Validation of Trammel Netting as a Means for Computing and Monitoring Population Trends for Diamondback Terrapins in the Charleston Harbor Complex

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ANNUAL REPORT TO THE U.S. FISH AND WILDLIFE SERVICE

For

Validation of Trammel Netting as a Means for Computing and Monitoring Population Trends for Diamondback Terrapins in the Charleston Harbor Complex

by

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EXECUTIVE SUMMARY

One hundred twenty-eight diamondback terrapins captured in creek and river habitats near Duck Island, SC (Ashley River, Charleston County) between April and October 2013 were examined, measured, sampled, tagged, and released. In addition to conventional marking and tagging, a subset of 12 females and 9 males was tagged with acoustic transmitters to investigate spatial distribution patterns, with an emphasis on investigating movement between creek and river habitats. Two techniques were used to locate acoustically-tagged terrapins (mobile searches and fixed position receivers); however, >99% of the data collected in the present study was derived from fixed position receivers.

Through 8 November 2013, a total of 58,752 unique detection events were recorded for these 21 diamondback terrapins (range = 494 to 5,629 detections per terrapin) at the Duck Island study area. Eighty-nine percent of detections were recorded by seven receivers deployed in river habitats, with the remainder of detections recorded by five receivers deployed in creek habitats.

Detections in both habitats were greatest during April and May, with a pronounced decline thereafter. Seasonal detection trends were highly correlated between males and females. Similar detection levels were observed for both males and females through June; however, between July and October, daily detections for males were nearly three times as great as for females. Seasonal detection trends were also highly correlated with seasonal catch rates for other sites in the Ashley River since 1995, but did not correlate as well to catch rates at the five trammel net sites associated with the present study. Variability in water temperature and salinity after the spring detection peak did not appear to exert much influence on detection patterns.

Contact with acoustically-tagged terrapins generally lasted <10 minutes during each detection event, reinforcing the cryptic nature of this species due to behavioral traits such as foraging in marsh grass which attenuates acoustic signals. Acoustically-tagged diamondback terrapins were detected by at least four and upwards to all 12 receivers deployed in the study area. Two individuals were also detected by similar receivers deployed 5 to 10 km away by another study, and these two individuals were the only terrapins known to emigrate away from the study area. Within-season spatial distribution patterns reflected variability among individuals, which has profound implications for analysis of catch rate data. Thus, we recommend continuation of telemetry data collection efforts until the observation data set is sufficiently robust to reliably predict the occurrence of diamondback terrapins across a range of trammel net sampling sites.

One generality which emerged in year one was that detection in creek habitats was significantly greater on flood tide stages, whereas the inverse observation was true for detection in river habitats. Detections occurred throughout the diel cycle, with a strong correlation between time of day and tide stage between creek and river habitats. These observations collectively suggest that terrapin activity is more influenced by water level than by photoperiod. Given that the trammel net survey samples predominantly during ebb tide stages, the long-term trammel net data set appears to be appropriate for monitoring temporal population changes once catch rates are adjusted for water level and other potential influences on marsh-edge river occurrence. A multivariate analysis to evaluate a corrective catch rate model will be developed in year two.

Introduction

Diamondback terrapins (*Malaclemys terrapin*) are the only exclusively estuarine turtle in North America (Wood, 1977) and are distributed between Massachusetts and Texas. Maximum carapace length is <30 cm (Ernst et al., 1994) and morphological differences between larger females and smaller males (Ernst et al., 1994) minimize foraging niche overlap between the sexes (Tucker et al., 1995; Levesque, 2000). In the late 1800's, diamondback terrapins were prized table fare; however, that commercial market crashed within a few decades following overharvesting (Carr, 1952). This long-lived species (Hildebrand, 1932) remains globally listed at low but near threatened risk (IUCN; http://www.iucnredlist.org/details/12695/0). In South Carolina, diamondback terrapins are one of 52 species in the reptile/amphibian guild that is listed as a species of concern (SC CWCS 2005, p. 2-11).

A terrapin fishery exists in South Carolina, but is "managed with discretion" due to the limited spatial and temporal scope of biological data (SC SWAP, 2005). Although no harvest permits for this fishery have been issued since at least 2004[1], fisheries mortality continues to occur annually in South Carolina as a result of incidental capture and subsequent drowning in crab traps (Roosenburg et al., 1997; Dorcas et al., 2007; Grosse et al., 2011). Incidental capture rates for diamondback terrapins in South Carolina waters are unknown, but as much as 78% of a local population has been estimated to be captured annually in other regions (Roosenburg et al., 1997). Despite this observation, mitigation measures to minimize diamondback terrapin entry into crab traps have not been mandated in South Carolina (unlike in other states) due to associated reductions in crab catches based on evaluations conducted to date (Powers et al. 2009a).

The development and implementation of "long-term coastwide standardized surveys to estimate the abundance and distribution of South Carolina's terrapin population" is a top Conservation Action for this species of concern in the South Carolina Wildlife Action Plan (SC SWAP, 2005). Diamondback terrapins are the fifth most frequently encountered species captured in a coastwide trammel net survey designed to monitor inshore fisheries (Arnott et al., 2013), and more than 18,000 diamondback terrapin collections have occurred in this survey since 1995[2]. Pronounced seasonal variability in catch rates is noted, with peak captures in the spring (Arnott et al., 2013) concurrent with peak incidental catch rates in commercial crab traps (Powers et al., 2009a). Spatial disparity in catch rates in this survey is also reported, with annualized catch rates in the Ashley River being twice as great as all other survey areas (Arnott et al., 2013). Across years, catch rates in the Ashley River have also remained relatively stable, whereas catch rates in the Wando River (which has historically had lower catch rates than the Ashley River; Bishop, 1983) have steadily declined since 1995, consistent with the statewide trend (Arnott et al., 2013).

In light of the degree of variability in catch rate trends among the estuaries sampled by the SCDNR trammel net survey, comprehension of the conditions that influence the 'detectability' (Anderson, 2001) of diamondback terrapins being present at trammel net sites is needed before this long-term catch rate data set can reliably be used for describing temporal trends. Mark- and

[1] Angel Curry-Brown, Permit Coordinator, Office of Fisheries Management, South Carolina Department of Natural Resources. Personal communication (email correspondence; BrownAC@dnr.sc.gov), 19 November 2013.

[2] Unpublished data. Inshore Fisheries Section, Marine Resources Research Institute, South Carolina Department of Natural Resources. Data provided by Dr. Steve Arnott, Principal Investigator.

tag-recapture data suggest small home ranges and fidelity to in-water and terrestrial capture sites (Gibbons et al., 2001; Szerlag-Egger and McRobert, 2007; Sheridan et al., 2010), which has led some to suggest their use as a sentinel species in contaminant studies (Blanvillain et al., 2007). Seasonal catch rate trends reported for South Carolina estuaries since 1995 are consistent with patterns reported for a Delaware Bay salt marsh in 1975 (Hurd et al., 1979), suggesting that the early season aggregation followed by dispersal is endemic to this species throughout its range. Localized within-season movements are also reported from radio and acoustic telemetry studies from numerous estuaries in the southeast U.S. (Spivey, 1998; Butler, 2002; Estep, 2005; Harden and Southwood Williard, 2012). Within-season movements likely reflect foraging forays given the diversity and tidal-mediation of prey consumed by this species (Tucker et al., 2001).

Tidally-mediated foraging suggests a high degree of variability in detectability of diamondback terrapins across habitat types, and therefore should be evaluated on a survey-specific basis. Tucker et al. (2001) reported that six radio-tagged female diamondback terrapins "…used creeks and tidal drainages as primary travel corridors both with and against currents during all tide levels." Foraging in the marsh consistently occurred when the marsh was flooded, but variable strategies such as burying in the mud or returning to main channels was observed as the waters receded (Tucker et al., 2001). These observations suggest a low probability of occurrence for diamondback terrapins in river edge habitats sampled by the trammel net survey, which are located adjacent to numerous creeks and tidal drainages as desribed by Tucker et al. (2001). Therefore, in spring 2013, we initiated an acoustic telemetry study to compare residence and movement patterns between river and creek habitats in order to evaluate the validity of using the trammel net data set as a means for monitoring long-term relative abundance trends for diamondback terrapin populations in South Carolina waters. Our objectives were as follows:

1) Test the null hypothesis of no difference in demographic parameters between river and creek captured diamondback terrapins.

2) Test the null hypothesis of no difference in residence and emigration patterns in river vs. creek habitats overall and with respect to diamondback terrapin sex.

