRAPIN TERRAPIN)

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Chapter 1: Introduction

Description

Diamondback terrapins are long lived, small to medium sized turtles, and part of the Emyidae (map turtle) family, which also includes cooters, sliders, and painted turtles (Mara, 1996). Most turtles in the Emyidae family occupy freshwater environments, but some are capable of surviving in estuarine type environments for a few days at a time. However, the diamondback terrapin is the only species in this family, and in North America, that exclusively lives in coastal saltwater habitats (Lovich and Gibbons, 1990). Terrapins adapt to high salinities living in seawater up to 31.8 ppt (Dunson, 1970) with the assistance of orbital salt glands that secrete excess salt from their blood (Cook, 1989). Eventually they require a source of freshwater to avoid dehydration (Davenport, 1992). Terrapins are rarely found in full strength ocean water, above 32 ppt (Cook, 1989), whereas sea turtles are generally restricted to marine waters.

In FASC: Seven subspecies of diamondback terrapin exist along the Eastern Atlantic Coast of the United States from Massachusetts to Texas (Carr, 1952). The northern diamondback terrapin, Malaclemys terrapin terrapin, is the most northern ranging species, and can be found from Cape Cod to North Carolina. Other subspecies include...
*M. t. centrata* (Carolina Diamondback Terrapin), *M. t. tequesta* (Eastern Florida Terrapin), *M. t. rhizophorarum* (Mangrove Diamondback Terrapin, Florida Keys), *M. t. macrospilota* (Oriental Diamondback Terrapin, West coast Florida), *M. t. pileata* (Mississippi Diamondback Terrapin), and *M. t. liddoralis* (Texas Diamondback Terrapin) (Ernst et al., 1994).

Northern diamondback terrapins have a carapace, which is black to light brown in color, some with well-defined darker concentric rings, and a yellowish to a greenish gray plastron (Ernst et al., 1994). The vertebral keel of the carapace does not have knobs and the sides deviate posteriorly. The skin of these terrapins is typically light gray to blackish in color and can have dark small speckles, spots, or even stripes. The jaws are generally light in color, but some may have a darker upper jaw resembling a “mustache” (Ernst et al., 1994).

Northern diamondback terrapins also display sexual dimorphism (Gibbons and Lovich, 1990). The female tends to be much larger than the male in length and head size. The adult female can grow up to approximately 9 inches and can range from 150 mm - 230 mm in carapace length, while the male grows up to half that size, about 5.5 inches and from 100 mm - 140 mm (Ernst et al., 1994). The female’s head tends to be much larger and wider than the male’s head, almost double in size, while the female’s tail is much shorter than the male’s (Ernst et al., 1994). Female and male terrapins may differ in mass as well. Lovich and Gibbons (1990) report a 2.91 female to male mass ratio in their study population with a mean mass of 705 g to 242 g respectively.
Habitat Use and Annual Pattern of Activity

Diamondback terrapins reside in the brackish waters of estuaries, salt marshes, tidal flats, and bays along the East Coast (Burger and Montevecchi, 1975) and utilize these wetland areas for feeding, basking, reproducing, and hibernating (Mara, 1996). The salinities in these areas can vary dramatically. In the study area, Barnegat Bay - Little Egg Harbor New Jersey, the estuary can range from 8 ppt - 32 ppt (Kennish, 2001), but terrapins are found mostly living in salinities from 11.3 ppt - 31.8 ppt (Dunson, 1970).

There is an annual pattern of activity exhibited by terrapins. In the spring, terrapins will emerge from hibernation, begin to feed, and mate (Cook, 1989). Courting and mating occurs in the water of the marsh creeks and lasts about three minutes including the approach and copulation period (Seigel, 1980b). Early summer brings about nesting activity and can extend well into the late summer. Female terrapins will leave the water and make their way to appropriate nesting sites on dry land (Roostenburg, 1991). After nesting, some females, both adults and juveniles, may be found feeding in the deeper waters of the salt marsh creeks (Hurd et al., 1979; Roostenburg, 1991).

Emergence of the hatchlings will occur in the late summer to early fall (Cook, 1989), typically after 61 - 104 days with a mean emergence of 76.2 days for all eggs nested in New Jersey (Burger, 1977). Some hatchlings will even overwinter in the nest and emerge the following spring (Lzell and Auger, 1981). As a result of decreasing temperatures during the fall and winter, terrapins of all stages will stop feeding and then use the mud and vegetation of the tidal creeks in the salt marshes to hibernate (Hurd et al., 1979). Juveniles and hatchlings may also stay within this vegetation for cover during other times
of the year (Lovich et al., 1991). Commonly groups of adult terrapins congregate and hibernate on the bottom of the creeks until spring (Draud, pers. comm.).

**Reproduction and Nesting**

Terrapins, like other turtles, grow and mature at a slow rate. Females generally reach sexual maturity when they are between 13.2 cm and 17.6 cm, approximately in their sixth year, and males generally mature at about 9 cm, and 3 - 4 years of age (Lovich and Gibbons, 1990). Roosenburg (1991) reports that females may take even longer to mature, ranging from 8 - 13 years. In New Jersey, it has documented the typical size for an egg laying female ranges from 13.2 cm to 18.4 cm in plastron length (Montevecchi and Burger, 1975).

Nesting times during the year can vary slightly among the subspecies with the farther southern species beginning nesting earlier than the northern species. Northern diamondbacks in New Jersey (Burger and Montevecchi, 1975; Burger, 1977) and Maryland (Roosenburg, 1991) have been observed nesting in June and July, over a 34 - 44 day period according to Burger (1977). However, in New York, Feinberg and Burke (2003) reported nesting for 51 and 57 days. Southern terrapins, in South Carolina (Zimmerman, 1992) and Florida (Seigel, 1980), can be found nesting from April to September and April to July for a period of 60 days and 52 - 57 days respectively. Butler (2000) even observed a nesting period of 78 days in Florida.
**Clutch Size and Number**

Female terrapins have a low reproductive rate (Roosenburg, 1991) and lay one to a few clutches per season, with the number of eggs produced per clutch varying among the subspecies. The northern subspecies terrapin may lay up to three clutches per season (Roosenburg, 1991), with an inter-nesting interval of approximately 17 - 19 days (Draud, pers. comm.). This was seen by Feinberg and Burke (2003) who observed some terrapins in New York laying two clutches per season, with a mean of 17.5 days between nesting. In Massachusetts, Auger and Giovannone (1979) also found terrapins laying at least two clutches of eggs.

Clutch size can also vary between the subspecies. At a maximum, the northern subspecies may lay up to 39 eggs per year (Roosenburg, 1991). Feinberg and Burke (2003) observed a mean clutch size of 10.9 eggs, with a range of 3 – 18 eggs/clutch in New York (2003). In New Jersey, Montevecchi and Burger (1975) found the mean clutch size to be 9.76 eggs, with a range of 4 - 18 eggs/clutch. In Maryland, Roosenburg (1991) noted a mean size of 13 eggs with a range of 7 – 22 eggs/clutch. Southern subspecies may lay more clutches, but with fewer eggs. Seigel (1980) observed *M. t. tequesta* on the east coast of Florida laying mean clutch sizes of 6.7 eggs, with a range of 5 - 10 eggs/clutch, and up to three clutches per year.

Terrapins may nest during all times of day. However, the evidence of this varies. It was once generally thought that terrapins only nest in the daytime, between dawn and dusk, as reported by Burger and Montevecchi (1975) in New Jersey and Cook (1989). However, Feinberg and Burke (2003) found terrapins nesting as early as 0930 h and as
late as 2115 h. Wood and Herlands (1997) in New Jersey and Roosenburg (1994) in Maryland found terrapins nesting at both day and night time.

**Nesting Habitat, Site Selection, and Environmental Conditions**

Terrapins and other turtles are oviparous reptiles and must lay their eggs on, or in, dry substrate (Roosenburg, 1991). Regions chosen by terrapins as nest sites often consist of higher elevated dunes with sandy or loose soils and very little vegetation; conditions are often consistent with sand dunes and some protected beaches (Burger and Montevicchi, 1975). The area should be high enough to minimize lengthy water exposure and flooding of the nest (Roosenburg, 1994), and may be related to the height of the tides. Butler *et al.* (2004) observed *M. t. centrata*, the Carolina and northeastern Florida subspecies, nested at or well above the high tide lines, also in areas with little vegetation. Roosenburg (1994) noted that along the Patuxent river system in Maryland, where true sand dunes do not form, terrapins nested in narrow sandy strips of beach along the open-water and the mainland with successful nests above the intertidal zone.

Terrapin nesting seems to be temperature dependent and occurs when certain environmental conditions are favorable. Terrapins prefer to nest on sunny to partly sunny days as opposed to cloudy or rainy days in New Jersey (Burger and Montevicchi, 1975), Florida (Seigel, 1980), and New York (Feinberg and Burke, 2003). Terrapins may reject nest sites that are too shady (Roosenburg, 1994), or too wet (Burger, 1977). Feinberg and Burke (2003) found significant correlations between the number of terrapins observed and the increasing tide in the Gateway National Recreation area in New York.
This was also observed by Burger and Montevecchi (1975) with terrapins nesting at Little Beach Island, in Brigantine, New Jersey, and may be used to minimize travel on land.

**Nest Site Fidelity and General Movement**

Female adult terrapins demonstrate nest site fidelity and often return to the same nest site each time they lay a new clutch (Roosenburg, 1991). Earlier studies illustrated this when terrapins returned to nest in the same dune area, year after year in Little Beach, New Jersey (Burger, 1977). They may return to the same location in successive years or even multiple times within one season (Roosenburg, 1994). Females may not move very far when they exit the creeks in search of nesting sites. Feinberg and Burke’s (2003) initial work found that the maximum distance terrapins were found from creeks was approximately 250 m. General movement of terrapins may also be low, indicating they may exhibit high home range site fidelity. Lovich and Gibbons (1990) recaptured both males and females within a few meters of their initial capture year after year, for up to a three year period. Similar results were also seen by Gibbons *et al.* (2001) during a 16 year study of a South Carolina terrapin population.

