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Changes in Population Structure of Diamondback Terrapins (*Malaclemys terrapin terrapin*) in a Previously Surveyed Creek in Southern New Jersey

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ABSTRACT. – Population structure of *Malaclemys terrapin terrapin* in an unaltered creek in southern New Jersey was compared to data collected 12–13 years earlier. I found significantly lower average carapace size of terrapins and lower frequency of adult females compared to the earlier survey, and speculate that road mortality of nesting females may be responsible for these trends.

The diamondback terrapin (*Malaclemys terrapin*) is endemic to United States coastal salt marshes. Major threats to this species include habitat loss (coastal development and wetland destruction), mortality from drowning in crab traps, and road mortality (Roosenburg et al. 1997; Wood and Herlands 1997). A combination of these factors has resulted in concern for this species' status and its listing as a "Species of Special Concern" in several states (Wood and Herlands 1997).

In southern New Jersey, the nesting season for diamondback terrapins lasts from late May to mid-July, and occurs primarily in sand dune and salt marsh habitats (Wood and Herlands 1997). Unfortunately, thousands of female terrapins are killed by motor vehicles each summer as they traverse roads adjacent to their nesting habitats (Wood and Herlands 1997). Elasticity analyses on other turtle species indicate that changes in survival of adults and subadults have the greatest proportional effect on population growth rate (Heppell 1998). Because growth rates of diamondback terrapin populations are likely sensitive to the same demographic parameters, and road mortality is an unnatural threat to mature females, it is important to assess whether terrapin populations are responding to these losses.

The primary objective of my study was to investigate diamondback terrapin population structure in an unaltered subtidal creek in southern New Jersey, and compare results to those found by Rountree et al. (1992) 12–13 years



Figure 1. Trapping sites were located in Schooner Creek and surrounding areas in Great Bay–Little Egg Harbor estuarine complex in southern New Jersey. Study sites are labeled as (1) Schooner Creek, (2) Hatfield Creek, (3) Fish factory, and (4) Rand’s Marina cove. Detailed view of Schooner and Hatfield creeks are shown in bottom left map. Upper left map courtesy of S. Hagan, other maps from MapTech Inc.

earlier in the same creek system. During the years between my study and that by Rountree et al. (1992), Hoden and Able (2003) documented high road mortality of adult female terrapins along the main road adjacent to the creek. This mortality may have influenced terrapin population structure that occurred since Rountree et al.’s (1992) survey. Because body size is closely correlated to age in terrapins (Cagle 1952), changes in size structure relate to changes in a population’s age composition. I expected a lower mean body size of terrapins and fewer adult females compared to Rountree et al.’s (1992) survey results from when there was presumably less road mortality. The road adjacent to the creek was not paved until the early 1990s, so vehicle traffic was less intensive and less of a threat to terrapins before Rountree et al.’s (1992) survey in 1988–1989. However, there is no documented road mortality data prior to 1988 to confirm this (K. Able, *pers. comm.*, December 2001).

Although drowning in crab traps is a substantial threat to terrapins across their range (Roosenburg et al. 1997), it should not be a factor affecting this population because the creek and its surroundings are closed to crabbing. Because diamondback terrapins exhibit high site fidelity and limited

dispersal (Gibbons et al. 2001), this population is functionally “closed” and it is therefore appropriate to compare demographic information collected in this study to results of Rountree et al.’s (1992) survey.

Secondary objectives of this study were to determine terrapin sex ratio and population size. This information could serve as a baseline for comparison in future monitoring efforts. Aspects of non-nesting terrapin habitat use (movement and distribution) in an unaltered creek were also described.

Methods. — During August–September 2001, I sampled brackish creeks and inlets in the Great Bay–Little Egg Harbor estuarine complex of southern New Jersey, with an emphasis on Schooner Creek near Rutgers University Marine Field Station (RUMFS), Tuckerton (39.508881 N, 74.32586 W) (Fig. 1). Schooner Creek is an unaltered subtidal creek with one connection to Great Bay, located 1.3 km from Little Egg Harbor inlet. It is 1160 m in length with a creek bed area of 24,000 m² (Rountree et al. 1992). The dominant surrounding vegetation includes *Spartina alterniflora* and *S. patens*, and at its closest point to a road, Schooner Creek is < 100 m away from Great Bay Boulevard. Depths at high tide range from 0.9 to 3.7

m from upper creek to mouth. The entire length of the study creek was surveyed to determine terrapin movement and distribution with respect to distance from creek mouth. Catch per unit effort (CPUE) was compared to water temperature, salinity, and time of day.