3) Assess the correlation between seasonal catch rates in a subset of trammel net stations and seasonal detection patterns in the acoustic telemetry study for the same stations.

4) Test the null hypothesis of no difference in localized movement patterns between diamondback terrapins captured in river vs. creek habitats overall and among sexes.

5) Test the null hypothesis of no difference in detection frequency with respect to tide stage, and assess the correlation between detections within the ebb tide stage during which 91% of all sampling effort in the SCDNR trammel net survey is associated[2].

6) Test the null hypothesis of no difference in detection distribution with respect to time of day, and assess potential interaction in detection trends throughout the day with regards to tide stage.

Methods

Study site description

This study was conducted in the Ashley River, the southernmost tributary of Charleston Harbor. Within the Ashley River watershed, the South Carolina Department of Health and Environmental Control (SCDHEC) reports 3,017.2 acres of estuarine habitat, and surface water quality is most often listed as "SA" (https://www.scdhec.gov/environment/water/shed/docs/50202-040.pdf).

We selected the Ashley River for this study given that it has consistently supported the highest diamondback terrapin catch rates of all estuaries sampled since 1995 (Arnott et al., 2013), which increased the probability of capturing adequate sample sizes for this study. Relative stability in annualized catch rates in the Ashley River since 1995 (Arnott et al., 1995) also suggested that the data collected during this telemetry study were more likely to reflect representative behaviors rather than a recent response to changing population structure.

Within the Ashley River, we deliberately selected five stations located near Duck Island, a large hummock island located on the south/west side of the river and situated nearly equidistant between the freshwater/saltwater dividing line and the Atlantic Ocean (Figure 1). Watershed development on the south/west side of the Ashley River at this location is predominantly of a residential nature, whereas development on the opposite side of the river (where the SCDHEC maintains a water quality monitoring station) is largely industrial. Consistent with our decision to conduct this study in the Ashley River, high catch rates relative to other Ashley River trammel net sites (Figure 2) also factored into the selection of the specific study sites; however, similar amounts of creek and river habitat, particularly around the island itself (Figure 3), were also an important consideration. Furthermore, these five trammel net stations were also associated with a diversity of adjacent marsh habitat abundance, creek order, and river width scenarios. Because of high catch rates in the trammel net survey in the Ashley River, most of the 1,245 terrapins tagged or marked in conjunction with five graduate theses (Levesque, 2000; Lee, 2003; Estep, 2005; Schwenter, 2007; Broyles, 2010) and one dissertation (Hauswaldt, 2004) between 2000 and 2010 originated in the Ashley River and were possibly available for recapture in our study.

Figure 1. The Duck Island study area in the Ashley River was located nearly equidistant between the freshwater/saltwater dividing line and the Atlantic Ocean.

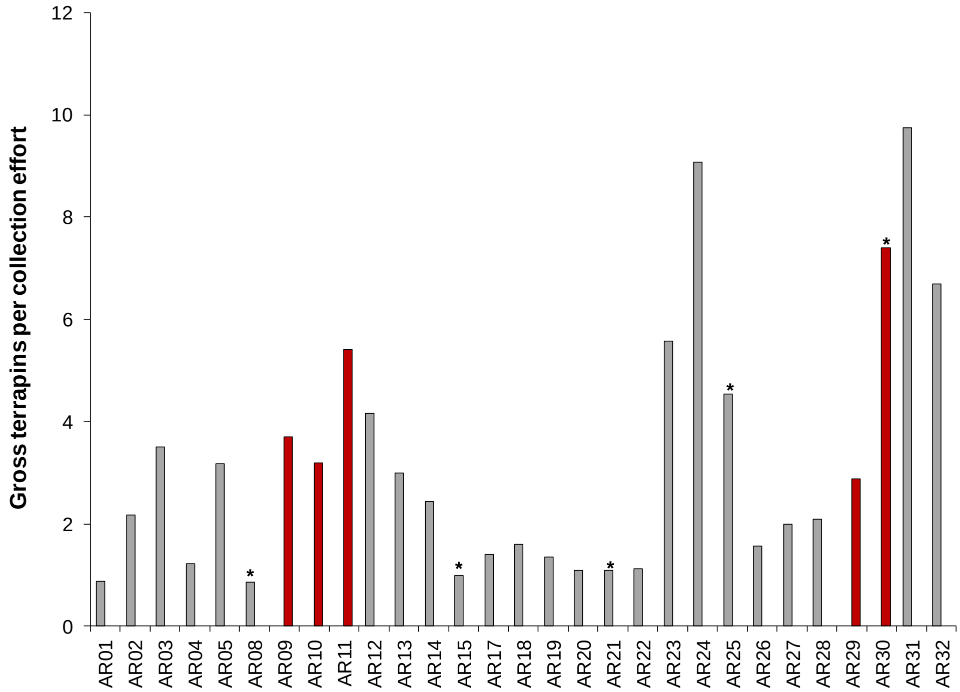

Figure 2. Gross diamondback terrapin capture rates at five sites near Duck Island (red bars) were among the highest reported among 29 trammel net sampling locations within the Ashley River since 1995. Asterisks indicate locations with <40 total collection efforts since 1995.

Figure 3. Similar amounts of river-edge habitats were associated with five trammel net stations (yellow text) near Duck Island and adjacent creeks (white text), and this study area was also associated with a diversity of marsh expanse, creek order, and river width conditions.

Capture and general processing
Diamondback terrapins collected for this study were primarily captured by trammel netting at locations near Duck Island that were randomly selected each month.

The trammel net (Figure 4a) is a 600 ft. monofilament net consisting of multiple panels with a minimum mesh size of 4" (stretch), which is rapidly deployed from the stern of a skiff along ~450' of shoreline as described by Arnott et al. (2013). After an initial soak of approximately five minutes, during which time noise is used to 'spook' fish and terrapins from the marsh grass into the net, it is steadily retrieved over a period of about 20 minutes.

A short (100 ft.) section of trammel net was also used sporadically in the creek to capture terrapins, and this gear was fished in the traditional manner as well as set across the creek to capture terrapins as they drifted down current. Short duration (<5 minute) sets were also made with a 15 ft. (1 in. stretch mesh) otter trawl (Figure 4b) from a 21' Privateer (125 HP motor) towing at ~1000 RPM. This sampling technique was used in both creek and river habitats.

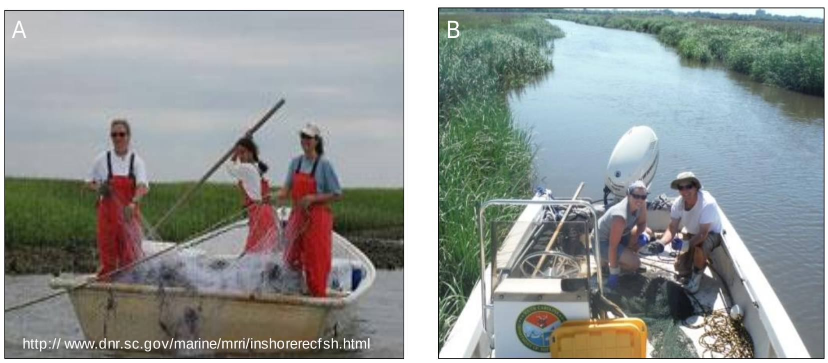

Figure 4. Diamondback terrapins were predominantly captured using a 600' trammel net (A), but sampling with a 15' otter trawl (B) was also used to collect specimens in 2013.

Captured terrapins were externally marked with a grease pencil to differentiate among capture locations while they were held in aggregate in a large, ventilated plastic bin which was partially covered to provide shade. With few exceptions, data were collected after terrapin transport to a climate-controlled, shore-based facility; terrapins were held overnight and released as close as possible to their capture locations the next day. Standard data collection included:

- Visually inspect terrapins and note pre-existing marks and injuries
- Assess sex based on dimorphism (head/body size, cloaca position/tail length)
- Scan all soft tissue for the presence of a PIT tag
- Measure (straight-line, cm) carapace length, width, and body depth with calipers
- Record body mass (kg) using a digital spring-scale
- Photograph dorsal, ventral, and lateral perspectives
- Drill small holes in marginal scutes using a multi-letter combination coding system
- Attach flexible shellfish tags (Floy Tag, Inc.) to the carapace using epoxy
- Assess reproductive condition of females using ultrasound
- Opportunistically collect and exam fecal matter to identify forage items

During the course of this study, two regional collaboration opportunities also arose. The first involved the removal of barnacles for a Ph.D. student (Christine Ewers) at the University of Georgia studying barnacle phylogeny. The second involved the collection of blood and keratin for assessing geographic variability in stable isotope levels among diamondback terrapins for a study managed by Dr. Kristin Hart of the U.S. Geological Service in Davie, Florida.