**Road Ecology**

Road Ecology can be defined as the interaction of organisms and the environment linked to roads and vehicles (Forman *et al.*, 2003). This science focuses on the relationships between natural ecosystems and road systems (Forman *et al.*, 2003), which can affect many different habitats, including terrestrial and aquatic environments, and the organisms that reside along them and in surrounding areas. Some of the consequences of roads
include; habitat fragmentation, population divisions, suppressed reproduction, increased air and water pollution, and increased vehicle related mortality, most of which are poorly documented (Angermeier et al., 2004). Roads are known to contribute to the endangerment of at least 94 species in the United States (Czech et al., 2000), and their ecological effects can extend 100 m - 1000 m from the roadways (Forman and Deblinger, 2000). The roads encountered by animals may be dirt, gravel, or paved, and the traffic patterns may be light to intense. However, none of these situations exclude organisms from being involved with vehicle collisions. Oxley et al. (1974) found that there were no differences between gravel and paved roads with respect to road mortality, because road type did not have an effect on the traffic speed, traffic volume, or animals decision whether or not to cross. However, traffic volume and speed may correlate with the amount of road mortality. Early studies conducted in 1939 by Dickerson found that vehicles traveling 40 mph or greater had a greater effect on songbirds and rabbits then cars that traveled slower (Dickerson, 1939). Oxley et al. (1974) also found that small mammals (less than 700 g) were killed when traffic volume was at its highest.

Victims of road mortality are from a wide range of organisms, including insects (Manguira and Thomas, 1992), mammals (Drews, 1995; Groot Bruinderink and Hazebroek, 1996), birds (Reijen and Foppen, 1994), amphibians (Fahrig et al., 1995; Ashley and Robinson, 1996; Hels and Buchwald, 2001), and reptiles (Bernardino Jr. and Dalrymple, 1992; Rosen and Lowe, 1994; Bonnet et al., 1999; Haxton, 2000; Gibbs and Shriver, 2002; Steen and Gibbs, 2004; Aresco, 2005). Animals who encounter roads may be searching for food, water, reproductive sites, or sites for thermoregulation. They can be affected in terms of reproductive success, changes in movement, and physiological
states (Trombulak and Frissell, 2000). In addition, collisions with vehicles often results from these interactions with roads. In some species of snakes, both males and females are killed during the mating and egg-laying season, which provides evidence of road mortalities decreasing reproductive output (Bonnet et al., 1999). Snakes may also undergo a “freezing” or halting response when encountering vehicles, increasing the time spent on the road and the chance of being killed (Andrews, 2003). For some small animals (those with a large biomass of road kill numbers and highly underrepresented because of their size) the impact of road mortality may be an even greater threat than natural diseases and predation (Forman et al., 2003).

Changes in the landscape may affect the number of organisms subjected to road mortality by creating an attractive habitat that draws them to the roadsides. Ashley and Robinson (1996) observed a significant amount of amphibians killed along the roadway in areas near roadside vegetation and for reptiles mostly in areas with nearby open water sites.

**PIT Tagging**

Traditional marking methods for herpetofauna, such as scute notching, toe clipping, or paint marking, may not be as effective when tracking individuals, estimating a population size or following movements, as newer methods that involve internally injected Passive Integrated Transponder (PIT) tags. Scute notching on turtles may be reliable for some time, however over time, the notches wear down, making it impossible to correctly identify individuals (Buhlmann and Tuberville, 1998). Toe clipping, often used for amphibian marking, may not be reliable because toes may grow back (Ott and Scott, 1999). In sea turtles, the traditional method of tagging involves using flipper tags.
However, the success rate of these external tags has been quite variable (Balazs, 1999), probably from general loss, corrosion from salt water, and outgrowing of the tag (when the tag is placed too tightly on the flipper skin area allowing no room for growth). Parmenter (2003) documented a failure rate of 80% when using plastic flipper tags for long term identification of the flatback sea turtle, Natator depressus. The use of internal PIT tags could eliminate many of the issues seen in other forms of marking.

PIT tags are tiny identification chips about the size of a grain of rice which are injected into specimens for permanent identification. Because the tags are surrounded by glass and inserted in the body, there is generally no breakage, corrosion, tearing, or loss of the tag (Balazs, 1999). The chip is passive; therefore it does not need any current but is read by means of a scanner which activates the tag temporarily with a low frequency radio signal. It provides a unique 10 - 15 element alphanumeric code read out (identification number) of the chip implanted in the animal. This eliminates the problem of misidentification among individuals. Even among different tagging manufacturers, no number is duplicated (Balazs, 1999).

Several studies have been conducted on a variety of organisms to assess any adverse effects of PIT tagging. Buhlmann and Tuberville (1998) tagged freshwater turtles and found that the tags did not seem to interfere with growth, as all turtles grew a few millimeters between recaptures. A study conducted by Jemison et al. (1995) found that PIT tags did not interfere with growth rates of yearly pygmy rattlesnakes either.

Infection is also a concern with using PIT tags. Tagged small freshwater turtles recaptured by Buhlmann and Tuberville (1998) had retained all PIT tags with no signs of illness due to tagging. Elbin and Burger (1994) tagged 163 wild pine snakes inhabiting
areas in the New Jersey Pine Barrens, and none of the animals experienced side affects of behavior alteration, infection, or death. Bog turtles have also been tagged and monitored for two years (Brenner *et al.*, 2002) with no signs of infection (Lewbart, pers. comm.).

PIT tagging does not appear to alter the behavior of tagged organisms. In sea turtles, individuals that were tagged continued to return to the same nesting beaches each year indicating their nesting site philopatry behavior was not disturbed (Balazs, 1999). Using the more traditional method of toe clipping in amphibians could alter the rate of movement or speed because of the missing appendage (Camper and Dixon, 1988). However, with PIT tagging that is not an issue. PIT tagging does not seem to alter the rate of movement in reptiles. In pygmy rattlesnakes, no difference was found in distance and rate of movement between tagged and control (non-tagged) individuals (Jemison *et al.*, 1995).

PIT tagged organisms have high tag retention rates, which provides yet another advantage over other tagging methods. In pine snakes, Elbin and Burger (1994) experienced a 100% success rate in tag retention in a two year mark-recapture study. A similar study by Jemison *et al.* (1995) on 29 individual wild pygmy rattlesnakes also had no PIT tag failures, and no differences were found in the recapture rates between control and tagged pygmy rattlesnakes. A blunt-nosed lizard study yielded a 4.1% tag loss from 558 tagged and recaptured individuals; however, these few losses may have occurred due to the aggressive nature of the male lizards engaging in combat (Frost and Etheridge, 1993).

The advantages of PIT tagging over other methods of marking may outweigh any associated costs. This technique allows researchers to keep reliable long-term records over decades that most likely could not be done with traditional tagging methods (Balazs,
1999). It may cause less stress overall to the organisms when being identified than traditional tagging studies, because it can reduce capture and handling time. Some scanners are capable of reading the tag up to a foot away, completely eliminating handling the organism (Biomark Inc. website 2005). PIT tagging may also prove to be a useful technique when studying the road ecology of the diamondback terrapin or other species that interact with road systems. Individual or population movement, frequency of individuals returning to the road, mortality of individuals, and nesting population size along the road are just a few advantages to be gained.

Rationale and Objectives

Northern diamondback terrapin (*Malaclemys terrapin terrapin*) populations along the East Coast have suffered due to a number of factors since the early 1900's. Over exploitation from hunting, drowning in commercial fishing gear and loss of habitat are main contributors to population decline (Roosenburg, 1991). Now, in some areas, the increasing threat of road mortality is leading to further declines in the terrapin population (see Wood and Herlands, 1997). In Massachusetts, the terrapin is threatened, and it is considered endangered in Rhode Island. In other states there is no official listing, or the terrapin is considered a species of special concern, or secure in the state status (Watters, 2004 unpublished review). Since diamondback terrapins are a species of high conservation interest (listed as a “Species of Special Concern” in New Jersey, New Jersey Department of Environmental Protection, Division of Fish and Wildlife, NJ Endangered and Nongame Species Program, website 2005), understanding the impact of road mortality is critical (Forman *et al.*, 2003). While terrapins have been studied in New
Jersey for some time, there is no real notable baseline for the population size. For that reason the degree to which road mortality affects this population may not be known or even considered a problem until it becomes dangerously critical (Aresco, 2005).

**Study Area and Past Research at the Jacques Cousteau National Estuarine Research Reserve**

The Jacques Cousteau National Estuarine Research Reserve (JCNERR) on the coast of New Jersey consists of approximately 110,000 acres of woodlands, wetlands, and aquatic habitats. Within the reserve, the Great Bay Wildlife Management Area peninsula consists of relatively pristine salt marsh wetlands and is the site of Great Bay Boulevard access road. This roadway was built in the 1930’s, but not paved until the 1940’s, and runs the length of the peninsula, through the salt marshes, and between the town of Tuckerton and the Rutgers University Marine Field Station. Five bridges cross over the main subtidal creeks and divide it into six transect sections to sample from (Figure 1, see Szerlag and McRobert, 2006). Telephone poles run parallel to the boulevard and are spaced approximately 54 meters apart. They are consecutively numbered from 18797 (closest to town, Sea Isle Drive) to 18948 (outside the field station). The lengths of each transect section range from 0.8 km - 2.0 km with coarse sand and gravel prevalent along the road in each of the sections. The sediment leading away from the road is made up of fine sand and clay. Organic matter in the sediment is low along the road and increases as one moves away from the road (Hoden and Able, 2003).

Average elevation along the road and distance to the nearest major sub-tidal creek differs within each transect section. Smaller intertidal salt marsh creeks and small and
large ponds exist along all the transect sections. Transect section 6, closest to Tuckerton and between Big Thorofare Creek, has the highest average elevation of 1.89 m and is 0.15 km from the nearest creek. Transect section 5, between Big Thorofare and Little Thorofare Creeks, has an elevation of 1.46 m and is 0.15 km from the nearest creek. Transect section 4, between Little Thorofare Creek and Jimmies Creek, has an elevation of 1.37 m and is 0.16 km from the nearest creek. Transect section 3, between Jimmies Creek and Big Sheepshead Creek, has an elevation of 1.46 m and is 0.1 km from the nearest creek. Transect section 2, between Big Sheepshead and Little Sheepshead Creeks, has an elevation of 1.4 m and is 0.14 km from the nearest creek. Transect section 1, between Little Sheepshead Creek and the Rutgers University Marine Field Station, has an elevation of 1.58 m and is 0.22 km from the nearest creek (see Hoden and Able, 2003).