Areas near Schooner Creek (Hatfield Creek, a cove near Rand's Marina, and the old fish factory in Great Bay) were also sampled to determine whether terrapins were moving between creeks and to experiment with different trapping gear, including crab traps and gill nets, set for up to 5 hours (Fig. 1). However, the terrapins captured in these areas were not considered in population structure comparisons between the two studies, to maintain consistency with Rountree et al.'s (1992) survey of Schooner Creek.

Twelve crab traps were set at various depths at 100-m intervals along the length of Schooner Creek, beginning at 50 m outside of the mouth (at the RUMFS boat basin). The crab traps were commercial-style 58-cm³ box wire frames with 4 oval openings and a biodegradable panel. The openings were stretched to a 15 cm diameter, which exceeds the maximum width of terrapins, to allow large individuals to enter the traps. Traps were deployed for 3 to 5 hours at flood tide and retrieved at high tide. Traps were set and pulled between the daylight hours of 0700 and 1900, 5 days a week from 16 August through 27 September 2001. Each trap was baited with Atlantic menhaden (*Brevoortia tyrannus*) or bluefish (*Pomatomus saltatrix*) at every setting. At each setting, I recorded the date, time of day, weather condition, surface water temperature, and salinity at mid-creek (500 m).

All captured terrapins were marked for individual identification by filing notches into unique combinations of their marginal scutes (Cagle 1939). Straight-line mid-carapace length (CL) was measured to the nearest mm with a caliper. The sex of each turtle was determined using head and tail characteristics: males have proportionally narrower heads and longer, thicker tails than females (Lovich and Gibbons 1990). Adult females are generally much larger than males, with males reaching maximum CL of 140 mm, while females can grow to 250 mm (Carr 1952). All terrapins were processed and released at capture location. Care was taken that terrapins did not remain in traps longer than 5 hours, and no terrapins drowned during this study.

Rountree et al. (1992) did not distinguish between males and females in their measurements of terrapins, so I could not back-calculate an accurate sex ratio for their population. To detect changes in sex ratio between the 2 data sets, I used frequency of adult females as an index for comparison. I classified any individual with a CL of 140 mm or greater as an adult female. That threshold value was chosen because it corresponds to the maximum size attained by males and concurs with estimates of female size at maturity (Carr 1952; Montevecchi and Burger 1975; Hurd et al. 1979). It is likely that many of the smaller terrapins (CL < 140 mm) in Rountree et al.'s

(1992) sample were also female, but they cannot be differentiated from the males by CL measurements alone.

To compare size structure data between the 2 studies, I pooled male and female size measurements and double-counted recaptures for consistency with Rountree et al.'s (1992) data, which did not discriminate between sexes or account for recaptured individuals. Only the August–September samples from Rountree et al.'s (1992) data were used for comparison to reduce potential biases due to seasonal changes.

The date and location of each recapture were recorded. The program CAPTURE was used to determine the probability of equal capture and to estimate population size (White et al. 1982). For this test, the 28 days of sampling were separated into 4 trapping "occasions" of 7 days each. Population size was also estimated using a modified Lincoln-Peterson model for comparison (Krebs 1998). The first 3 trapping/markings episodes were considered the initial trapping/markings sample (n_1), and the remaining trapping days were lumped as the second sample (n_2) because most of the marking occurred within the first 3 days of trapping.

Differences in mean CL between turtles captured in 1988–1989 (Rountree et al. 1992) and this study were compared using a two-sample *t*-test. A Chi-squared test was used to determine significance in frequency differences of adult females (CL \geq 140 mm) found in this study and Rountree et al.'s (1992). CPUE was calculated as the daily number of terrapins captured (including recaptures) divided by trap-hours (= number of traps multiplied by number of hours). The relationships between CPUE and time of day, water temperature, and salinity were analyzed for correlation. Statistical tests were computed using the 1996 version of PC-SAS.

Results. — Fifty-three diamondback terrapins were captured in Schooner Creek, and 9 were caught elsewhere (1 in Hatfield Creek, 2 by Rand's Marina in Great Bay, and 6 near the old fish factory) (Fig. 1). The latter were not included in population size and structure analyses, for consistency and comparability with Rountree et al.'s (1992) data. Eight of the 53 marked turtles were recaptured within Schooner Creek, some on multiple occasions, for a total of 11 recaptures and 64 (53 + 11) independent capture events.