Acoustic transmitter attachment and evaluation

Because sexual dimorphism reduces foraging niche overlap (Tucker et al., 1995) and because prior to this study multi-season very little habitat use data were available for male diamondback terrapins (Harden and Southwood Williard, 2012; Tulipani, 2013), we wished to study males as well as females. The sampling design goal was to attach acoustic transmitters to six adult male and six adult female diamondback terrapins captured in both creek and river habitats in order to compare residence and movement patterns with respect to sex and habitat type.

Prior to attachment, barnacles and encrusting bryozoans were gently scraped from the vertebral and costal scutes while fine-scale organic matter such as algae was scrubbed off using alcohol-soaked gauze pads. Loose keratin scutes were carefully peeled away and 100-grit sandpaper was lightly applied to ensure no loose keratin remained.

Acoustic transmitters (V9-2H; Amirix Systems, Inc.) were attached to the second vertebral scute, but offset from center due to the vertical relief associated with vertebral scutes. A base layer of epoxy was first pressed to the carapace across at least three scute seams to minimize the risk of transmitter loss due to detachment of a single scute. The epoxy was molded into a shape that had a centralized dome. Next, the transmitter was pressed onto the epoxy dome with the transducer end of the transmitter facing towards the rear of the animal. In "pig in a blanket" fashion, epoxy was then applied over top of the transmitter and blended evenly.

Acoustic transmitters measured 9 mm (diameter) by 29 mm (length) and weighed 4.7 g in air (2.9 g in water). Approximately 9.5 g of a two-part epoxy putty (SonicWeld™; Ed Greene and Company) was used to secure these transmitters to the carapace. This use of a quick-setting epoxy to attach transmitters is standard for most diamondback terrapin telemetry studies conducted to date (Spivey, 1998; Butler, 2002; Harden and Southwood Williard, 2012), and has resulted in transmitter retention for nearly a year. For male diamondback terrapins, the total weight associated with the transmitter plus epoxy exceeded the 2% of body weight rule suggested by Winter (1996), but was comparable to transmitter package weights (4 to 39 g) previously reports for this species (Spivey, 1998; Harden and Southwood Williard, 2012).

Estep (2005) also achieved an annual transmitter-retention rate by drilling a hole in the marginal scutes and then securing acoustic transmitters with a plastic zip-tie before applying epoxy; however, this technique was only used with female terrapins. Thus, prior to initiating the present field study, we compared these two attachment techniques, as well as evaluated a third brand of quick-setting epoxy in partnership with the South Carolina Aquarium.

On 10 October 2012, 'dummy' transmitters were attached to three males and two females using the drill-and-secure method as well as attached to the anterior carapace of female terrapins using the epoxy-only method. One male and one female served as study controls. Animal care and tagging was monitored closely by the South Carolina Aquarium veterinarian, Dr. Shane Boylan, D.V.M., who also anesthetized and recovered the five diamondback terrapins subjected to marginal scute drilling. Direct, qualitative observations indicated no difference in behavior between untagged and tagged terrapins upon return to familiar habitats a day after handling and processing (Figure 5). Three drill-and-secure transmitters were shed or otherwise detached after 176 to 393 days; the fourth transmitter was lost after 84 days when a male died from causes unrelated to tagging, and the fifth transmitter remained attached to a male diamondback terrapin as of 20 November 2013. The first epoxy-only transmitter was shed after 394 days, but the second remains attached. Based on initial results, we opted to use the epoxy-only technique in the field study, but restricted transmitter attachment to males ≥300 g (Tulipani, 2013) despite the smallest male in the transmitter retention study at the South Carolina Aquarium weighing 340 g.

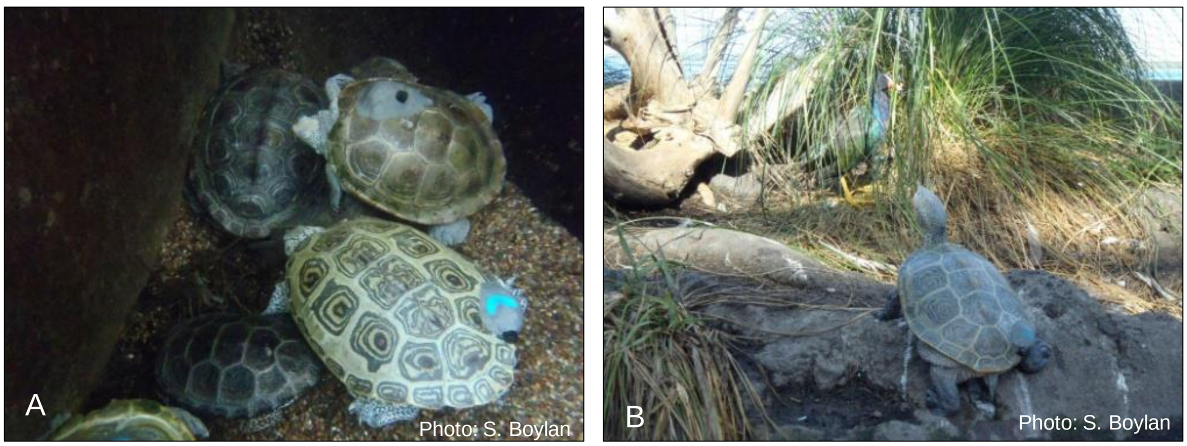

Figure 5. Tagged and untagged diamondback terrapins displayed no evidence of altered behavior in (A) or out of (B) the water after being returned to their familiar aquarium habitat.

Acoustic telemetry data collection
Acoustic transmitters emitted coded signals (which distinguished individual terrapins) on a frequency of 69.0 kHz at random intervals between 180 and 300 seconds.

VR2W receivers (Amirix Systems, Inc.) were deployed near the water surface in a PVC (Sch 40) housing that floated, with the hydrophone end of the receiver facing downward (Figure 6a). This housing slid up and down a 1.5 in. diameter galvanized pole that measured 14 to 21 ft. in length depending on water depth and sediment consistency. Housing buoyancy was provided by an air and foam-filled PVC base and later augmented by surface-oriented air-filled PVC tubes. A 2 in. diameter PVC pole that measured 15 to 20 ft. in length (of which <5 ft. was exposed at high tide) was positioned behind each galvanized pole to restrict the receiver housing from swaying during water level changes, as well as to mark the site during the highest water levels.

Acoustically-tagged terrapins were also detectable from the research vessel using a VR60 receiver and omni (VH65) and directional (V10) hydrophones (Figure 6b). This boat-based system enabled searches for acoustically-tagged terrapins to be conducted in areas outside of the reception range (estimated to be <200 m) from the fixed site VR2Ws, such as in the upper reaches and bends of creeks where direct line-of-sight fetch was limited.

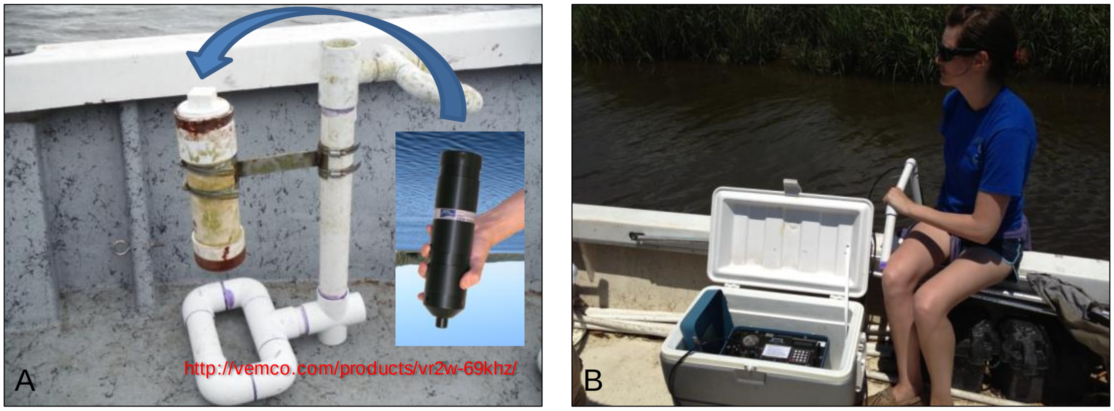

Figure 6. Acoustic detections were recorded by VR2W receivers deployed in buoyant PVC housings (A), as well as opportunistically by a VR60 receiver and hydrophone system (B) during visits to the study area.