Plant communities begin approximately 3 ft - 10 ft from the edge of the road, vary slightly, but are generally consistent in all transects sections (see Montgomery and Newcomb, 1975). The dominant plants include *Panicum virgatum* (switch grass) and *Festuca rubra* (red fescue), *Rumex acetosella* (sheep’s sorrel), *Plantago lanceolata* (plantain), *Stachys tenuifolia* (hedge nettle), and other weedy species. Other grasses include *Phragmites australis* (common reed), *Spartina alterniflora* (cordgrass) and *S. patens* (saltmeadow hay). Trees and woody shrubs include *Myrica* (bayberry), *Juniperus* (red cedar), and *Pinus* (pine). *Rhus* (winged sumac and poison ivy), *Iva frutescens* (marsh elder), and *Baccharis halimifolia* (groundsel-tree) are also present on occasion (Montgomery and Newcomb, 1975).
The terrapins at JCNERR have been the focus of past research studies (from 1988 - 2002, see Hoden and Able, 2003). However, there has been little focus on road mortality with regard to traffic patterns along this access road.

The objective of this study was to describe relationships that may exist and to gain a better understanding of the effects of traffic on terrapins by monitoring road occurrence, mortality, traffic patterns, and ecological factors during the 2004 and 2005 nesting seasons. PIT tagging was a secondary objective to monitor roadside habitat use and nesting behaviors (multiple clutching and nest site fidelity) along Great Bay Boulevard.
Literature Cited


Chapter 2: Road Occurrence and Mortality of the Northern Diamondback Terrapin

Abstract

We examined road occurrence and mortality of the northern diamondback terrapin, *Malaclemys terrapin terrapin*, in the Jacques Cousteau National Estuarine Research Reserve during the 2004 nesting season (May - July). Traffic volume estimates were obtained using measuring devices stationed on sections of Great Bay Boulevard, an access road through a salt marsh habitat in Tuckerton, New Jersey. Six hundred adult female terrapin occurrences were recorded, 53 of those being road mortalities (8.83%). A significantly greater proportion of road kills was found in the section of the road with the highest traffic volume. There was also a positive correlation between road kills and increasing traffic volume throughout the day. Approximately half of the road mortalities were discovered in the first survey hour, suggesting that some nesting terrapins were being killed during the night or in the early morning hours. The information gathered suggests that terrapins are attracted to the roadside as it meets the requirements for a suitable nesting habitat.
Introduction

Of all the organisms encountering roads, amphibians and reptiles seem to be affected the most. This may be because they are much slower (Rosen and Lowe, 1994; Ashley and Robinson, 1996; Hels and Buchwald, 2001), may not be aware of the potential danger of automobiles (Ashley and Robinson, 1996), or because their activity throughout the day may coincide with greater traffic loads in certain areas (Rosen and Lowe, 1994; Hels and Buchwald, 2001). Reptiles encounter roads while searching for food, water, breeding or nesting sites (Ashley and Robinson, 1996). Snakes have been shown to use roads for temperature regulation and during migration to water (Bernardino Jr. and Dalrymple, 1992), and roadsides are utilized by turtles for nesting (Wood and Herlands, 1997; Haxton, 2000; Aresco, 2005). Turtles may also encounter roads while simply moving through their environment in search of terrestrial habitat (Buhlmann and Gibbons, 2001) or when emerging from hibernacula (Hoden, pers. comm.).

The effect of road mortality on turtle populations (Haxton, 2000; Gibbs and Shriver, 2002; Steen and Gibbs, 2004; Gibbs and Steen, 2005) is becoming an ever increasing problem and may be associated with factors such as traffic density, nesting behavior, or ecological features surrounding the roadway. Road mortality may contribute to skewed sex ratios in aquatic species as females are lost while nesting (Steen and Gibbs, 2004; Aresco, 2005; Gibbs and Steen, 2005) or act as a major source of local extirpation (Rosen and Lowe, 1994). Road mortalities of adult turtles could lead to rapid population decrease since they are unable to be replaced quickly (see Brooks et al., 1991).

Increased vehicular traffic has increased road mortality of many herpetofauna (Fahrig et al., 1995; Forman et al., 2003), including turtles of terrestrial, semi aquatic and
aquatic species (Gibbs and Shriver, 2002) and may also impact the northern diamondback
terrapin, *Malaclemys terrapin terrapin*. Because terrapins are a "Species of Special
Concern" in New Jersey (New Jersey Department of Environmental Protection, Division
of Fish and Wildlife, NJ Endangered and Non-Game Species Program, website 2005), an
understanding of the impact of road mortality is critical (Forman *et al.*, 2003).

While some studies have documented road kills, few traffic related mortality
studies have been conducted on the terrapin. In southern New Jersey, a study on the
Cape May Peninsula from 1989 - 1995 obtained 4,020 road kills on roadways adjacent to
salt marsh habitat (Wood and Herlands, 1997). Wood and Herlands (1997) suggested
that increased weekend traffic did not correlate with daily changes in mortality, however
it is unclear as to how traffic and road kills were analyzed or if increased monthly or
daily traffic affected mortality as well. Previous studies at the Jacques Cousteau National
Estuarine Research Reserve (JCNERR) reported that between 1999 and 2002, 71% of the
634 terrapins recovered on Great Bay Boulevard died because of automobile traffic
(Hoden and Able, 2003). Approximately half of the adult females observed were victims
of road mortality (N total = 208; N dead = 98). In that study however, transect surveys
were only made once in the morning and afternoon and no estimates of traffic activity
were made.

Accordingly, this more detailed and rigorous study was performed to acquire
accurate estimates of traffic volume, road occurrence of terrapins, and road mortality
rates. The objective of this study was to describe relationships that exist between the
road mortality of the northern diamondback terrapin and the traffic they encounter on
Great Bay Boulevard in Tuckerton, New Jersey.
Materials and Methods

Study area

We conducted field work near the Rutgers University Marine Field Station in the Jacques Cousteau National Estuarine Research Reserve in Tuckerton, New Jersey. Within the reserve, the Great Bay Wildlife Management Area is a 2,168 hectare peninsula consisting of relatively pristine salt marsh wetlands. Great Bay Boulevard, an access road, is a two-way, 8.1 km paved road that runs through the salt marshes of the management area between the town of Tuckerton and the field station. Five bridges along the road cross over the subtidal creeks that flow through the salt marshes and divide the road into six transect sections (Figure 1). The lengths of each transect section range from 0.8 km - 2.0 km with coarse sand and gravel prevalent along the side of the road in each of the sections.

Overall Data Collection

We conducted surveys of Great Bay Boulevard during the terrapin nesting season from 25 May – 31 July 2004. Eight to ten surveys were completed each day, approximately five to six days per week for a total of 299 samples. Sampling by car or bike began when terrapins were first sited in May, and lasted until two weeks after the last terrapin was seen in July. Surveys were conducted consistently from 0800 h - 1600 h, with one beginning at 0745 h and some ending after 1700 h. A total of 12 random night transects were made during 5 nights of the season from 2100 h - 0100 h, generally 2 - 4 surveys on each occasion. Volunteers also reported terrapins on or along the roadside while surveying by car during the day. Typically there was one volunteer working per day of
sampling. Survey data included; date, time of day a terrapin was sited, location of terrapin(s) (transect section and telephone pole number), and the condition of the individual (alive or dead).

For each terrapin we measured and recorded sex, stage of development (hatchling, juvenile, or adult), and size; midline carapace length (CL) and plastron length (PL) were measured using a digital 300 mm caliper (Fowler Company, Model # S54-100-112), and were double-checked by eye using the manual metric ruler on the caliper. The sex of adults was determined by the overall length of the individual, head size, and tail characteristics (size of the tail and location of the cloaca differ between males and females). Stage of development was determined based on the midline carapace length. Adult females were considered to range from 150 mm - 230 mm and males from 100 mm - 140 mm (Ernst et al., 1994), juveniles (not sexed) ≥ 35 mm to ≤100 mm, and hatchlings (not sexed) < 35 mm carapace length (Hoden and Able, 2003). During this survey only adult females and one juvenile were observed.

After measurements were taken, living terrapins were released at the side of the road, and positioned in the direction they appeared to be heading prior to collection. We moved terrapin carcasses several meters off the road in the marsh to prevent duplicate counting.

*Measuring Traffic*

We used traffic volume measuring devices (TRAX I Plus Counter/Classifiers provided by JAMAR Technologies Inc. of Horsham, PA) to attain highly accurate estimates of traffic flow. These devices allowed traffic to be monitored 24 hours a day, 7 days a week. The
devices were stationed in the middle of each of the four transect sections of Great Bay Boulevard. At the start of the study, all 6 sections had traffic counters, but due to vandalism and theft (in sections 3 and 4), only sections 1, 2, 5, and 6 had traffic devices running the entire season. We downloaded traffic data weekly using a laptop computer. The average volume of sections 2 and 5 were added and then divided by two to estimate the volumes for sections 3 and 4. Given that Great Bay Boulevard dead ends in transect 1, and no traffic can enter the system except at section 6, the estimated volumes for sections 3 and 4 were probably comparable to their actual volumes because they had to be less than section 5 and greater than section 2.

Data Analysis

The proportion of road mortality between transect sections was tested using Pearson chi-square analysis with an alpha level of 0.05, assuming equal survival status for all sections of the road. Monthly proportions of mortality were also tested in the same manner. Spearman’s rank order correlation with one tailed probability, and $P = 0.05$ was used to test the relationship between road mortality rates and hourly mean traffic volume during the survey hours of 0901 h – 1600 h because more consistent sampling was performed during these times. Mortalities by transect section between these hours were pooled ($N = 29$) because of few numbers within sections, and compared with the traffic pattern entering the Great Bay Boulevard road system. Although not all mortalities occurred in section 6, values from this section were used for comparison because traffic patterns were relatively similar across all sections.
Results

Road Occurrence

We observed 600 adult female terrapins (mean = 175 ± 1 mm (CL), mean = 158 ± 1 mm (PL)) on the road during the nesting season with three distinct peaks of nesting activity on or near the full and new moons (Figure 2). In all six transect sections, live and dead terrapins were found during most hours of our sampling (Table 1). In the first survey hour 0801 h - 0900 h, approximately half of the road mortalities were discovered and a smaller second peak was noted between 1001 h – 1100 h. All other road mortalities were scattered throughout the day with a few found during night sampling (Table 2).

The effects of traffic volume on road mortality

We observed 53 adult female terrapin road mortalities on Great Bay Boulevard (8.83%). In transect section 6, a significantly greater percentage of mortalities by proportion was found compared to the other transects ($P < 0.001, \chi^2 = 22.44, df = 1$) as well as the greatest mean volume of vehicles/day (Table 1). There was a decrease in traffic volume from section 6 to the end of the roadway in section 1. Many vehicles that entered Great Bay Boulevard (at transect 6), did not travel all the way to the end (transect 1), but turned around at different points on the road and returned to town. This accounted for a greater volume of traffic in transect 6. During our sampling period from 0901 h - 1600 h, road mortality rates correlated positively with increasing traffic volume ($P = 0.026$, Spearman’s correlation coefficient = 0.750). Comparing results from the different months during the survey, the proportion of road mortalities was not significantly
different \( (P = 0.896, x^2 = 0.219, \text{df} = 2) \) and the amount of traffic entering the system was relatively similar (mean = 826, 892, 987 vehicles/day by month, respectively).