Female terrapins in Schooner Creek ranged in size from 95.4 to 190.0 mm CL, and males ranged from 98.3 to 120.7 mm CL. The mean CL of terrapins I captured ($= 118.4 \pm 2.48$) was significantly lower than Rountree et al.'s (1992) mean terrapin size ($= 154.3 \pm 3.29$, $n = 89$) ($t = 19.3255$, $df = 1$, $p = 0.0001$) (Fig. 2). Of the 53 terrapins captured in crab pots in Schooner Creek, 36 (68%) were females (of all sizes) and 17 (32%) were males. Of these 36 females, 8 (22.2%) were considered large adults (CL \geq 140 mm). Given this proportion, it is likely that many of Rountree et al.'s (1992) smaller terrapins (CL < 140 mm) were also female, although actual ratios are unknown. The frequency of adult females was significantly lower in this study ($8/53 = 15.1\%$) than

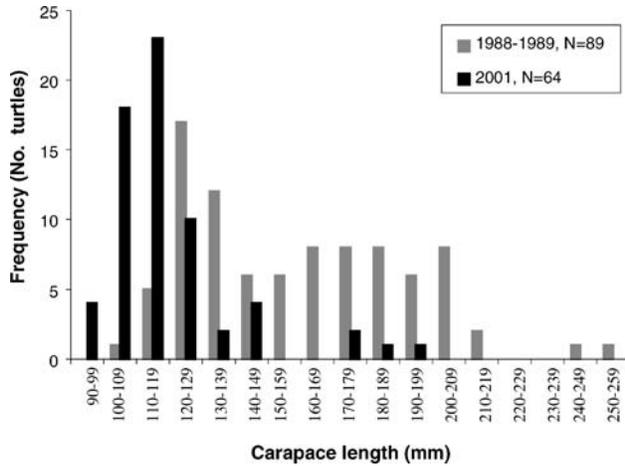


Figure 2. Size-frequency distributions of diamondback terrapins: comparison of CL data sets from 1988–1989 ($= 154.3 \pm 3.29$, $n = 89$; Rountree et al., 1992) and 2001 ($= 118.4 \pm 2.48$, $n = 64$; this study) ($p = 0.0001$).

in Rountree et al.’s (1992) survey ($55/89 = 61.8\%$) ($\chi^2 = 29.355$, $df = 1$, $p \leq 0.001$). Only 5 terrapins were caught in gill nets, 3 of which were female (60%) and 2 were males (40%).

The estimated population size in Schooner Creek was 119 ± 31.46 using the Lincoln-Peterson model. Program CAPTURE determined unequal capture probability of terrapins. Using the trap response model M_b (constant probability removal estimator), the program estimated a population size of 54 ± 1.65 individuals. With a 95% confidence interval, the population size in Schooner Creek was 57–181 (Lincoln-Peterson) to 54–62 (CAPTURE) individuals.

The 7 females that were recaptured ranged in CL from 104.4 to 129.7 mm, and the single recaptured male measured 116.7 mm. The number of days at liberty (days between captures and recaptures) was not correlated with distance traveled ($r^2 = 0.0033$). Days at liberty ranged from 1 to 25 days, and distance traveled ranged from 50 to 700 m (Fig. 3). No terrapin movement was detected

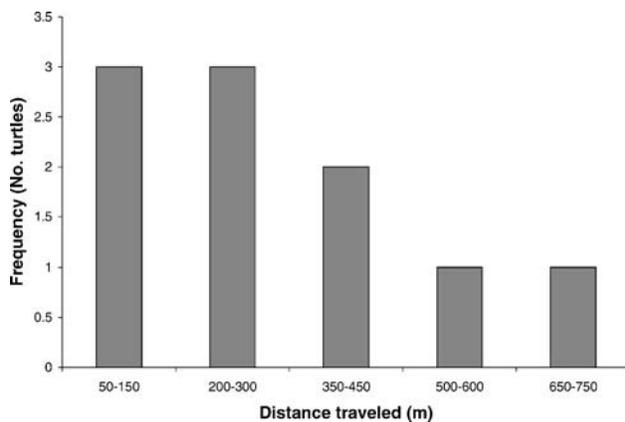


Figure 3. Frequency distribution of distance traveled between captures of diamondback terrapins in Schooner Creek, New Jersey, August–September 2001.