VR2W acoustic receivers were deployed at five trammel net locations regularly sampled by the trammel net survey, at five sites across two creek systems adjacent to Duck Island, and at two locations in the Ashley River on the north and south side of the confluence of the largest creek system monitored in this study (Figure 3). Acoustic receivers provided continuous monitoring capability when submerged; however, because of the tidal nature of this study area, all receivers were exposed at low tide (Figure 7). Nonetheless, trammel nets can only be deployed when sufficient water levels are present; thus, the VR2W receivers monitored the entire tidal window of opportunity that trammel net sampling could occur each day of the study. VR2W receivers were removed from PVC housings every four to six weeks and the data were uploaded to a laptop computer using the VUE software and a Bluetooth USB connection. Concurrent with data uploading, biogenic fouling was removed from the PVC housing. Prior to redeployment ~10 minutes later, lithium grease was re-applied to the threaded fittings for the PVC housing cap and the stopper coupling on the galvanized pole, to assist with future data uploading missions.

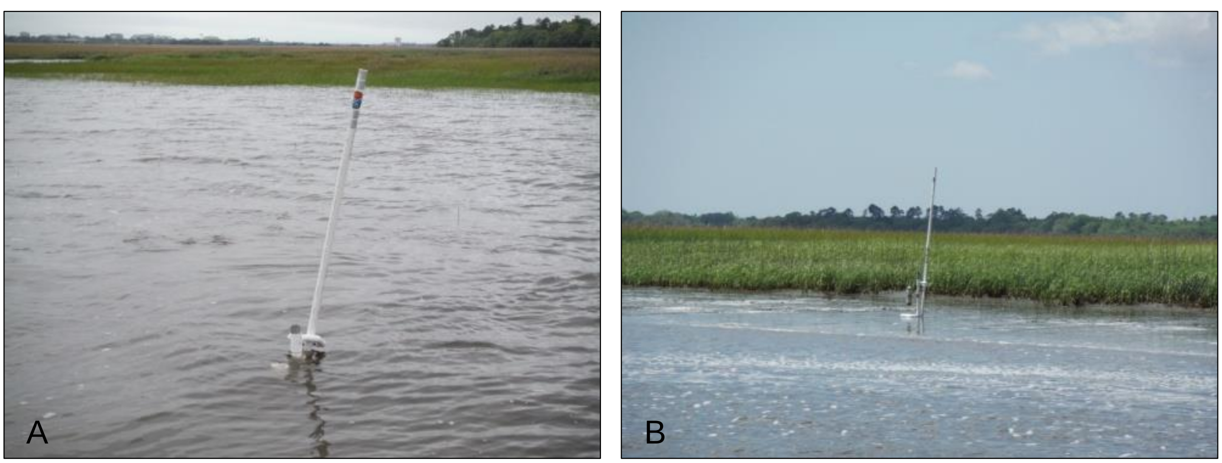

Figure 7. VR2W receivers provided continuous monitoring coverage when submerged (A), but were exposed at low tide (B) due to large tidal amplitudes typical of estuaries in this region.

Attribute data sets
A Levelogger Junior (Solinst, Inc.) CTD data logger was deployed at the central VR2W receiver location (SCB) in the South Creek to record water temperature (°C), conductivity (uS cm^{-1}), and water level (m) every 15 minutes. Water level readings for flood and ebb tide stages were adjusted for barometric pressure by subtracting the mean water level from the preceding dry period. For tidal cycle changes where the Levelogger was not exposed at low water, 0.05 was subtracted from the lowest water level associated with a given ebb or flood tide stage, and this value was then subtracted from every water level reading for the given ebb or flood stage. Between 9 April and 8 November 2013, the difference between mean dry period water level and the lowest water level associated with the preceding ebb or flood tide stage (n = 738 observations) was 0.056 ±0.002 m (mean ±standard error, SE).

After assignment of individual water level observations to ebb, flood, or dry cycles, two additional tidal metrics, cycle duration and tidal amplitude, were computed based on the difference between the first and last and highest and lowest values for each cycle, respectively. The difference between transmitter detection time and the start of each water level cycle was used to compute the percent of the water level cycle elapsed at the time of detection.

Daily percent illumination and moon phase data were obtained from the U.S. Naval Observatory (http://aa.usno.navy.mil/data/docs/MoonFraction.php). Hourly wind speed, wind direction, and air temperature data were obtained from the National Ocean Service for the Charleston, SC Customs House (station 8665530; http://tidesandcurrents.noaa.gov/met.html?id=8665530).

Analyses
Data distributions were checked for normality in Minitab 15® (Minitab, Inc.) prior to selecting and conducting the appropriate statistical test. Unless otherwise specified, all statistical testing was also performed in Minitab 15.

Differences in sex-specific size distributions between river and creek habitats were tested with a two-sample t-test for normally distributed data and using non-parametric Kruskal Wallis rank testing. Differences in the overall detection of males and females between creek and river habitats were tested with a 2 x 2 Chi-square contingency test.

Linear regression was used to test for a significant relationship between total detections and the number of days between the first and last detection for each transmitter. A One-Way Analysis of Variance was then used to test for differences in the distribution of total detections among four terrapin sex and capture habitat combinations. A two-tailed Fisher's exact test was performed using Vassar Stats (http://vassarstats.net/tab2x2.html) to statistically compare the ratio of the number of different transmitters detected to the number of mobile search efforts expended in creek and river habitats.

Correlation in the monthly percent of acoustically-tagged diamondback terrapins detected at least once per month was tested between creek and river habitats. Correlation in monthly mean daily percent detection of available male and female terrapins was also evaluated, and Kruskal-Wallis rank tests were also used to evaluate monthly differences in daily presence rates among sexes. Note: four fewer observation days were available for males (12) than females (16) in April.

Daily detections per transmitter values were computed to facilitate comparisons between male and female diamondback terrapins. Similarity in monthly mean daily detections per transmitter values for males and females was compared using correlation testing. Because data were not normally distributed and because disproportionately more observations were available for female diamondback terrapins, statistical comparisons were based on 95% confidence intervals (CI) rather than non-parametric rank testing. Confidence intervals were computed as the product of the standard error for each month multiplied by the appropriate t-statistic listed in Table B.3 of Zar (1996) based on the degrees of freedom for male and female terrapin data points each month.

Monthly VR2W detection frequency (detections combined by sex and habitat) was computed as the number of total monthly detections divided by the sum of possible monthly detection days for each transmitter. Correlation was used to test for similarity between this data series and monthly diamondback terrapin capture rates at trammel net sites located in the Ashley River. For 2013 capture data, monthly values represented the percent of all captures irrespective of capture location. For capture data between 1995 and 2012, a site-specific gross percent capture rate was computed, from which the mean (and SE) was computed for five Duck Island trammel net sites as well as 24 other trammel net sites located in the Ashley River.

Linear regression was used to test for a significant relationship between the number of different acoustic receivers a given transmitter was detected at and the maximum number of detections for that transmitter recorded by a single receiver. A One-Way Analysis of Variance was then used to test for differences in the maximum number of detections for a transmitter at a single receiver with respect to capture habitat and diamondback terrapin sex.

Sequential detections were assigned a unique visit ID to provide a fine-scale metric for assessing temporal variability in activity. When >15 minutes passed between successive detection records or when a subsequent detection occurred at a different location area regardless of time interval, a new visit code was assigned. Location areas were defined based on the following receiver locations: Duck Island North (AR09, AR10); Cove (AR11, AR30, AR29); North Creek (2 receivers); Duck Island East (VR2Ws located to the north and south side of the confluence of the South Creek); South Creek (3 receivers). When the same transmission was recorded at receivers across two areas, a hybrid area designation was used (i.e., Cove-North, Cove-North Creek, East-South Creek). The percent frequency of the number of detections per visit was created for each month, and linear regression was used to test temporal trends as appropriate.

Monthly variability in detections among receiver location areas was evaluated based on the percent of monthly detections associated with each receiver location area. Because the number of acoustically-tagged diamondback terrapins providing data varied among months, correlation testing was performed to assess interaction effects between transmitter ID and subsequent location trends. All 21 acoustically-tagged diamondback terrapins were assigned to a group based on the area where the receiver of its greatest overall detection was located. The percent of monthly detections (irrespective of detection area) was computed for the aforementioned groups, and the correlation strength for these values was assessed for appropriate detection areas. Similarly, the percent of monthly detections associated with female diamondback terrapins was also assessed; regression was used to test for a significant linear trend with respect to female detection contribution across months, and correlation was used to assess potential significance in the relationship between location area detections and the sex of diamondback terrapins detected.