**Discussion**

**Terrapin nesting**

During the 2004 nesting season, three peaks of terrapin occurrences were observed on Great Bay Boulevard, on or around the full and new moons when the tides were highest. By nesting during the spring tides, female terrapins may decrease the walking distance to the nesting locations (Burger and Montevecchi, 1975). Females were known to utilize roadside areas for nesting because newly made nests, abandoned nests, and eggs that were preyed upon were observed. Many eggs were also found on the road near the killed terrapins.

It is generally thought that terrapins prefer higher elevations, usually above the high tide line, with sandier soils and little vegetation, as nesting sites (Burger and Montevecchi, 1975; Butler *et al.*, 2004). Consequently, the sides of access roads, such as Great Bay Boulevard, which run through coastal wetlands, provide conditions that are suitable as nesting sites. A lack of sand dunes or isolated sandy beaches, as in our study area and other developed coastal communities, may encourage terrapins to nest along the edges of roads. Furthermore, loss of habitat due to human disturbance and activities such as bulk heading and development, may force terrapins to nest in alternative sites like roads (Roosenburg, 1994). In fact, some terrapins may even prefer roads. Seigel (1980) observed terrapins nesting only on dike roads even though sand dunes and other possible
sites were available. Other species of turtles such as the snapping turtle also utilize roadsides during the nesting season (Haxton, 2000).

**Mortalities and Traffic**

Certain reptiles may be more vulnerable to traffic during specific times of the day depending on they way they utilize the road. For example, some species of snake are more active at night (Rosen and Lowe, 1994) and may be utilizing road heat to help regulate their body temperature. Some turtles lay their eggs at night (S. McRobert, pers. obs.) and may cross roads looking for nest sites. These types of behaviors around roads would undoubtedly increase the chances of road mortality. For terrapins, we found approximately half of the mortalities were discovered during the first survey hour. These deaths may have occurred either in the late hours of the previous evening or in the early daylight hours when traffic was beginning to increase. Wood and Herlands (1997) observed night nesting for *M. t. terrapin* and found nearly half of the mortalities noted in their study between 2130 h – 0500 h. However, Burger and Montevecchi (1975) did not observe terrapins nesting before dawn or after sunset in New Jersey, and Seigel (1980) noted nesting only in daylight hours in Florida. In contrast, Roosenburg (1994) encountered nesting terrapins at all times, day and night in a study conducted in Maryland. If nesting primarily takes place in the morning hours, this might account for a good portion of terrapin mortalities found in the first survey hour.

Traffic volume appeared to play a large part in terrapin road mortalities within road sections and throughout the day with increased traffic intensity seeming to contribute to increased mortality rates on Great Bay Boulevard. A significantly greater
proportion of road mortalities was observed in the transect section closest to the town of Tuckerton, which exhibits the highest traffic volume. These findings are similar to past studies demonstrating that there are greater road mortalities of reptiles and amphibians where there is greater traffic volume. Rosen and Lowe (1994) observed greater snake mortality during peak periods of automobile traffic. Bernardino Jr. and Dalrymple (1992) suggested a correlation between the number of vehicles and the number of snakes found dead or mortally injured. In amphibians, particularly frogs and toads, it has been calculated that the probability of being killed increases with greater traffic volume (Fahrig et al., 1995; Hels and Buchwald, 2001).

The correlation between traffic volume and mortality was also noted when comparing road mortality rates throughout the day. Even though there were more terrapins on the road before 1200 h during our sampling, the traffic volume was lower during this time and the rate of mortality was also lower. The traffic volume continued to increase up until 1500 h along with the mortality rate despite the fact that fewer terrapins were on the road.

Simply looking at individual numbers of road kills may conceal the effects of traffic on mortality of local populations. Fewer mortalities seen on the road may give the appearance that there is no real problem. However, if the number of terrapins utilizing an area is relatively small, the outcome may actually be quite detrimental. A decrease in road mortalities may actually be an indication of a severely decreasing population from road mortality in combination with other mortality sources (Wood and Herlands, 1997).

With increasing traffic loads year after year (National Research Council, 1997), the number of animals killed may represent a large portion of the terrapins utilizing the
roadsides, specifically mature females. This is what we suspect we observed when fewer
terrapins were found nesting in the area of the highest mortality. With relatively little
movement between creeks and high site fidelity to one particular creek documented for
terrapins (Gibbons et al., 2001), this group within the local population may have fewer
individuals because of greater numbers of road mortalities over the years contributing to
a decrease in abundance compared to other sections of Great Bay Boulevard. Fahrig et
al. (1995) also suggest this happens for amphibian traffic related mortalities contributing
to differences in total numbers observed on roads in Canada. If road mortality is not
removed or reduced as a source of the adult mortality for nesting females of this
particular section, it may not ever recover as it could take at a minimum one generation to
replace (Gibbons et al., 2001).

Great Bay Boulevard, like many coastal roadways, is providing nesting sites but
also subjecting terrapins to the risk of road mortality. Since encounters with vehicles
may eliminate reproductively active females, as well as eggs and hatchlings, traffic
related mortalities may be a significant contributor to decreasing populations (Brooks et
al., 1991). Comparing the numbers of live and dead animals on the road with traffic
volume, as in this study, seems to provide a clear picture of the effects of traffic on
mortality. Road surveys at JCNERR should continue to be made to further monitor the
effects of road mortality on this local population. Future studies on roads with differing
traffic loads, similar to Fahrig et al. (1995) should be done to see if these trends exist for
terrapins in other areas.
Acknowledgments

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Literature Cited


Figures and Tables

Figure 1: Detailed map of the study site, Great Bay Boulevard, in the Jacques Cousteau National Estuarine Research Reserve (see Hoden and Able, 2003). Transect sections of the road are numbered 1 through 6.
Figure 2: Northern diamondback terrapin occurrences on Great Bay Boulevard during the nesting season, 25 May – 31 July 2004.
<table>
<thead>
<tr>
<th>Transect Section</th>
<th>Live</th>
<th>Dead</th>
<th>Mean Traffic Volume (vehicles/day)</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>57</td>
<td>2 (3.39 %)</td>
<td>233.70</td>
</tr>
<tr>
<td>2</td>
<td>101</td>
<td>9 (8.18 %)</td>
<td>262.71</td>
</tr>
<tr>
<td>3</td>
<td>189</td>
<td>13 (6.44 %)</td>
<td>363.36&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>8 (8.70 %)</td>
<td>363.36&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>91</td>
<td>10 (9.90 %)</td>
<td>464.00</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>11 (30.56 %)*</td>
<td>936.40</td>
</tr>
<tr>
<td>Total</td>
<td>547</td>
<td>53 (8.83 %)</td>
<td></td>
</tr>
</tbody>
</table>

*(P < 0.001, $\chi^2 = 22.44$, df = 1)

<sup>a</sup>Estimated traffic volumes

Table 1: Summary results of terrapin occurrences, mortalities, and average traffic volumes by transect section on Great Bay Boulevard. A significantly greater percentage of mortality by proportion was found in section 6, which also exhibited the greatest traffic volume.
<table>
<thead>
<tr>
<th>Hour</th>
<th>Live</th>
<th>Dead</th>
<th>Mean Traffic Volume (vehicles/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2401-0100</td>
<td>1</td>
<td>0</td>
<td>7.14</td>
</tr>
<tr>
<td>0101-0200</td>
<td>-</td>
<td>-</td>
<td>4.47</td>
</tr>
<tr>
<td>0201-0300</td>
<td>-</td>
<td>-</td>
<td>3.16</td>
</tr>
<tr>
<td>0301-0400</td>
<td>-</td>
<td>-</td>
<td>2.60</td>
</tr>
<tr>
<td>0401-0500</td>
<td>-</td>
<td>-</td>
<td>3.19</td>
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<tr>
<td>0501-0600</td>
<td>-</td>
<td>-</td>
<td>16.42</td>
</tr>
<tr>
<td>0601-0700</td>
<td>-</td>
<td>-</td>
<td>33.98</td>
</tr>
<tr>
<td>0701-0800</td>
<td>1</td>
<td>0</td>
<td>37.16</td>
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<tr>
<td>0801-0900</td>
<td>51</td>
<td>24a</td>
<td>49.43</td>
</tr>
<tr>
<td>0901-1000</td>
<td>71</td>
<td>2 (2.74%)</td>
<td>47.00</td>
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<tr>
<td>1001-1100</td>
<td>167</td>
<td>12 (6.70%)</td>
<td>54.30</td>
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<td>1101-1200</td>
<td>129</td>
<td>4 (3.01%)</td>
<td>64.69</td>
</tr>
<tr>
<td>1201-1300</td>
<td>46</td>
<td>0 (0.00%)</td>
<td>71.00</td>
</tr>
<tr>
<td>1301-1400</td>
<td>31</td>
<td>3 (8.82%)</td>
<td>71.81</td>
</tr>
<tr>
<td>1401-1500</td>
<td>21</td>
<td>3 (12.5%)</td>
<td>79.67</td>
</tr>
<tr>
<td>1501-1600</td>
<td>16</td>
<td>2 (11.11%)</td>
<td>75.02</td>
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<tr>
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<td>0</td>
<td>71.34</td>
</tr>
<tr>
<td>1701-1800</td>
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<td>56.55</td>
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<td>1801-1900</td>
<td>1</td>
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<td>49.02</td>
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<td>1901-2000</td>
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<td>50.64</td>
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<td>0</td>
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<td>41.70</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>547</strong></td>
<td><strong>53</strong></td>
<td></td>
</tr>
</tbody>
</table>

*aReflects deaths of unknown times (overnight and early the following morning)*

Table 2: Summary results of terrapin mortality discoveries and average traffic volumes by hour (traffic entering the Great Bay Boulevard road system). Mortality rate was positively correlated with average traffic volume by hour between 0901 h – 1600 h ($P = 0.026$, Spearman’s correlation coefficient = 0.750).
Chapter 3: PIT tagging to Monitor Occurrence, Mortality and Nesting Activity of the Northern Diamondback Terrapin Along a Salt Marsh Access Road

