Status of Diamondback Terrapins
(*Malaclemys terrapin*) in North Inlet–Winyah Bay, South Carolina

Peter King¹,* and John P. Ludlam²

¹Department of Biology, Francis Marion University, Florence, South Carolina 29502 USA [pking@fmun.edu];
²Department of Biology and Chemistry, Fitchburg State University, Fitchburg, Massachusetts 01420 USA [jluudlam@fitchburgstate.edu]
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1Department of Biology, Francis Marion University, Florence, South Carolina 29502 USA [pking@fmun.edu];
2Department of Biology and Chemistry, Fitchburg State University, Fitchburg, Massachusetts 01420 USA [jludlam@fitchburgstate.edu] *Corresponding author

ABSTRACT. — Diamondback terrapin (Malaclemys terrapin) population dynamics in North Inlet-Winyah Bay, South Carolina, a relatively undeveloped salt marsh estuary, were determined from 6 yrs of mark-recapture data. Total terrapin abundance in 4 adjacent creeks was estimated annually at 260–360 terrapins (144–200 terrapins/km) and the mean annual survival probability for terrapins was 0.78. This study in a protected terrapin habitat will provide data for population models and comparisons with threatened populations.

Diamondback terrapins (Malaclemys terrapin) are obligate residents of coastal salt marshes and mangrove habitats along the Atlantic and Gulf coasts of North America and use these habitats for feeding, breeding, and nesting (Gibbons et al. 2001). Terrapins are prominent consumers in the salt marsh, where they feed on the periwinkle, Littoraria irrorata, as well as crabs, barnacles, and clams (Tucker et al. 1995). Terrapins may play an important role in the functioning of marine estuaries by consuming periwinkles, which can suppress salt marsh cordgrass (Spartina alterniflora; Levesque 2000; Silliman and Zieman 2001). Because they are long-lived animals with small home ranges, diamondback terrapins are an ideal sentinel species for assessing ecosystem health and environmental changes. We analyzed population structure and dynamics of diamondback terrapins in North Inlet-Winyah Bay, South Carolina, based on 6 yrs of mark-recapture data.

The coastal habitats that terrapins require are being altered by human population growth and development. Road and housing construction fragment dunes and marshes and terrapins may be killed when crossing roadways. Development also leads to habitat loss, nest-site alteration, and increased nest predation (Butler et al. 2006). Increased recreational fishing and boating have
Figure 1. Tidal creeks sampled for terrapins in North Inlet–Winyah Bay, South Carolina. Average catch per unit effort (number of terrapins per seineing visit) followed by number of visits in parentheses. Some sites were sampled multiple times per year. The DOT marsh site is indicated by a heavy dashed line. BA represents the terrapin breeding aggregation observed in March 2009.

Intensified impacts on marine life, especially in estuarine salt marshes. For example, terrapins may enter recreational crab traps and drown (Roosenburg et al. 1997). Nutrient enrichment alters the structure and function of salt marsh habitats (e.g., Deegan 2002) and climate change is causing increases in temperature and sea level (Nicholls et al. 2007).

Terrapin population status, habitat needs, and threats posed by encroaching development are nevertheless still not well understood. In South Carolina, the current status of diamondback terrapins is described as unknown due to insufficient population surveys (Butler et al. 2006; Griffin et al. 2006) and there is a similar lack of data in North Carolina and Georgia. Monitoring programs in both impacted and relatively pristine areas are needed to assess and mitigate the effects of development. The only published long-term study of terrapins in South Carolina found them to be declining in some areas near Kiawah Island (Hoyle and Gibbons 2000; Gibbons et al. 2001), with recreational crab trapping implicated as a contributing factor (Dorcas et al. 2007). The terrapins exhibited high site fidelity to tidal creeks in salt marsh areas around the island and there was very little migration to repopulate creeks where terrapins were extirpated. Mature female terrapins are larger than males and are less likely to enter crab pots because of the size of the trap openings. Thus, population age structure and sex ratios were altered by the capture of juveniles and small males in crab pots (Dorcas et al. 2007).

Terrapins are particularly vulnerable to human impacts due to their longevity and the relatively low survival of eggs and hatchlings (Burger and Garber 1995). Understanding how these threats affect population size and structure is critical in determining the long-term viability of populations. Baseline data on population dynamics and habitat use from relatively pristine estuarine areas such as the North Inlet–Winyah Bay estuary in South Carolina will contribute to state and national efforts to determine population statuses and develop conservation plans for this species. The objectives of the present study were to determine population size structure, sex ratio, and population dynamics using 6 yrs of mark-recapture data from a relatively pristine salt marsh. We expected terrapin survival to be lower for females because of mortality associated with reproduction (e.g., nesting activity and travel to nesting areas) and that females would have higher encounter probabilities because of their larger size.