For all but two acoustically-tagged diamondback terrapins with known emigration away from Duck Island, every possible detection hour from the time of first VR2W detection was assigned to ebb, flood, or dry water stages based on *in situ* Solinst Levelogger measurements. Assignment was based on numerical dominance (out of four possible observations per hour) for each stage. Multiple water stages were present in 18% (n = 899 out of 5,108) of possible monitoring hours, for which numerical dominance could not be established for one-third (n = 297) of observations; thus, water stage for these 297 observations was assigned based on chronological stage order. Detection frequency and abundance were then descriptively compared among creek and river habitats with respect to water stage, with an emphasis on non-detection periods, as a precursor for assessing overall data distribution and appropriate multivariate model selection for evaluating environmental influences on observed detection patterns in these two primary habitats.

Correlation testing was used to compare detections within creek and river habitats with respect to tide stage (ebb, flood). The total number of detections for each habitat type was pooled among each of 24 hourly bins with respect to ebb and flood stages, then expressed as a percentage of the total detections recorded (irrespective of tide stage) for that habitat. Correlation testing was also used to compare binned hourly detections (irrespective of tide stage) between these two habitats. Lastly, correlation testing was also used to compare overall binned hourly detections for each of these two habitats with the proportion of ebb or flood tide stage CTD observations to evaluate potential interaction between hourly bins and tide stage.

Results

Capture and processing overview

Seventy-four of 95 diamondback terrapins captured in 18 of 26 randomly selected trammel net sets near Duck Island between January and December 2013 were examined, measured, sampled, marked, tagged, and photographed in conjunction with the present study. Logistical constraints prevented the processing of one diamondback terrapin captured in March, 14 captured in June, and six captured in November.

Twenty-seven additional diamondback terrapins were captured during eight trammel net sets deployed at the Duck Island stations for the purpose of achieving the desired acoustic tagging sample sizes. Similarly, 14 trammel net sets captured 23 diamondback terrapins in the two creek systems behind Duck Island. Sixteen sampling events with other gear types only captured two diamondback terrapins in each of the creek and river habitats (Table 1).

Table 1. Trammel net sets in river habitats were associated with the highest capture rates among 64 diamondback terrapin capture event efforts expended between January and November 2013.

		# of gear sets		# of Terrapins		Gross terrapins/set	
Gear type	Set (min)	Creek	River	Creek	River	Creek	River
600' trammel	20	14	34	23	122	1.6	3.6
100' trammel	10	5	n/a	1	n/a	0.2	n/a
15' otter trawl	5	5	6	1	2	0.2	0.3

Size and sex ratio
Males accounted for 75% (n = 96) of diamondback terrapin collections, of which 82% (n = 79) were captured in river habitats. Male diamondback terrapins ranged in size from 9.2 to 13.3 cm SCL, and a significant difference was not detected (T_{23} = 0.61, P = 0.546) in size distribution between creek and river habitats (Figure 8).

Thirty-two female terrapins were collected between April and November 2013. Females measured between 14.2 and 23.3 cm SCLmin, and all but one (11.0 cm SCLmin) was larger than the largest male. Only 25% (n = 8) of female terrapin collections occurred in creek habitats. Female size distribution was not significantly different (H_1 = 1.97, P = 0.161) between creek and river habitats (Figure 8).

Sex was not able to be determined for one diamondback terrapin (Figure 8) captured in the river in October which had a SCL length that was 0.6 cm smaller than the smallest female captured, but which was also captured in the river a month earlier. Overall, males outnumbered females at a ratio of 2.1 to 1 in the creek and 3.1 to 1 in the river; however, sex ratio was not significantly different between these two habitat types (X^2_1 = 0.972, P = 0.324).

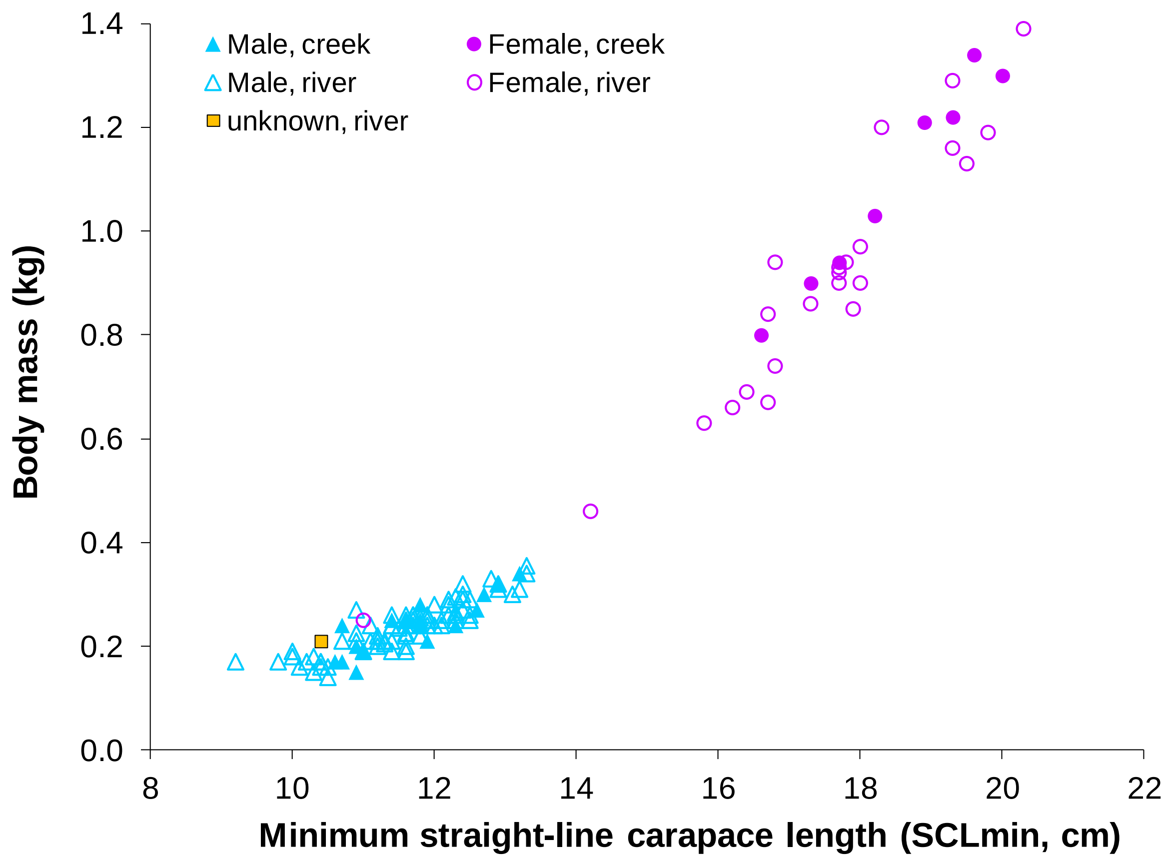

Figure 8. Diamondback terrapin size distributions were sexually dimorphic, but were not significantly different with respect to capture habitat.

Opportunistic observations
Ultrasound examinations were performed on all 28 female terrapins captured through August (Appendix 1). Numerous small to large follicles were observed through early May, with shelled eggs first detected by late April. Only one of 16 female terrapins captured through early May did not exhibit signs of reproductive activity. No reproductive observations were recorded for the next two months due to not processing diamondback terrapins in June and not capturing female diamondback terrapins in July. Ultrasound data for 11 female diamondback terrapins captured in August were largely inconclusive; however, follicles were detected for several females.

Fecal samples were examined for 33 (18 male, 15 female) diamondback terrapins, of which all but four samples originated from diamondback terrapins captured in river habitats (Appendix 2). Seventy-nine percent (n = 26) of fecal samples contained snail spires and/or opercula, and 52% (n = 17) of fecal samples contained crab parts (most often *Uca* sp. claws). Plant matter consisting of *Ulva* sp. and/or unidentified filamentous algae was observed in seven specimens (21%). An unusual bolus that was also filamentous in nature (with red and white strands) was also included in a fecal sample defecated by a male terrapin on 21 May (Figure 9).

Barnacles were present on 15% (n = 20 out of 128) of diamondback terrapins captured in 2013, of which barnacle samples from 16 of these animals were saved for a Ph.D. candidate (C. Ewers) at the University of Georgia. An additional collaboration with Dr. Kristen Hart of the U.S. Geological Service in Davie, Florida was initiated in October to examine stable isotope levels in blood and keratin, for which seven blood samples were collected.