Abstract

Northern diamondback terrapins, *Malaclemys terrapin terrapin*, were tagged with passive integrated transponder (PIT) tags to monitor their activity along an access road through salt marsh habitat in Tuckerton, New Jersey. The road occurrence, mortality, nesting activity and movement of the terrapins, particularly females, was monitored as part of a mark-recapture study. Over a two year sampling period (2004/2005), 300 adult females were tagged during the initial weeks of nesting. Ninety-two subsequent recaptures were made from 65 individual terrapins with long term recaptures within and among seasons. Some females crossed the road multiple times while searching for nest sites, but approximately 50% searched within 50 m of their initial tagging location. The time of recapture ranged from the same day of tagging to 45 days later within one season and some recaptures occurred the following year. Possible nest site selections of all multiple nesters varied greatly from approximately 4 m – 1307 m from their initial tagging location, however, nearly 39% were found within 50 m. One-third of yearly nesters demonstrated an inter-nesting distance within 25 m from their first year tagging location, while an inter-nesting distance within 50 m of the initial tagging location was seen in
40% of seasonal multiple nesters. These results indicate that some females return to lay multiple clutches throughout the season and demonstrate nest site fidelity within seasons and among sampling years on Great Bay Boulevard. Furthermore, this study shows that PIT tagging can be a dependable method for tracking adult female terrapin encounters with an access road during the nesting season as the overall success recapture rate was almost 22%.
Introduction

Collecting data from tagged animals can lead to a better understanding of general movement and migration patterns, reproductive strategies, population sizes, specific use of habitat, and individual behaviors (Balazs, 1999). In reptiles, passive integrated transponder (PIT) tags have been utilized in snakes (Elbin and Burger, 1994; Jemison et al., 1995), lizards (Frost and Etheridge, 1993), sea turtles (Parmenter, 2003), and freshwater turtles (Buhlmann and Tuberville, 1998; Brenner et al., 2002) with high success rates of recapture and few complications of infection, death, or problems associated with growth and reproduction. In sea turtles, PIT tags have been useful for collecting information on nesting sites, foraging grounds, and migration paths (Balazs, 1999). PIT tags have been applied to terrapins in previous studies (Butler, Wood, pers. comm.), but there has been little information reported on their effectiveness to track these herptiles.

Terrapins may display high site fidelity and nest site philopatry while moving to nest sites based on reproductive or general survival strategies (Roosenburg, 1994; Gibbons et al., 2001). They have been recaptured numerous times within a 100 m section of the same creek (Gibbons et al., 2001) and nest site philopatry has been observed within and among years by Roosenburg (1994). Cooke (1989) suggested nesting females may find appropriate locations within 200 yards of water, whereas Feinberg and Burke (2003) found nesting areas of terrapins a maximum of 250 meters from water. Other studies report even farther distances, as recaptured females nested several hundred meters from water (Roosenburg, 1994). Burger (1977) found that terrapins may move to many different sites before ovipositing, digging up to 10 different nests before choosing
the final one. These nest site selections ranged from 10 mm to several meters from the initially selected one (Burger, 1977).

Despite movement ranges that have already been documented, there has been little attention paid to the amount of habitat terrapins may utilize and how distances may vary between nests along roadsides. It has been previously documented that females nest beside roads as the conditions are suitable for nesting, which often leads to encounters with vehicular traffic and results in road mortalities (Wood and Herlands, 1997; Szerlag and McRobert, 2006).

At the present time there seems to be little, if any, literature on the application or success of PIT tagging terrapins. Therefore, this study focuses on establishing a baseline estimation of success for using PIT tags to monitor nesting terrapin females. By using PIT tags in a mark recapture study, the number of road encounters, mortalities due to vehicles, nesting activity and the range of habitat use and movement along an access road was determined for adult female terrapins.

Materials and Methods

Study Area

Field work was conducted near the Rutgers University Marine Field Station on Great Bay Boulevard in Tuckerton, New Jersey. The overall site (Great Bay Wildlife Management Area) is a 2,168 ha peninsula consisting of relatively pristine salt marsh. Great Bay Boulevard is an 8.1 km paved roadway, between the town of Tuckerton and the field station, located along the vertical centerline of the marsh peninsula (Figure 1). Along it,
five bridges cross over the subtidal creeks and telephone poles run parallel to the road, spaced 54 m apart.

**Overall Data Collection**

Surveys of Great Bay Boulevard were conducted during the terrapin nesting season in the summer of 2004 and 2005. Sampling began when terrapins were first sighted (end of May/beginning of June) and lasted until the last terrapin was seen (end of July). Adults are generally absent from the road all other times of the year (Hoden and Able, 2003). Eight to ten surveys were completed each day by car or bike, approximately five-six days per week for a total of 299 samples in 2004 and 272 in 2005. Surveys were typically conducted between 0800 h - 1700 h with a few conducted after dark between 2100 h - 2400 h. Parameters recorded during sampling included; date, time of day, location of terrapin(s) found (telephone pole number and GPS (hand-held unit, GARMIN GPSMAP 76) coordinates (telephone pole GPS recapture sites for 2004 and actual GPS recapture sites for 2005)), size (carapace length (CL) and plastron length (PL)), and whether the individual was alive or dead and tagged for each encounter. Adult females were determined by physical characteristics (head size, tail length and location of cloaca) and considered to be larger than 150 mm in length (Ernst et al., 1994), although we rarely saw males, juveniles, or hatchling during this time period.

**PIT tagging Procedure**

Overall, 300 adult female terrapins (100 in 2004 and 200 in 2005) were tagged during the first week(s) of terrapin nesting using PIT tags (12 x 2.1 mm - Biomark Inc.). When
tagging during the nesting period, it was preferred that females oviposited before a tagging attempt was made to reduce stress on the gravid females.

The methods for tagging were based on the procedure by K. Buhlmann & T. D. Tuberville (1998) and the Guidelines for Use of Live Amphibians and Reptiles in Field Research, Second Edition (2004). The technique of injection site placement and syringe insertion was demonstrated before the study began by John Wnek of the Marine Academy of Technology and Environmental Science in Barnegat Bay, NJ who had previous experience tagging terrapins in a separate study area in central New Jersey.

Sterile, internally injected PIT tags, were used to tag individual terrapins with one tag and injector each. PIT tags were inserted in the right plastral area above the hind limb and close to the margin. Before tag insertion, the area of skin was cleansed with 70% isopropyl alcohol and a sterile gauze pad. A small amount, approximately the size of a dime, of a commercial brand of triple antibiotic ointment with pain relieving ingredient (Praxamine HCL), was placed on the tip of the injector before injection. A commercial liquid bandage tissue adhesive was applied to the puncture site to seal the area. The animal was checked for adverse reactions or discharge from the injection site, and then scanned with the PIT tag pocket reader to verify the tag number. After the procedure, terrapins were released back in the marsh, in the same direction they were heading before tagging.

*Calculation of distances between road crossings and nest sites*

Straight-line inter-nesting distances and distances between road crossings were estimated using the GPS coordinates obtained for each terrapin location and entering them into
ArcView GIS (vers. 3.3 ESRI, Redlands, CA). Data was projected using ArcView to Universal Transverse Mercator units (UTMs) in meters to allow calculation of these distances on an aerial image of the study site.

Results

Mark-Recapture

Ninety-two recaptures were made from 65 of 300 (21.67%) adult female terrapins that had been tagged (mean = 176 ± 1 mm (CL), mean = 159 ± 1 mm (PL)) on Great Bay Boulevard over the two year study period. We observed 2 tagged terrapin mortalities by automobiles, one in each year. During the 2004 nesting season, we documented 25 total recaptures from 16 individual females and in 2005, 50 total recaptures from 38 individuals. Additionally, we made 17 recaptures of the 2004 tagged group from 15 different individuals in 2005 (Table 1, Table 2).

Time varied between recaptures within the season ranging from same day of tagging to up to 45 days later (Figure 2). Long term recaptures (17 + days after initial tagging in a season or the following year) were observed within and among years (Table 1, Table 2). One female was recaptured 45 days after her initial tagging and confirmed to be gravid by x-ray for a 2nd or possibly even a 3rd time in the 2004 season.

Road Side Habitat Use and Movement/Nesting

We recaptured a majority of multiple nesting females (38.71%) within 50 m of their original nesting sites. Possible subsequent sites were within an inter-nesting distance range of 4.00 m - 1307.35 m with an average of 202.75 m along Great Bay Boulevard.
We found 40% of within season second nesters (N = 15) within 50 m (mean = 171.79 m, range = 4.00 m – 916.40 m), and 33% of yearly multiple nesters (N = 15) within 25 m, 40% within 50 m (mean = 239.28 m, range = 6.83 m – 1307.35 m) of inter-nesting distances.

Terrapins were recaptured crossing the road multiple times each season while searching for suitable nest sites. Distances between road crossings (N = 53) ranged from 3.99 m – 934.01 m, with a mean of 132.09 m, yet 49.06% searched within 50 m of their initial tagging location. One female, crossed the road, a minimum of 5 occasions, and utilized an area of 162.44 m along Great Bay Boulevard.

Discussion

PIT Tagging

The results obtained from this study provide a preliminary basis for PIT tagging of terrapins and provides a measure of usefulness of this technique for monitoring nesting activity in these animals. We found no evidence indicating infection, death, or any other problems of altered behavior, growth or reproduction were caused by the use of PIT tags. The individual code for each terrapin proved to be highly reliable and unmistakable when read by the scanner. Traditional forms of marking such as scute or shell notching is commonly used in turtles, but may not be as reliable as PIT tagging as the number of marked increases and combinations will eventually run out. Furthermore, over years, notches may become impossible to identify to the correct individual (Buhlmann and Tuberville, 1998).
Mark Recapture along Great Bay Boulevard

The overall recapture rate was nearly 22%, but possibly would have been greater if more people had been available for sampling Great Bay Boulevard during the study. For instance, some female terrapins may have been missed as they crossed the road in sections that were not being monitored. Although, it would seem as these terrapins are continually monitored over the years, the success rate of recapture may rise as Gibbons et al. (2001), observed a mean recapture rate of 78% over a five year period.

Recapture results are similar to others who have previously completed mark-recapture studies. Long term recaptures (assuming multiple nesters) were found 17+ days after their initial tagging. For this study, 17 days was considered “long term” based on previous studies that report an approximate 17 day inter-nesting interval for terrapins (Klemens, 1993; Feinberg and Burke, 2003). Six individual long term recaptures in 2004 were made, which is similar to results of Feinberg and Burke (2003) who tagged 133 adult females and recaptured 6 individuals in a year period, two of which were confirmed to be nesting for a second time in the season. Within 2005, the recapture rate of long term nesters was slightly lower at 18% compared to 24% the previous year. This may have occurred due to a shorter nesting season (possibly fewer second nestings), which began approximately 12 days later than the previous year and ended around the same time.