Methods. — North Inlet–Winyah Bay (lat 33.33°N, long 79.18°W) is a relatively pristine 33-km² salt marsh estuary with extensive areas vegetated with salt marsh cordgrass (Spartina alterniflora; Fig. 1; Buzzelli et al. 2004) and is a designated National Estuarine Research Reserve. Low (intertidal) marsh within North Inlet–Winyah Bay is 23.4 km² in area (North Inlet–Winyah Bay National Estuarine Research Reserve 2013). Terrapin abundance and survival models were based on terrapin capture data from the 4 tidal creeks (Debidue W1, Old Man E4, Old Man E5, and Town After Old Man; combined seineed length = 1.8 km, mean = 0.45 ± 0.05 km SD) that drain a section of marsh (designated as DOT in Fig. 1). Capture data from these 4 creeks were combined for analysis because of the low overall number of recaptures. The DOT marsh site is bounded on 4 sides by large creeks that terrapins appear to use infrequently (Debidue, Old Man, and Town creeks) and on the fourth side by a large oyster flat. North Inlet is surrounded by undeveloped forest, Winyah Bay, and a barrier ridge. A low-density housing development is located to the north of the inlet. The inlet lacks public roads or a public boating access. Some fishing and commercial crabbing occurs in the inlet, but recreational crabbing is limited.

Terrapins were collected by seineing salt marsh creeks annually at or near low tide in the months of May–August 2006–2011 following methods of Dorcas et al. (2007). Trammel nets were not used in this study. More than 20 creeks have been seineed at least once during the study. Within the DOT marsh site, Old Man E4 and E5 were sampled beginning in 2006, Town After Old Man was
added in 2007, and Debidue W1 was added in 2008. All DOT marsh site creeks were seized at least once per year from 2008 to 2011 and the number of visits varied among years (2008, 12 visits; 2009, 12 visits; 2010, 14 visits; 2011, 8 visits). Terrapins were also collected by hand in creeks during seizure events. Each terrapin was sexed (adult males have a thicker and longer tail, adult females are larger and have wider heads) and carapace length (CL) was measured with calipers. Terrapins were individually marked by notching marginal scutes on the carapace (modified from Cagle 1939).

Abundance was estimated with a Jolly-Seber (JS) open population mark–recapture model (McGlinchy and Barker 2005; Pollock et al. 1990). Three models were evaluated: time-varying survival and capture probabilities, constant survival and time-varying capture probabilities, and constant survival and capture probabilities. The first 2 models were best supported by the data and results from the more parsimonious constant survival model are presented. An assumption of this method is that the sampling area is constant over time. Thus, only years when all 4 DOT marsh creeks were sampled (2008–2010) were included and data from the 4 creeks were pooled for the analysis.

Survival and encounter probability were estimated with a Cormack-Jolly-Seber (CJS) open population model for the DOT marsh site for 2006–2011. Survival modeling was performed in MARK 6.2 (White 2000) and candidate models were ranked using Akaike Information Criterion corrected for small sample size (AIC$_c$, Burnham and Anderson 2002). Four candidate models were evaluated. The global model ($\phi_t \times P_{it} \times P_{it}$) included gender and time dependence for encounter probability ($p$) and survival probability ($\phi$). The model ($\phi_t \times p_{it}$) represented the hypothesis that gender did not influence encounter or survival probability. The model ($\phi_t \times p_{it}$) represented the hypothesis that encounter and survival probability were constant over time. Dorcas et al. (2007) found seining caught more male terrapins than females compared with trammel nets, so we evaluated whether encounter probabilities were sex-biased using the model ($\phi_t \times P_{it}$), which represented the hypothesis that encounter probability, but not survival probability, differed by gender. Survival and encounter probabilities were model-averaged to produce reported parameter estimates and variances. Goodness-of-fit evaluated using a bootstrapping test and Program Release indicated that model fit was adequate. Model results were adjusted for over-dispersion with the variance inflation factor ($\hat{\sigma}$ = 1.12) to produce quasi-AIC values (QAIC$_c$).

**Results.** — Six years of seining in more than 20 creeks produced 413 terrapin captures and 118 recaptures overall. There were 67 turtles caught in 2 yrs, 10 turtles caught in 3 yrs, and 1 turtle caught in 4 yrs. The sex ratio of the 413 terrapins collected during the study was male-biased (2.4:1 male:female ratio). Males ($n = 290$) ranged in size from 100 to 135 mm CL (117.7 ± 6.4 mm SD) and females ($n = 123$) ranged from 128 to 191 mm CL (158.4 ± 12.8 mm SD; Fig. 2). Catch per unit effort varied among tidal creeks (Fig. 1) and was highest in the DOT marsh site and adjacent to North Island (4 sites in southeast of map).