Figure 9. An unidentified filamentous mass was observed in a fecal sample provided by MT0082, a male diamondback terrapin captured in the Ashley River on 21 May 2013.

Acoustic tagging overview
Acoustic transmitters were attached to 21 (12 female, 9 male) diamondback terrapins in 2013. All river-captured females were tagged and released between 10 and 19 April, whereas females originating from the creek were captured between 19 and 30 April (Table 2). Because of the lower incidence of finding males large enough to carry tags, acoustically-tagged male diamondback terrapins were released over a more protracted schedule than females. Six river-captured males were released between 21 April and 10 July, and three creek-captured males were released between 19 April and 18 September (Table 4).

Table 2. Acoustic transmitters were attached to 21 (out of 24 slated) diamondback terrapins captured near Duck Island, South Carolina in 2013.

Transmitter	TerrapinID	Sex	SCL (cm)	Habitat	Location	Day
25217	MT0002	F	18.3	River	AR10	10-Apr
25218	MT0003	F	17.3	River	AR10	10-Apr
25219	MT0004	F	16.4	River	AR10	10-Apr
25220	MT0030	F	16.2	River	AR09	19-Apr
25221	MT0037	F	18.0	River	AR30	19-Apr
25222	MT0038	F	15.8	River	AR30	19-Apr
25223	MT0033	M	12.4	River	AR09	19-Apr
25224	MT0042	M	12.9	River	AR30	19-Apr
25225	MT0079	M	13.2	River	AR10	22-May
25226	MT0080	M	13.1	River	AR10	22-May
25227	MT0083	M	12.4	River	AR10	10-Jul
25228	MT0084	M	13.3	River	AR29	10-Jul
25229	MT0043	F	18.9	Creek	North Creek	19-Apr
25230	MT0044	F	18.2	Creek	North Creek	19-Apr
25231	MT0048	F	19.3	Creek	North Creek	19-Apr
25232	MT0053	F	17.3	Creek	South Creek	19-Apr
25233	MT0057	F	17.7	Creek	South Creek	30-Apr
25234	MT0061	F	20.0	Creek	North Creek	30-Apr
25235	MT0045	M	13.2	Creek	North Creek	19-Apr
25236	MT0065	M	12.9	Creek	South Creek	10-May
25237	MT0117	M	12.7	Creek	North Creek	18-Sep

Residence
A total of 58,752 detections (excluding three false detections) were recorded across 12 VR2W acoustic receivers at Duck Island between 11 April and 08 November. Total detections per transmitter ranged from 494 to 5,629 (Figure 10). The interval between first and last detection for individual transmitters spanned 11 to 210 days (mean ±SE = 135 ±12 days), and a significant linear relationship was detected (F_{20} = 7.50, P = 0.013, r^2 (adj.) = 0.25) between detection interval and total detections (Figure 10). Detection intervals among four combinations of habitat and terrapin sex (Figure 10) were not significantly different (F_{20} = 2.21, P = 0.124).

Nineteen out of 21 acoustically-tagged diamondback terrapins were detected (52 observations) during 94 mobile search efforts on 10 sampling dates (0.8 to 6.4 search hours each) between 24 April and 4 September 2013. Detection frequency ranged from 77% (10 out of 13 transmitters) on 24 April to 0% (spanning 0.8 to 5.0 hrs) on three occasions. Seventy-four percent (n = 14) of diamondback terrapins detected during mobile searches were detected on two or fewer search dates, with a maximum detection during five out of 10 search dates. For 12 acoustically-tagged diamondback terrapins detected on two or more search dates, subsequent detection occurred between six and 133 days later (mean ±SE = 38.3 ±10.8 days). A significant difference (Fisher's exact test; P = 0.002) was noted in mobile search detection capability between habitat types, with 49 detection observations during 62 river habitat search efforts, compared to three detection observations during 26 creek habitat search efforts.

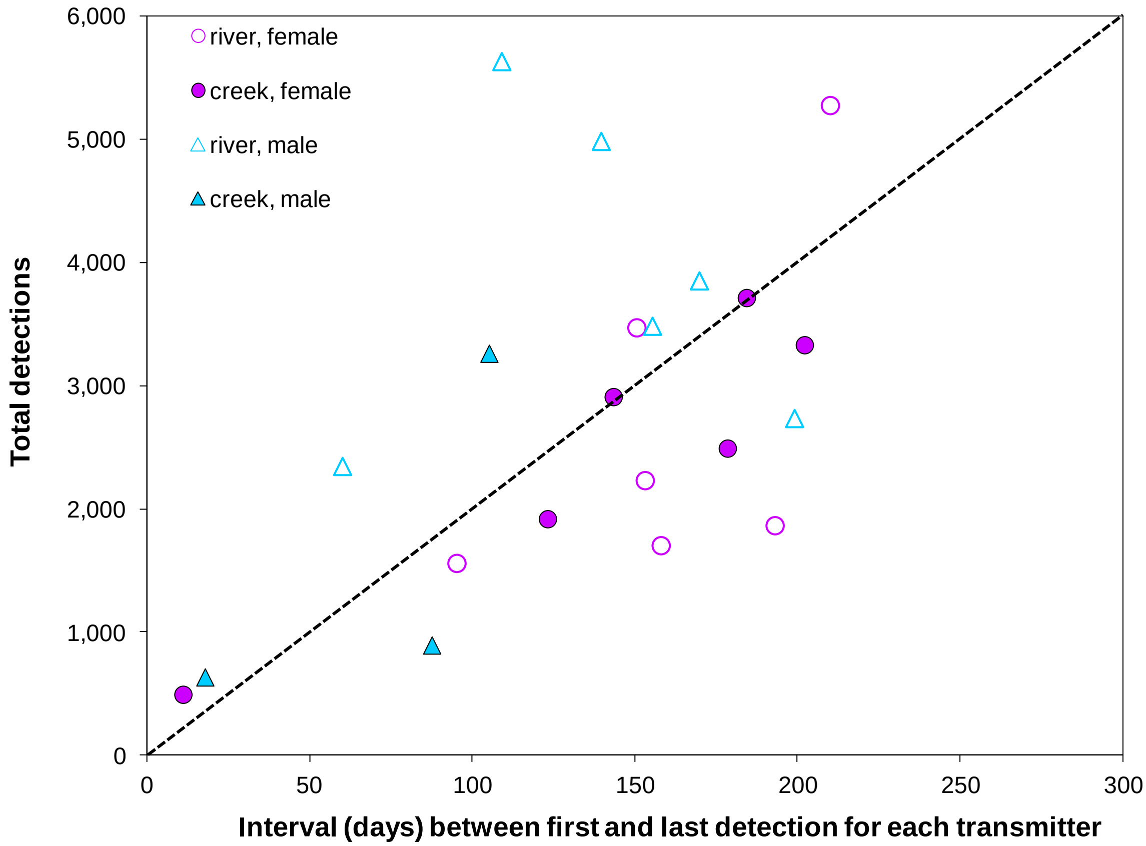

Figure 10. A significant (P<0.05) linear relationship was detected between total detections and the interval between first and last detection for each transmitter; however, total detections were not significantly different among four capture habitat and terrapin sex combinations.

Emigration
Only two diamondback terrapins acoustically-tagged in this study were detected by VR2W receivers associated with ongoing research studies outside of the Duck Island study area, and represented two of the three diamondback terrapins for which fewer than 1,000 individual detections were recorded near Duck Island.

Female 25234 was released in the North Creek on 30 April and detected by both VR2W receivers in this habitat as well as by all VR2W receivers associated with the cove and the north side of Duck Island through 11 May. Between 07:00 and 12:00 hours local time on 11 May, against a predominantly flooding tide stage, a directed movement away from the cove and then down the north and east sides of the island was documented. Nearly 16 hours after the last detection at the Duck Island receiver array, three successive detections for this female were recorded by a VR2W receiver located 8 km away near Wappoo Cut (Figure 11). Eight hours later, three successive detections of this female were also recorded by a VR2W receiver at the James Island Yacht Club located an additional 2 km seaward in the Charleston Harbor. No further detections were recorded or sightings reported for this female through 8 November.

Male 25235 was released in the North Creek on 19 April where it was detected for 0.5 hrs before contact was lost. Two days later it was detected by a VR2W receiver near the I-526 bridge approximately 5 km upriver (Figure 11), where a total of 60 detections was recorded during the next 24 hours. Twelve hours later, this male returned to Duck Island where it was predominantly detected (194 detections) on the north side of the island for the next two days, before returning to the North Creek. Between 25 April and 10 May, 597 detections were recorded for this male in the North Creek and on the north side of Duck Island, after which it was detected at the I-526 receiver location 50 hours after last being detected at Duck Island. Between 11 May and 25 August, when this male was last detected, only 24% of detections (95 out of 404) recorded for this male occurred at Duck Island, during a three-day period between 13–16 July.