Several individuals were recaptured multiple times in the same day, the following day, and up to a week from initial tagging, possibly still searching for a suitable nesting site. Continuous searching behavior has previously been observed by Burger (1977) who found terrapins may “test” many locations before settling on a final site to nest.
Roadside Habitat Use and Movement/Nesting

Long distance movements of terrapins have been reported as limited in Malaclemys (Gibbons et al., 2001). Gibbons et al. (2001) observed one female who completed a round trip distance of 5.5 km after leaving her home range, nesting on a dune, and then returning. In this study, females were found to move even greater distances between nest sites alone, not even taking into account other travel that may have occurred before and after nesting. Distances from initial tagging site to subsequent recaptures along Great Bay Boulevard revealed a variable distance range (4 m – 1307 m) but nearly all terrapins nested within 450 m of their original site, with the majority within 50 meters. However, three females were recaptured further than 900 m. Other species of turtles such as Spotted (Clemmys guttata) and Blanding’s (Emydoidea blandingii) have traveled similar distances while nesting, 70 m - 570 m and 100 m - 1620 m respectively, even though the nearest wetland from the chosen nest site was a shorter distance away (1 m - 120 m and 70 m - 410 m respectively) (Joyal et al., 2001). Painted turtles (Chrysemys picta) have been shown to have an inter-nest distance range of 5 m - 405 m, with an average of 93.9 m among years and a 106.2 m average with a range of 6 m - 500 m within a season (Rowe et al., 2005).

Evidence of nest site fidelity

In this study area, a majority of recaptures were made in the same general area along the roadside of Great Bay Boulevard indicating possible nest site fidelity for some individuals. This has been seen in high percentages in other species of turtles, such as Blanding’s where 73.3% of females returned to the same beach to nest in 3 consecutive
years of a study (Standing et al., 1999). From these results, an inter-nesting distance of 0 m - 50 m was considered to be evidence of nest site fidelity. Currently, nest site fidelity distances are lacking in the literature for terrapins, but in other turtles of the same family (Emyidae), particularly painted turtles, 50 m or less has been considered fidelic (Rowe et al., 2005). A majority (33 - 40%) of the females in this study was found within 50 m of the original site in all cases; within seasons of 2004 and 2005 individuals and among years of 2004 tagged females. Inter-nest distance values of a painted turtle study revealed approximately 30% of individuals nested within 25 m of their previous years nest (Rowe et al., 2005). We had similar results, with 33.33% of terrapins nesting within 25 m between years. Nest site fidelity has been observed in earlier studies on Little Beach Island in New Jersey where Burger (1977) found some terrapins returned to nest on the same dunes, multiple years. Roosenburg (1991) in Maryland also documented females returned to the same nesting area each time they laid a new clutch, consecutive years and even multiple times within one season (Roosenburg, 1994). Similar results were also seen in New York by Feinberg and Burke (2003) whose second nesters within a season were found in the same general area.

**Road Crossings and Risks of Traffic Encounters**

Terrapins may search multiple areas before deciding on a final location to nest, similar to Blanding's turtles that arrive at nesting areas several days prior to nesting and make numerous attempts before effectively completing one (Standing et al., 1999). In this study nearly 50% of terrapins who crossed multiple times searched within 50 m along the roadside, while a few traveled well over 300 m in a relatively short period of time (within
the same day or a few days). Terrapins, like most turtles, require specific conditions when nesting (i.e., little vegetation, high elevations, and sandy soils), and because this area is human altered, the roadside habitat may be quite variable to their needs. Therefore, some females may be forced to travel longer distances along Great Bay Boulevard to successfully nest.

Multiple crossing made by terrapins will continually subject them to becoming victims of road mortality. There may actually have been a greater number of PIT tagged road killed terrapins than what was observed. Overall, 101 terrapin deaths were related to encounters with traffic over two years (see Szerlag and McRobert, 2006); however, only two tagged females were positively identified. One of the individual’s tag was found outside of the carcass as it had been hit moments after tagging. The other individual had retained its’ tag. If tags are ejected from the body occasionally, they may have been missed on the roadway as scavengers are present in the area and may have ingested the tag themselves. Alternatively, the tag may have been crushed by a vehicle or just accidentally missed visually.

**Conclusions**

The results from this study may provide insights to management strategies in this and other areas where terrapins encounter roadways. Fencing has been used to help reduce mortalities of some turtles (Aresco, 2005). Movements and distances made by terrapins, revealed from this study, may influence an area to be protected by fencing.

Monitoring nesting females is just one instance of how this type of PIT tagging may be useful to this species. Based on the rationale of ones study, it may be beneficial
to use a combination of the two methods of tagging, PIT and shell notching, as absolute identification of an animal in all situations (Gibbons and Andrews, 2004).

Acknowledgments

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Research was conducted in accordance with Saint Joseph’s University Institute Animal Care and Review Committee (IACUC protocol #: PR - 0503) and under The State of New Jersey, Department of Environmental Protection, Division of Fish and Wildlife permit # 0423 and # 0521 issued to Rutgers University Marine Field Station and its seasonal employees.
Literature Cited


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Figures and Tables

Figure 1: Map of the study site, Great Bay Boulevard, within the Great Bay Wildlife Management Area of the Jacques Cousteau National Estuarine Research Reserve in Tuckerton, New Jersey.
<table>
<thead>
<tr>
<th>Year</th>
<th>Total no. tagged</th>
<th>Total no. recaptures</th>
<th>No. of individuals recaptured</th>
<th>Total no. individuals multiple clutched</th>
<th>Total road crossing events</th>
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<tr>
<td>2004</td>
<td>100</td>
<td>25</td>
<td>16 (16%)</td>
<td>6 (24%)</td>
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<td>2005</td>
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<td>50</td>
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<td>9 (18%)</td>
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<tr>
<td>2004 – 2005</td>
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<td>15</td>
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<td>65 (21.67%)</td>
<td>16 (17.39%)</td>
<td>61 (67.03%)</td>
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Table 1: Summary results of PIT tagged terrapins within and among nesting seasons on Great Bay Boulevard.
<table>
<thead>
<tr>
<th>Terrapin No.</th>
<th>Date of tagging</th>
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<td></td>
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</table>

Table 2: Summary results of terrapins tagged in 2004 and recaptured the following nesting season in 2005 on Great Bay Boulevard.
Figure 2: Number of terrapins recaptured after initial tagging (Day 0) to next recapture day on Great Bay Boulevard. Many terrapins were recaptured the same day or within the same week possibly still searching for a nest site. Terrapins that were recaptured after 17 days or more were possibly laying a second clutch of the season.
Figure 3: Inter-nesting distances of all multiple nesting terrapins on Great Bay Boulevard. A majority of terrapins (38.71%) nested again within 50 m of their original nest site.
Chapter 4: Evaluating Road Mortality of the Northern Diamondback Terrapin: A two year study

Abstract

Roads can have many negative effects on wildlife and the environment with road related mortalities being the most obvious and possibly the most detrimental. However, few studies have assessed the impact of traffic on road mortality of the diamondback terrapin or the ecological significance of the road kill. Over a two year study period we found a 9% mortality rate (104 dead) of all terrapin occurrences on Great Bay Boulevard, in Tuckerton, New Jersey. In the section of road that exhibited the greatest traffic volume, 20.23% of terrapins seen were killed, with a significant proportion observed in the first season. In both years, mortality rates correlated positively with increasing traffic volume by hour. Access roads that run through wetland environments are commonly bordered and intersected by tidal creeks. Accordingly, their location in relation to the road may contribute to specific areas of terrapin mortality. Consequently, we found that 50% of terrapin mortalities in 2005 were < 70 m from the nearest major creek. These distances varied between road sections probably due to differences in topography, however the median distance of most sections was approximately < 80 m. In section 6 (the area with
the least amount of open water), we found the lowest median distance (36.47 m) between road kills and the nearest major creek, with a clustering of road kills around a large creek intersecting Great Bay Boulevard.
Introduction

Road Ecology, defined as the science of the interaction of organisms and the environment linked to roads and vehicles (Forman et al., 2003), is an area of science presently underrepresented, but becoming more popular due to the increased awareness of the negative impact of roads on wildlife and the surrounding habitat. Understanding the impact of roads may be critical to the survival of certain species. Roads can act as the primary source of mortality (Bangs et al., 1989), limit recovery (Smith et al., 1996), or contribute to endangerment (Dalrymple and Reinenbach, 1984).

Roads can have a significant effect, particularly on slow moving, long living, or later reproducing animals, such as herpetofauna (Ashley and Robinson, 1996). Especially sensitive are species that exhibit migratory and large or frequent home range movements (Bonnet et al., 1999; Carr and Fahrig, 2001; Seiler, 2001). Many species of turtles demonstrate some type of dispersal or migration throughout their life, but often it is the adult females who make movements when nesting, leading to a greater probability of becoming involved in encounters with vehicles (Aresco, 2005). The diamondback terrapin is just one example of a turtle that makes such movements as females seek suitable nesting sites each summer. Often times, these searches result in death as they encounter vehicles when nesting along access roads (Wood and Herlands, 1997; Hoden and Able, 2003; Szerlag and McRobert, 2006).

Traffic intensity, the most obvious factor contributing to road mortality, is an ever increasing problem as traffic loads continue to rise year after year (National Research Council, 1997), most likely leading to more mortalities for amphibians and reptiles. For frogs and toads, the probability of being killed on a road increased as traffic increased
(Fahrig et al., 1996; Hels and Buchwald, 2001). Turtle populations, particularly land
turtles and large - bodied turtles, have been suggested to experience excessive road
mortality in conjunction with mounting vehicle density (Gibbs and Shriver, 2002).

The distribution of these mortalities on roads may be influenced by a number of
factors, such as traffic intensity, landscape features, and specific aspects of the biology of
the organism (Seiler, 2001). Previous road mortality studies have found road kills may
not necessarily be random, but may occur, or even cluster, in certain areas along a road
(Bashore et al., 1985; Clevenger et al., 2001; Clevenger et al., 2003). Gunther et al.
(1998) found that some large mammals were significantly killed more often in non-
forested areas such as grasslands, shrublands, and natural forest openings than in forested
cover types. Similar results have been documented for birds, as they are more likely to
be killed in open habitats than forested areas (Clevenger et al., 2003). Amphibian road
kills have been linked with roadside vegetation and turtle mortality has been significantly
associated with open water areas adjacent to roads (Ashley and Robinson, 1996).
Identifying factors that contribute to the spatial distribution of road kills may lead to
better predictions of where they can occur and create more effective mitigation measures
in the future.