In the DOT site there were 365 overall captures with 65 terrapins recaptured in the DOT site at least once in a subsequent year. The JS model with constant survival rate and time-specific capture probabilities estimated population abundance as 360 (95% confidence interval [CI] = 149–572) in 2009, 260 (95% CI = 69–451) in 2010, and 336 (95% CI = 8–663) in 2011 in the DOT marsh site (Fig. 1). Density (terrapins per seined creek length) in the 4 creeks in the DOT marsh ranged from 144 to 200. Capture probabilities were $0.10$ (95% CI = 0.03–0.18) in 2009, $0.33$ (95% CI = 0.08–0.58) in 2010, and $0.07$ (95% CI = 0.00–0.14) in 2011. Survival probability was estimated as 0.73 (95% CI = 0.43–1.00).

### Table 1. Model rankings for Cormack-Jolly-Seber open population model for the DOT marsh site for 2006–2011. Models described in detail in “Methods”. QAIC is quasi-AIC.

<table>
<thead>
<tr>
<th>Model</th>
<th>QAIC$_c$</th>
<th>$\Delta$QAIC$_c$</th>
<th>QAIC$_c$ weights</th>
<th>Model likelihood</th>
<th>No. of parameters</th>
<th>QDeviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_t \times p_{it}$</td>
<td>407.68</td>
<td>0.0</td>
<td>0.639</td>
<td>1.000</td>
<td>9</td>
<td>51.17</td>
</tr>
<tr>
<td>$\phi_t \times P_{it}$</td>
<td>408.91</td>
<td>1.2</td>
<td>0.345</td>
<td>0.539</td>
<td>14</td>
<td>41.61</td>
</tr>
<tr>
<td>$\phi_{it} \times P_{it}$</td>
<td>415.01</td>
<td>7.3</td>
<td>0.016</td>
<td>0.026</td>
<td>18</td>
<td>38.82</td>
</tr>
<tr>
<td>$\phi \times p_{it}$</td>
<td>433.55</td>
<td>25.9</td>
<td>0.000</td>
<td>0.000</td>
<td>2</td>
<td>91.58</td>
</tr>
</tbody>
</table>
The 2 best supported CJS mark–recapture models ($\hat{p}_t$, $P_0$, and $P_0 P_{ex}$) based on AICc indicated that both survival and encounter probabilities varied with time (Table 1; Fig. 3). Additionally, in the second-ranked model, encounter probabilities differed by gender. There was little support for differences in survival between the sexes over time. Likewise, there was little support for constant survival and encounter probabilities over time. Model-averaged survival probabilities ranged from 0.69 to 1.00 and were highest from 2007 to 2008. Encounter probability was highest in 2008 and 2010 and encounter probabilities were higher for females than for males (mean = 0.264 for females, 0.226 for males; Table 1, Fig. 3).

Terrapins tended to be recaptured in the same creeks where they initially had been captured (86 of 99 DOT marsh site captures, 87%). For all creeks sampled, only 12% of terrapins were recaptured in a different location from their first site of capture (8 females and 6 males). One mature female terrapin was captured in a nesting area and recaptured in the DOT marsh site 1.3 km away and 1 mature female crossed a large subtidal channel (Old Man Creek, 250-m width). The remaining relocations occurred within the DOT marsh site over relatively short distances, <700 m from creek mouth to creek mouth. Females were more likely to disperse than males relative to the 2:4:1 male:female population sex ratio ($\chi^2_1 = 5.021$, $p = 0.025$).

Discussion. — Terrapin populations are of declining or poorly known status throughout their range and declines have been associated with intensive human activity, including recreational crab trapping (e.g., Dorcas et al. 2007). In contrast, our study was conducted in the relatively pristine and isolated North Inlet–Winyah Bay. The normal size distribution of both males and females indicates recruitment of young terrapins into the adult population (Fig. 2). This contrasts with the modal size distribution of a declining population described by Dorcas et al. (2007), where the average size of both males and females increased over time with declining recruitment of juveniles. Terrapins < 100 mm in CL were not encountered in our study and the juvenile habitat refuge used before joining the adult population has not been found in North Inlet. The mesh size (2.5 cm) of the seines was such that small juveniles would have been caught had they been present.