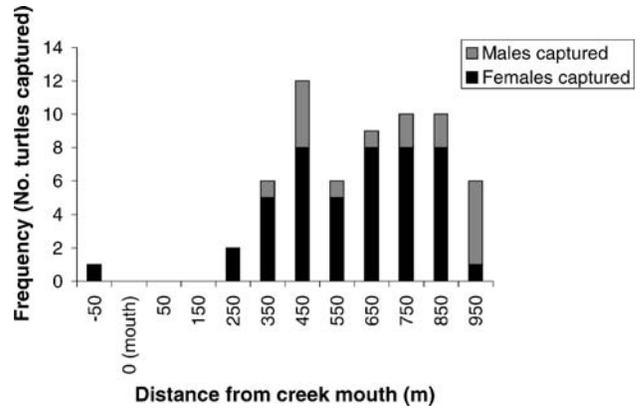


Figure 4. Diamondback terrapin capture frequency with respect to location in Schooner Creek, New Jersey, August–September 2001.

between Schooner Creek and the other sites. Only one terrapin was captured in a trap set within the lower 200 m of Schooner Creek, and all of the males were captured in the upper creek (Fig. 4).

Water temperatures during the trapping period ranged from 18° to 27°C, and salinity ranged from 27 to 30 ppt. The CPUE decreased over time (Fig. 5) and was significantly correlated with water temperature ($r^2 = 0.2507$, $df = 20$, $p = 0.0088$), but not with time of day ($r^2 = 0.0002$, $df = 25$, $p = 0.4708$) or salinity ($r^2 = 0.124$, $df = 21$, $p = 0.0964$).

Discussion. — Average CL was smaller in 2001 (118.4 ± 2.48 mm) than in 1988–1989 (154.3 ± 3.29 mm). The largest CL in this study was 190 mm, while Rountree et al. (1992) found CL up to 250 mm. They also found significantly more individuals in size classes greater than 140 mm, and fewer individuals in smaller-size categories (90–119 mm) than I found. The frequency of large individuals captured in my study was significantly less than it was in 1988–1989, which could be cause for concern. Because size and age are highly correlated in terrapins (Cagle 1952), the decrease in mean size may correspond to a loss of older females. The loss of adult females from the population due to road mortality could be responsible for this change in size composition.

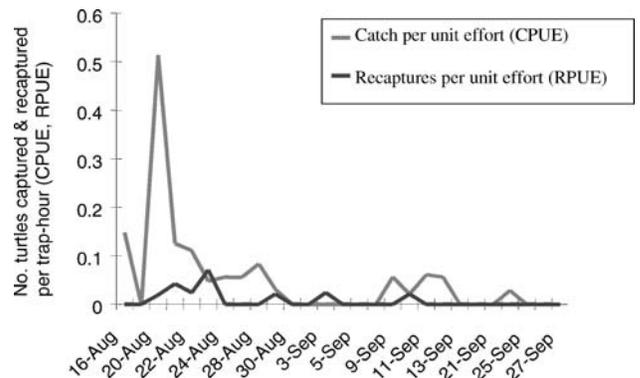


Figure 5. CPUE and recaptures per unit effort (RPUE) over time in Schooner Creek, New Jersey, August–September 2001.

Sampling bias may be partially responsible for the differences detected between the 2 studies. Rountree et al. (1992) pooled their captures from 3 subtidal creeks (including Schooner), sampled at the creek mouth only throughout ebb tides, and used active capture gear (weirs) rather than passive gear (crab traps). In this study, crab traps were set throughout Schooner Creek at flood tides and retrieved at high tide. Perhaps terrapins were rarely caught in the lower creek because they avoided this area at high tide. It may also be possible that smaller terrapins inhabit the upper creek while larger terrapins stay near the mouth, so Rountree et al.'s (1992) weir at the creek mouth yielded larger-sized captures. Furthermore, older (larger) individuals may have been more likely to avoid traps than younger individuals and thus could have been under-represented in this sample. If adults avoided crab traps and were distributed in the lower creek, it would explain why there were few captures in the lower creek, and few large individuals trapped in general.

However, it is doubtful that the gear-bias explanation fully accounts for the size-structure differences observed. I captured large individuals in the crab traps on several occasions, and other researchers have not found evidence for differential trap-avoidance by adults (M. Hoyle, *pers. comm.*, December 2001). I compared captures from crab traps and gill nets within Schooner Creek to determine whether there was a size bias due to collection gear. While there were too few captures in the nets ($n=4$) for significant conclusions, results indicated that terrapins caught in crab traps were similar in CL (100.0–118.7 mm) to those caught in gill nets (110.0–118.7 mm).