Accordingly, this detailed road mortality study addresses the effects of traffic on
mortality in the northern diamondback terrapin, Malaclemys terrapin terrapin. As part of
this study the influence of ecological factors, such as creek location, on the location of
road kills on an access road are analyzed.
Materials and Methods

Study Area

Field work was conducted out of Rutgers University Marine Field Station, located on a fairly pristine salt marsh peninsula in southern New Jersey within the Great Bay Wildlife Management Area of the Jacques Cousteau National Estuarine Research Reserve. The road being studied, Great Bay Boulevard is a two-way, 8.1 km paved access road that runs north to south through the center of this peninsula. The road begins in Tuckerton, New Jersey and ends at the field station (Figure 1a). Five major exposed creeks (> 15 m) cut through the marsh perpendicular to the peninsula with smaller tidal creeks, ditches, and pools/ponds running throughout (Figure 1b).

Survey Regimen

Surveys were conducted along Great Bay Boulevard during the terrapin nesting season (May - July) for a total of 299 surveys in 2004 and 272 in 2005. One survey consisted of beginning at transect section 1 or 6 and completing the full 8.1 km survey to the last section of road. Therefore, all sections were surveyed an equal number of times. Generally, 8 - 10 surveys were completed each day, 5 - 6 days a week by car and bike. Surveys began in the morning between 0800 h - 0900 h and lasted until 1600 h - 1700 h each day. Occasionally, a few surveys began before 0800 h and ended after 1700 h. Random night surveys between 2100 h and 0100 h were made on 10 nights between the two seasons (5 nights/season). The parameters recorded included; date, time of day, location of terrapin (transect section, closest telephone pole number, and GPS data point (2005)), and the status of the terrapin (live or dead).
Traffic Measurements

We used traffic measuring devices (TRAX I Plus Counter/Classifiers, JAMAR Technologies Inc, Horsham, PA), set up in the middle of each transect section on the road to attain all traffic data. These counters operated during all times of the study season and data was downloaded using a laptop computer on a weekly basis.

Data analysis

Road Mortalities and Traffic

Comparisons of road mortality rates by proportion between sections of Great Bay Boulevard were tested using Pearson chi-square analysis with \( P = 0.05 \). Spearman’s rank order correlation with one tailed probability and \( P = 0.05 \) was used to test the relationship between road mortality rates and hourly mean traffic volume during the survey hours of 0901 h - 1600 h. We chose analysis during these hours because more consistent sampling was done between these times.

Road Mortalities and Major Creek Locations

GPS data points were recorded for all terrapin road kills, converted to Universal Transverse Mercator units (UTMs) in meters for distance calculations, and projected on an aerial image of the peninsula - Great Bay Boulevard using ArcView GIS (vers. 3.3 ESRI, Redlands, CA). This allowed us to measure straight-line distances (m) from the road kills to the nearest major creek the terrapins may have initially traveled from. The types of major creeks used in distance measurements were as follows; exposed creeks (> 15 m wide and cuts through the marsh), extra large creeks and ditches (> 15 m wide),
large creeks (5 - 15 m wide), and exterior basin areas (partially enclosed basin) (Lathrop, pers. comm.). Although we had recorded GPS data points of the nearest telephone pole for each road kill in 2004, our analysis focused more on the 2005 mortalities because these GPS points were taken directly at the site of mortality and therefore are more accurate.

Results

Overall Findings

Over the two year study period we observed 104 vehicle induced mortalities (8.66%) out of 1200 road occurrences on Great Bay Boulevard. Fifty-three terrapins were killed in 2004 and 51 terrapins were killed in 2005.

Road Mortality and Traffic

In 2004, we found a significantly greater percentage of mortality by proportion \( P < 0.001, \chi^2 = 22.44, \text{df} = 1 \) in transect section 6 which also exhibited the highest traffic volume (see Szerlag and McRobert, 2006). However, in 2005, the only difference found between sections was that section 2 had significantly less mortality by proportion \( P < 0.005, \chi^2 = 8.299, \text{df} = 1 \) (Table 1). Average traffic volumes (vehicles/day) of the transect sections exhibited the same general pattern, decreasing from section 6 (where all the traffic enters) to the end of Great Bay Boulevard in section 1 both years, although traffic volume increased in all sections except section 6 in 2005 (Table 1).

In both years we found a positive correlation between road mortality rates and increasing traffic volume between 0901 h - 1600 h (2004, \( P = 0.026 \), Spearman’s
correlation coefficient = 0.750 (see Szerlag and McRobert, 2006); 2005, \( P = 0.036 \), Spearman’s correlation coefficient = 0.714). The average traffic volumes per hour were very similar in both years.

\textbf{Mortalities and Nearest Major Creeks}

We compared the distances between road kill and the nearest major creek for both years and found a wide range of distances from 6.24 m – 334.89 m (mean = 65.29 m, median = 49.16 m) in 2004 and from 4.87 m – 283.31 m (mean = 81.37 m, median = 69.86 m) in 2005.

In each transect section, mortalities were generally closest to one type of particular creek, except in section 3. For example in transect section six, 15 out of 17 mortalities were closest to large creeks (Table 2). Distances between road kill and the nearest major creek also varied between the transect sections of Great Bay Boulevard, with a few large distances that positively skewed the data in some cases (Figure 2). We found median distances were less than 80 m for all sections, except section 1 (Table 3, Figure 2). In section 6, we found the lowest median distance (36.47 m) and a highly variable distribution, which was positively skewed ranging from 4.87 m – 283.31 m (Table 3, Figure 2).

\textbf{Discussion}

Openness (i.e. less vegetation cover, more open canopy) along roadsides may provide ecological situations that are attractive for terrapin nesting. Nesting females prefer areas of sandy soil, high elevation, and little vegetation (Burger and Montevecchi, 1975).
Since the roadsides of access roads typically meet these specific conditions, many females crossed and nested along Great Bay Boulevard. Consequently, approximately 9% of adult female road occurrences ended in road mortality. Similar overall mortality rates were seen each season.

Most terrapin activity was observed throughout the day, but some occurred during the late evening hours. Data suggest that temperatures on dark asphalt roads tend to be warmer in the evening than the surrounding habitat, (Shine et al., 2004) and thus may be attractive to female terrapins throughout the night. Even though fewer vehicles use Great Bay Boulevard at night, there are no street lights and some motorists drive extremely fast (above 95 mph in a few cases), so a terrapin in the roadway would undoubtedly have a slim chance of evading an encounter with a vehicle. Terrapins were very difficult to see even when driving 10 mph during surveys after 2100 h. The combination of the night activities of some terrapins and motorists, in addition to reduced visibility overnight, may have contributed to mortalities (N = 56, 53.85%) found during the first survey hours of this study. Alternatively, deaths may have resulted from early morning nesting activity in combination with increasing traffic before surveying began (Szerlag and McRobert, 2006).

*Road Mortalities and Traffic Intensity*

In 2004, we observed a significantly greater proportion of mortalities in the section with the greatest traffic volume (section 6, 30.56%), providing evidence that traffic intensity may influence the likelihood of road mortality by road section. However, it may not be consistent from year to year. In 2005, we did not find the same significant evidence,
although the mortality rate was still relatively high for section six (12.5%). In addition, the overall mortality rate by proportion (20.23%) for this section of the road was still greater, by roughly 50 – 75%, compared to all other sections. It has been suggested that in some animals there is a negative correlation between road kills and proximity to towns (Clevenger et al., 2003). The section of road being examined (section 6) is nearest to downtown Tuckerton, and the point where all traffic enters the system. The increased traffic volume appeared to be the major contributor to increased mortality, despite fewer terrapins utilizing this area. The insignificant mortality results found within sections in 2005 may be explained by the later start of terrapin nesting compared to the previous season, which potentially exposed terrapins to fewer days of intense traffic. Traffic volume in 2005 also increased in all sections other than section 6, possibly contributing to more evenly distributed road mortality.

Traffic intensity, however, did significantly contribute to an increased rate of mortality with increasing average traffic volume throughout the day, over the entire study period.

Road Mortality Ecological Significance (Creek Topography)

Road kills may be of ecological significance in understanding the complex relationship between wildlife and roads and predicting the most probable areas of mortality. It has been documented that some species of snakes utilize roadways that are located in close proximity to perennial streams, especially large rivers (mean distance = 1.1 km) and often impacted by road mortality (Rudolph et al., 1998). Ashley and Robinson (1996) found that painted and snapping turtles road mortalities were significantly associated with
sections of the road adjacent to ponds. Cooke (1995) also observed concentrated road mortality of common toads near breeding ponds. The location of tidal creeks within the salt marsh and their spatial relationship to an access road, such as Great Bay Boulevard, may also influence where the terrapins are initially emerging and being killed.

We found that the distance between the road kills and the nearest major creeks varied for each transect section, although the median was generally less than 80 m. The range of distances may be a function of the particular creek topography within each section (see Figure 1b). Some creeks cut through the marsh rather than head up the marsh and intersect the road or run within a close proximity to it. This type of topography may provide terrapins with easier access to potential nesting sites yet subject them to increased road mortality. In section 1, we found a greater median distance compared to all other sections. This distance may have been greater because the creeks that run parallel to GBB are slightly farther away (>100 m) than creeks within other sections. Differences in topography have been the main factors in determining areas of road kill for other animals, including mammals, birds, and small vertebrates (Clevenger et al., 2003).

Creeks that intersect or run closely to GBB may cause road kills to be grouped around that type of location. We found evidence of this in most sections, but it was especially obvious in section 6. This section had the lowest median road kill to creek distance (less than 37 m) compared to other sections and has a lower open water to marsh surface ratio (Lathrop et al., 2000) compared to the rest of the peninsula, and therefore fewer creeks (Figure 1b). The large creeks directly intersect Great Bay Boulevard (Figure 1b, Figure 3), as a result, a majority of road mortalities were clustered within a
short distance of the most southern large creek (Figure 3). Eight of 11 mortalities (72.72%) from 2004 and 2 of 6 (33.33%) from 2005 were found in that particular cluster (Figure 3).