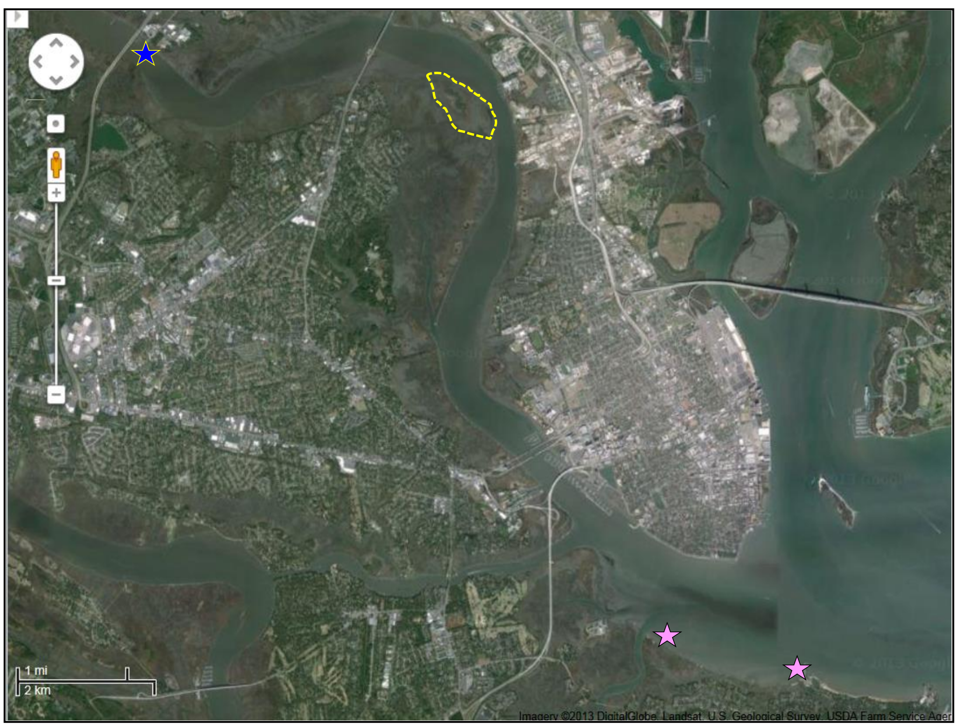

Figure 11. Two out of 15 diamondback terrapins tagged in April emigrated away from the Duck Island (yellow circle) study area within 14 days of tag and release. Two days after release, male 25235 (blue star) was detected by a VR2W receiver located 5 km west and upriver from Duck Island; through August, this male routinely traveled between this location and Duck Island. Female 25234 departed Duck Island 12 days after release and she was last detected by two VR2W receivers (pink stars) 8 to 10 km downriver and in Charleston Harbor a day later.

Seasonal trends

Pronounced seasonal variability in detection frequency was noted for acoustically-tagged diamondback terrapins at the Duck Island study area between April and November (Figure 12). The proportion of acoustically-tagged diamondback terrapins detected at least once per month systematically declined from 87–100% in April to 0–24% in November (Figure 12). A greater proportion of diamondback terrapins was detected in river vs. creek habitats in all months, but temporal trends between habitats were significantly correlated ($P < 0.001$, Pearson $r = 0.950$).

A significant correlation ($P < 0.001$, Pearson $r = 0.974$) was also observed in the temporal decline in the percent of male and female diamondback terrapins detected each day (Figure 13). With the exception of April, June, and November (Table 3), a significantly ($P < 0.05$) greater proportion of male diamondback terrapins were detected daily as compared to their female counterparts.

Monthly trends in mean daily detection levels between male and female diamondback terrapins (Figure 14) were also significantly correlated ($P = 0.004$, Pearson $r = 0.880$). Overlap or marginal overlap in 95% CI around mean daily detection levels between males and females was observed in April, May, June, and November (Figure 14), suggesting that detections levels were not significantly different between sexes during these months. However, non-overlap of 95% CI between July and October (Figure 14) suggests that male diamondback terrapins were detected significantly more than their female counterparts during these months.

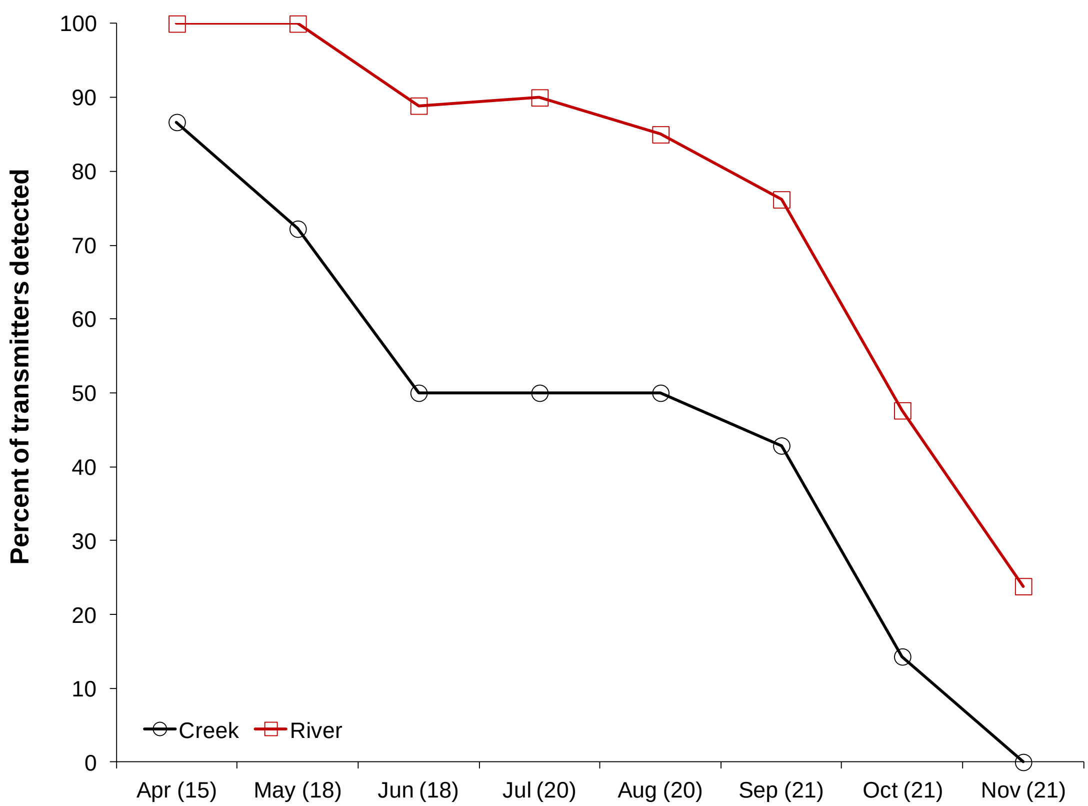

Figure 12. A significant ($P < 0.001$) and systematic decline in the proportion of diamondback terrapins detected each month occurred between April and November. Numbers in parentheses denote the number of acoustically-tagged diamondback terrapins available to be detected.