We estimated the terrapin population of 4 adjacent creeks in the DOT marsh site at 260–360 terrapins annually (approximately 144–200 terrapins/km). In our study, terrapin abundance did not appear to be declining, but low recapture rates in some years produced large CIs around our estimates. In comparison, Grosse et al. (2011) measured terrapin density in 29 creeks in Georgia across a gradient of anthropogenic pressures (crabbing and road proximity). Median density was 65 terrapins/km, but density was negatively related to crabbing pressure. On average, creeks without crab pots had about 170 terrapins/km whereas creeks with ≥3 crab pots had about 16 terrapins/km. Crab pots were not used in creeks within the DOT marsh site, although pots were set in nearby large subtidal channels. Dorcas et al. (2007) estimated terrapin population size in 4 creeks near Kiawah Island, South Carolina, at approximately 100–500 terrapins per creek, but creek length was not provided. Terrapin populations in 3 of the 4 creeks sampled at Kiawah Island declined over time, probably because of by-catch in crab traps (Hoyle and Gibbons 2000; Dorcas et al. 2007), and terrapins were exterminated in 1 creek during the study. Direct comparisons of total population size or density among studies are difficult because most studies estimate abundance per creek rather than per area or creek length and creeks vary in size. Terrapins may spend more time foraging and basking in the low marsh than they do in creek habitats (Harden et al. 2007) but terrapins are most easily collected in creeks and at nesting sites (e.g., Mitro 2003).

In general, turtles are long-lived animals with high egg and hatchling mortality, so adult survival is critical to population persistence. In our study, top-ranked models included time-dependent encounter and survival probabilities and gender-dependent encounter probabilities. We
expected female survival to be less than male survival because of risks associated with reproduction, but top-ranked models did not include gender-dependent survival probabilities. Tucker et al. (2001) also found survival rates for male and female terrapins were similar, though female survival was more variable.

Surprisingly, estimated terrapin survival probability (CJS model) in our study (mean = 0.78) was lower than reported estimates in the literature from both stable (Hart 1999; Mitro 2003) and declining populations (Tucker et al. 2001), although they are within our 95% CIs. Mitro (2003) found that female terrapin survival probability in a Rhode Island marsh declined from 0.959 to 0.944 from 1990 to 2000. Hart (1999) found terrapin survival probability in a Massachusetts marsh was 0.86 from 1980 to 1996. Tucker et al. (2001) found terrapin survival probability in 4 creeks at Kiawah Island, South Carolina, from 1982 to 1998 was 0.84 and was similar for males and females. However, our estimates did not have a temporal trend, whereas Tucker et al. (2001) demonstrated negative trends over time, with survival probabilities in some creeks declining to less than 0.50. Terrapin population declines at Kiawah Island were associated with recreational crabbing (Hoyle and Gibbons 2000; Tucker et al. 2001). Survival probability of adults is one important aspect of stability in a population, but lower survival probability can be compensated for by higher recruitment. It is possible that the lack of recreational crabbing and other human interference in this relatively protected area allows sufficient juvenile survival to create the conditions of stability in abundance observed. Such an evolved balance is dependent on many environmental factors, including food resources and predation not recorded in this study. However, lower survival probabilities of adults in North Inlet–Winyah Bay may indicate a greater fragility and susceptibility to human disturbance than populations in the Rhode Island marsh (Mitro 2003) and a Massachusetts marsh (Hart 1999).

Terrapins tended to be recaptured in the same creeks over time, but females were more likely to move than males. Likewise, Tucker et al. (2001) found that net movement probabilities among creeks were higher for females than males (0.044 for males vs. 0.215 for females). Other studies have also demonstrated limited movement in terrapins, apart from female movement to nesting areas (e.g., Gibbons et al. 2001; Dorcas et al. 2007). However, Sheridan et al. (2010) found that female terrapins have larger home range sizes than male terrapins and that approximately 21.5% of terrapins at 1 site were captured at multiple locations. In contrast, genetic measures of dispersal demonstrated high levels of gene flow within the population (Sheridan et al. 2010). In March 2009, an aggregation of about 100 terrapins was observed in a deep-water channel, Debidue Creek. The aggregation included males and females and they appeared to be a mating aggregation. This was observed from the surface, with females surfacing to breathe with males behind them. Mating aggregations within a population provide an explanation for gene flow within that population yet general low dispersal and site fidelity to certain key parts of a home range.

In conclusion, North Inlet is a relatively pristine terrapin habitat, and there was no evidence of terrapin population declines during the course of this study. This study adds to our knowledge of the status of diamondback terrapins in South Carolina, which is currently described as unknown (Griffin et al. 2006). Other terrapin studies in the region have tended to focus on impacted and declining populations (e.g., Dorcas et al. 2007) and there is a need for studies at reference sites to provide data for comparison with threatened populations. Moreover, this study provides baseline data on population dynamics and habitat use in a relatively protected habitat that can be used in population models and to develop conservation plans. Clearly, more work is needed to understand the conservation status of terrapins throughout their range.

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LITERATURE CITED