**Management Implications**

If adult female mortalities by vehicles continue to increase, it would be expected that we may see reduced population growth (Findlay and Bourdages, 2000), or evidence of a declining population (Brooks *et al.*, 1991). In other organisms with similar life history traits to turtles, models show that an annual 3% loss for 10 years would take a population 50 years to recover (Miller and Botkin, 1974). Road mortality results of 8.83% and 8.5% each season may indicate this local terrapin population is potentially in severe trouble. Wood and Herlands (1997) believe their terrapin population is experiencing a local crash despite decreased road kill numbers, in conjunction with increased road surveying. They suspect fewer road kill may actually indicate a declining population from road mortality in combination with other mortality sources (Wood and Herlands, 1997). The northern diamondback terrapin is already considered a “Species of Special Concern” (New Jersey Department of Environmental Protection, Division of Fish and Wildlife, NJ Endangered and Non-Game Species Program, website 2005), so additional mortalities in association with roads, especially to mature females, will contribute even further to the decline of the species.

Because many road mortalities occurred in close proximity to tidal creeks throughout the study period, recommendations toward mitigation are in order. At a minimum, increased road patrolling particularly in those specific areas and possibly
installation of temporary drift fencing should occur. A drift fencing pilot study showed positive results of a reduction in road mortalities without interruption of nesting (Atkinson, 2005). Although some caution should be taken as Clevenger et al., (2001) found areas of highest mortality were near the ends of highway mitigation fencing. Both of these actions would require some effort but are relatively inexpensive and not permanent to the layout of the road. In the future, more costly but permanent measures, such as habitat creation should be considered for alternative terrapin nesting sites.

Acknowledgments

We would like to thank Kenneth Able, Michael Kennish, Roger Hoden, and Scott Haag of the Rutgers University Marine Field Station facility for technical support, and Deborah Lurie of Saint Joseph’s University for assistance with data analysis. We give much appreciation to Yen Tang-Dietrich for assistance with GIS and to Timothy Egger for equipment assistance. We would also like to thank the Jacques Cousteau National Estuarine Research Reserve volunteers and Rutgers University Marine Field Station technicians.

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Research was conducted in accordance with the State of New Jersey, Department of Environmental Protection, Division of Fish and Wildlife permit #0423 and #0521 issued to Rutgers University Marine Field Station and its seasonal employees.
Literature Cited


Figure 1a: Great Bay Boulevard and transect sampling sections (1 - 6) within the peninsula of the Great Bay Wildlife Management Area of the Jacques Cousteau National Estuarine Research Reserve.
Figure 1b: The salt marsh peninsula surrounding Great Bay Boulevard emphasizing the water and marsh areas (see Lathrop et al., 2000).
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57</td>
<td>2 (3.39%)</td>
<td>233.70</td>
<td>83</td>
<td>4 (4.60%)</td>
<td>250.38</td>
</tr>
<tr>
<td>2</td>
<td>101</td>
<td>9 (8.18%)</td>
<td>262.71</td>
<td>96</td>
<td>1 (1.03%)*</td>
<td>337.71</td>
</tr>
<tr>
<td>3</td>
<td>189</td>
<td>13 (6.44%)</td>
<td>363.36*</td>
<td>153</td>
<td>20 (11.56%)</td>
<td>621.39</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>8 (8.70%)</td>
<td>363.36*</td>
<td>91</td>
<td>13 (12.5%)</td>
<td>707.22</td>
</tr>
<tr>
<td>5</td>
<td>91</td>
<td>10 (9.90%)</td>
<td>464.00</td>
<td>84</td>
<td>7 (7.69%)</td>
<td>749.41</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>11 (30.56%)**</td>
<td>936.00</td>
<td>42</td>
<td>6 (12.5%)</td>
<td>905.97</td>
</tr>
<tr>
<td>Total</td>
<td>547</td>
<td>53 (8.83%)</td>
<td></td>
<td>549</td>
<td>51 (8.5%)</td>
<td></td>
</tr>
</tbody>
</table>

** (P < 0.001, $x^2 = 22.44$, df = 1)
* (P < 0.005, $x^2 = 8.299$, df = 1)

*Estimated Traffic Volumes
2004 results; see Szerlag and McRobert, 2006

Table 1: Summary results of terrapin occurrences, mortalities, and average traffic volumes (vehicles/day) by transect section on Great Bay Boulevard during the nesting seasons.
<table>
<thead>
<tr>
<th>Section</th>
<th>Exposed Creek</th>
<th>Extra Large Creek</th>
<th>Large Creek</th>
<th>Ditch</th>
<th>Exterior Basin</th>
<th>Total road kill</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>2 (124.08 m)</td>
<td>4 (117.60 m)</td>
<td>N/A</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>6 (59.02 m)</td>
<td>4 (55.15 m)</td>
<td>N/A</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8 (54.27 m)</td>
<td>7 (79.81 m)</td>
<td>13 (38.69 m)</td>
<td>N/A</td>
<td>5 (69.12 m)</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>21 (83.78 m)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>11 (72.23 m)</td>
<td>6 (65.29 m)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>1 (4.87 m)</td>
<td>15 (97.67 m)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>48</td>
<td>9</td>
<td>41</td>
<td>1</td>
<td>5</td>
<td>104</td>
</tr>
</tbody>
</table>

(Average distance)

Table 2: Summary results of total terrapin road mortalities by transect section of Great Bay Boulevard (2004 and 2005) and average distances (m) to nearest major creek type.
<table>
<thead>
<tr>
<th>Transect Section (2005 Data)</th>
<th>Section 6</th>
<th>Section 5</th>
<th>Section 4</th>
<th>Section 3</th>
<th>Section 2</th>
<th>Section 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>6</td>
<td>7</td>
<td>13</td>
<td>20</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Mean</td>
<td>98.41 m</td>
<td>83.36 m</td>
<td>87.25 m</td>
<td>64.35 m</td>
<td>79.23 m</td>
<td>123.64 m</td>
</tr>
<tr>
<td>Range</td>
<td>4.87 - 283.31 m</td>
<td>26.61 - 156.71 m</td>
<td>18.00 - 201.22 m</td>
<td>9.19 - 118.48 m</td>
<td>79.23 m</td>
<td>106.71 - 141.44 m</td>
</tr>
<tr>
<td>Percentile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>10.74 m</td>
<td>57.91 m</td>
<td>34.80 m</td>
<td>47.05 m</td>
<td>79.23 m</td>
<td>109.17 m</td>
</tr>
<tr>
<td>50</td>
<td>36.47 m</td>
<td>68.59 m</td>
<td>70.75 m</td>
<td>61.57 m</td>
<td>79.23 m</td>
<td>123.20 m</td>
</tr>
<tr>
<td>75</td>
<td>233.33 m</td>
<td>129.03 m</td>
<td>141.69 m</td>
<td>81.58 m</td>
<td>79.23 m</td>
<td>138.55 m</td>
</tr>
</tbody>
</table>

Table 3: Summary results of terrapin road mortalities (2005) by transect section of Great Bay Boulevard and distances (m) to nearest major creek.
Figure 2: Distances (m) between terrapin road mortalities (2005) and the nearest major creek by transect section on Great Bay Boulevard. The thick black line represents the median.
Figure 3: Road mortalities of 2004 (yellow circles) and 2005 (green circles) clustered around the most southern large creek intersecting Great Bay Boulevard in transect section six.
Appendices

Appendix A:

Northern diamondback terrapin occurrences on Great Bay Boulevard during the nesting season, 25 May – 21 July 2004 (blue line) compared to nesting season, 06 June – 21 July 2005 (green line). Peaks of terrapin occurrences took place on or around the lunar phases each year.
Appendix B:

Summary results of terrapin mortality discoveries and average traffic volumes by hour (traffic entering the Great Bay Boulevard road system) of 2005. Mortality rate was positively correlated with average traffic volume by hour between 0901 h – 1600 h ($P = 0.036$, Spearman’s correlation coefficient = 0.714).

<table>
<thead>
<tr>
<th>Hour</th>
<th>Live</th>
<th>Dead</th>
<th>Mean Traffic Volume (vehicles/hr)</th>
</tr>
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<tbody>
<tr>
<td>2401-0100</td>
<td>0</td>
<td>0</td>
<td>6.35</td>
</tr>
<tr>
<td>0101-0200</td>
<td></td>
<td></td>
<td>4.68</td>
</tr>
<tr>
<td>0201-0300</td>
<td></td>
<td></td>
<td>3.38</td>
</tr>
<tr>
<td>0301-0400</td>
<td></td>
<td></td>
<td>2.19</td>
</tr>
<tr>
<td>0401-0500</td>
<td></td>
<td></td>
<td>3.95</td>
</tr>
<tr>
<td>0501-0600</td>
<td></td>
<td></td>
<td>20.41</td>
</tr>
<tr>
<td>0601-0700</td>
<td></td>
<td></td>
<td>29.35</td>
</tr>
<tr>
<td>0701-0800</td>
<td>3</td>
<td>12(^a)</td>
<td>36.00</td>
</tr>
<tr>
<td>0801-0900</td>
<td>44</td>
<td>20(^a)</td>
<td>50.77</td>
</tr>
<tr>
<td>0901-1000</td>
<td>141</td>
<td>7 (4.73%)</td>
<td>46.31</td>
</tr>
<tr>
<td>1001-1100</td>
<td>152</td>
<td>1 (0.65%)</td>
<td>52.30</td>
</tr>
<tr>
<td>1101-1200</td>
<td>122</td>
<td>3 (2.40%)</td>
<td>61.94</td>
</tr>
<tr>
<td>1201-1300</td>
<td>47</td>
<td>1 (2.08%)</td>
<td>69.35</td>
</tr>
<tr>
<td>1301-1400</td>
<td>13</td>
<td>2 (13.33%)</td>
<td>72.33</td>
</tr>
<tr>
<td>1401-1500</td>
<td>6</td>
<td>1 (14.29%)</td>
<td>75.11</td>
</tr>
<tr>
<td>1501-1600</td>
<td>11</td>
<td>1 (8.33%)</td>
<td>73.16</td>
</tr>
<tr>
<td>1601-1700</td>
<td>0</td>
<td>1</td>
<td>67.03</td>
</tr>
<tr>
<td>1701-1800</td>
<td>0</td>
<td>0</td>
<td>55.87</td>
</tr>
<tr>
<td>1801-1900</td>
<td>0</td>
<td>0</td>
<td>46.76</td>
</tr>
<tr>
<td>1901-2000</td>
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<td>44.35</td>
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<tr>
<td>2001-2100</td>
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<td>42.86</td>
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<td>2101-2200</td>
<td>0</td>
<td>0</td>
<td>22.73</td>
</tr>
<tr>
<td>2201-2300</td>
<td>8</td>
<td>2</td>
<td>13.16</td>
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<tr>
<td>2301-2400</td>
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<td>8.89</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>549</strong></td>
<td><strong>51</strong></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Reflects deaths of unknown times (overnight and early the following morning)