Although road mortality affects primarily female terrapins, the sex ratio could still be female-biased if the population has more females to start with (Hildebrand 1932; Hurd et al. 1979). Terrapin sex determination is temperature-dependent, with warmer incubation temperatures favoring production of females (Hildebrand 1932; Lovich and Gibbons 1990; Roosenburg 1996). There could be a naturally female-biased population near Schooner Creek if surrounding nest sites experienced warmer temperatures due to higher ambient temperatures, decreased shading from vegetation removal, or changes in characteristics of sediment deposits on the marsh. Because Schooner Creek is surrounded by abundant potential nesting habitat, there may also be a disproportionate number of females in the creek after the nesting season.

There are several assumptions associated with the Lincoln-Peterson model that, if not met, may cause biases in the population size estimate. The model assumes that the population is closed, meaning that no death, recruitment, or emigration/immigration occurred during the 2 sampling episodes n_1 and n_2 . It is unlikely that terrapins died or were recruited over the span of this sampling period, but movement in and out of Schooner Creek cannot be ruled out. However, none of the marked terrapins were captured at other sites, and terrapins recaptured in Schooner Creek generally did not move

far. Other studies confirm that terrapins exhibit high site fidelity, with little evidence for immigration or emigration (Hurd et al. 1979; Lovich and Gibbons 1990). These findings suggest that the closure assumption of this model can be accepted.

Program CAPTURE (White et al. 1982) concluded that there was a trap response and accounted for it in its population-size estimate by using the M_b model. If there actually was a behavioral response to traps by the terrapins (trap-avoidance), then program CAPTURE M_b is an appropriate population-size estimator. However, if unequal capture probability was due to emigration or reduced terrapin activity, the Lincoln-Peterson model is a more realistic estimator because it does not assume that marked terrapins have a lower capture probability than terrapins that were not previously captured.

There were too few recaptures to draw conclusions on terrapin movement patterns. However, it was noted that the terrapins were rarely captured in the lower 200 m of the creek, where Rountree et al. (1992) caught all of their terrapins with a weir. It is unclear why more terrapins were not captured in the lower creek, particularly males, as they were found exclusively in the upper creek (Fig. 4). Perhaps terrapins only passed through this area at certain times of day or tidal cycles (weir was set throughout ebb tides; traps set during flood tides). Disturbance, in the form of frequent boat activity or water intake by the field station, could also have influenced the terrapins' use of the lower creek. The abrupt drop in CPUE may have been due to a reduction in terrapin activity with the onset of cooler water temperatures, or perhaps a "trap-shy" behavioral response by the terrapins (Fig. 5). There was a trend for higher CPUE during sunny days than overcast days, but sunny days did not decrease in frequency over time.

Consistent long-term monitoring is necessary to detect temporal changes in the population size and structure. Regular surveys of roads and creeks, using comparable methods, should be conducted to detect population changes. It is also important to understand terrapins' habitat use after the nesting season and before the hibernation period, because environmental conditions and resources available to terrapins during this time may influence their future health and fecundity. Knowing when and how terrapins use marsh creeks could help identify critical habitat for protection.

Assuming that no gear or sampling bias occurred, the changes I detected in diamondback terrapin average body size and frequency of adult females over the 12–13 years are biologically and statistically significant. These time-related changes in population structure suggest selective mortality of adult females, a trend that terrapin populations cannot sustain, according to elasticity analyses. Because there is no crab-trap mortality in this area, road mortality of nesting females is a likely explanation for this age- and sex-specific loss, and if this is the case, conservation action will be required.

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Allometry and Sexual Dimorphism in the Snail-Eating Turtle *Malayemys macrocephala* from the Chao Phraya River Basin of Central Thailand

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ABSTRACT. – Allometric growth and sexual dimorphism of the shell is evident in *Malayemys macrocephala* from the Chao Phraya River Basin of central Thailand. Differences in allometric growth between males and females produce sexually dimorphic adults. Adult females exhibit larger sizes and have relatively wider and higher shells and longer plastra than males.

Brophy (2004) recently reviewed the systematics of the genus *Malayemys* (Testudines: Geoemydidae [Batacuridae]) and argued for the presence of two taxonomically distinct species. Analyses of head-stripe and shell characters revealed a clear pattern of geographic variation that was consistent with the topography of Southeast Asia and the poor dispersal abilities of these turtles. Turtles from the Mekong River Basin retained the name *M. subtrijuga* (Schlegel and Müller 1844), whereas those from the Chao