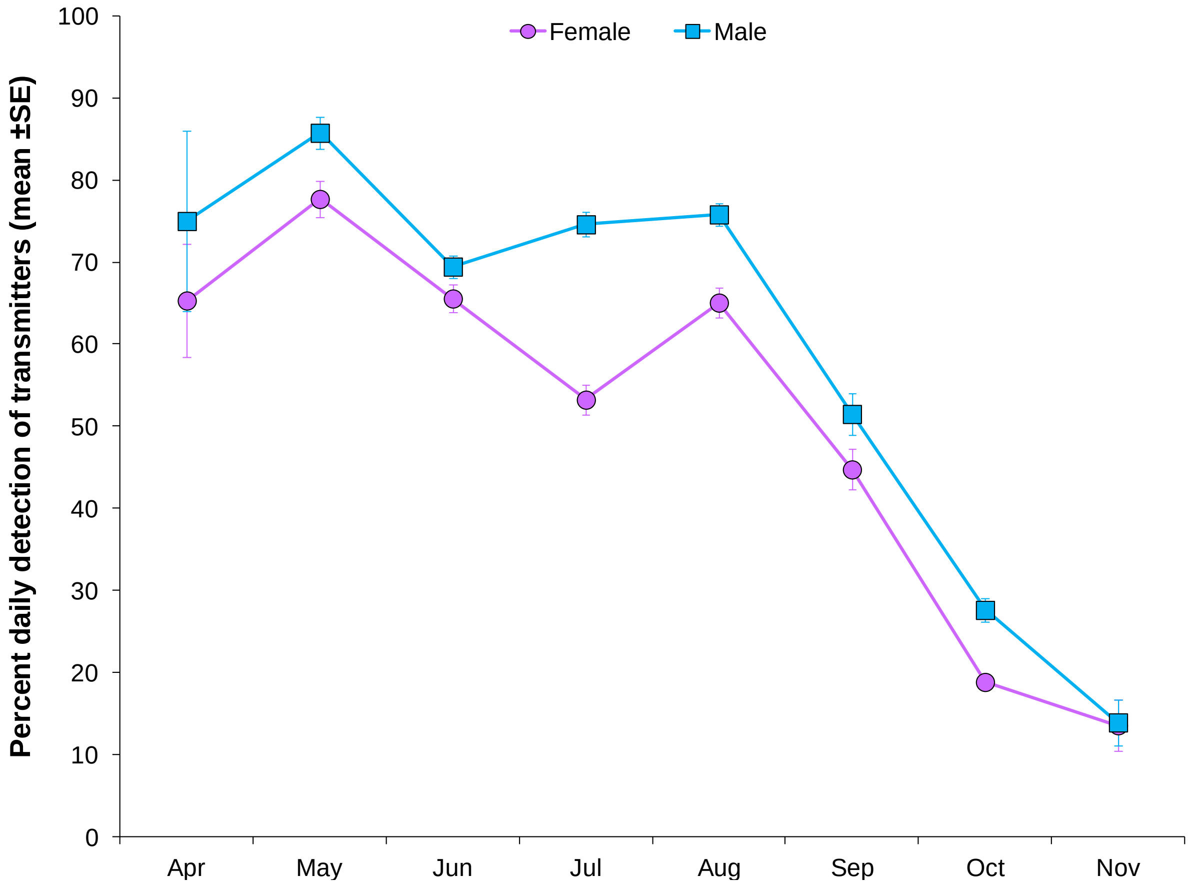

Figure 13. Daily detection frequency for female (pink line) and male (blue line) diamondback terrapins declined on similar schedules between April and November 2013.

Table 3. Statistical differences (*) in percent detection distributions were observed between male and female diamondback terrapins in all months except for April, June, and November.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
H-stat	2.65	5.18	1.9	39.01	17.05	3.97	16.47	0.07
P-value	0.104	0.023*	0.168	<0.001*	<0.001*	0.046*	<0.001*	0.790

Seasonal decline in monthly (pooled by sex) detections per possible transmitter detection day was not significantly correlated with the monthly percent of diamondback terrapin captures at five Duck Island trammel net stations in 2013 ($P = 0.280$, Pearson $r = 0.436$) nor with the mean monthly capture percent at these sites during 1995–2012 ($P = 0.092$, Pearson $r = 0.633$). However, seasonal decline in monthly detections per possible transmitter detection day was significantly correlated ($P = 0.001$, Pearson $r = 0.938$) with the mean monthly percent capture of diamondback terrapins at all other trammel net stations located in the Ashley River (Figure 15).

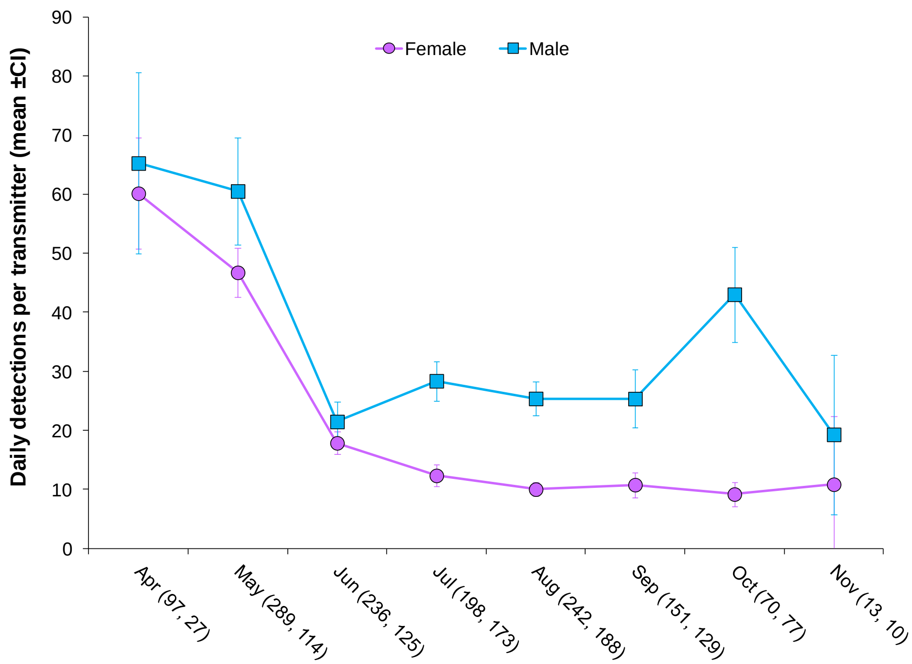

Figure 14. Temporal decline in detection was significantly correlated (P = 0.004, r = 0.880) between male and female diamondback terrapins; however, between July and October, detections for males were generally three times as great as detections for females.

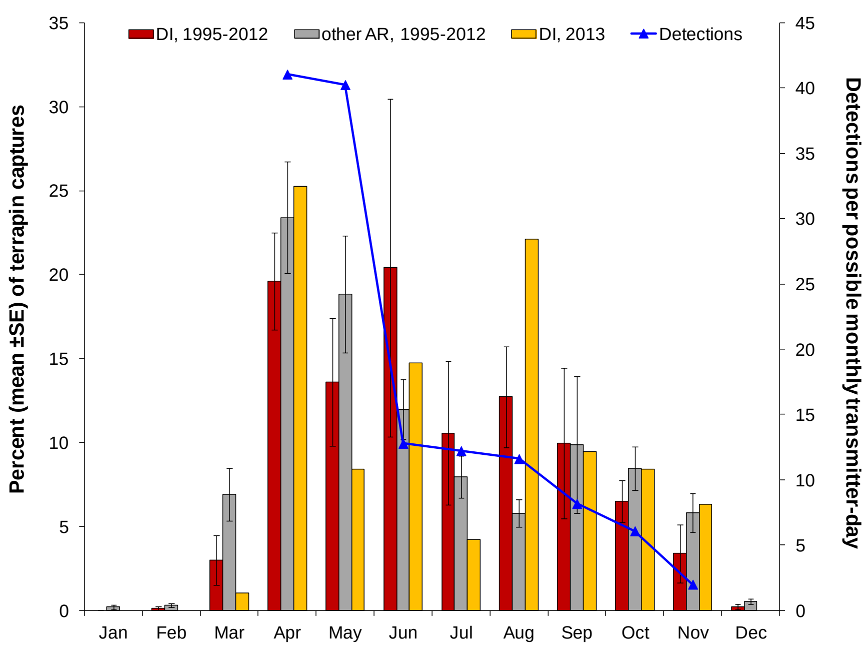

Figure 15. Monthly detections per possible transmitter day (blue line, second y-axis) were not significantly correlated with the percent capture distribution (absolute or mean) of diamondback terrapins at five trammel net stations at Duck Island in 2013 (orange bar) or during 1995–2012 (red bar); however, a significant (P<0.05) correlation with the mean percent capture distribution at all other trammel net stations in the Ashley River during 1995–2012 was detected.

Habitat preferences and localized movement patterns
Only 11% (6,476 out of 58,752) of all acoustic detections at Duck Island were recorded by creek-based receivers, with an additional 0.1% (*n* = 112) of detections simultaneously recorded by receivers in both creek and river habitats.

All acoustically-tagged diamondback terrapins were detected by at least four and up to all 12 acoustic receivers at the Duck Island study area between April and November 2013 (Figure 16). The maximum detection receiver for 10 diamondback terrapins was located on the north side of Duck Island, and accounted for 58.4 ± 6.2% (mean ±SE) of total detections for those individuals. The maximum detection receiver for six diamondback terrapins was located in the cove of Duck Island, and accounted for 60.0 ± 10.0% of total detections for those individuals. The maximum detection receiver for five diamondback terrapins was located on the east side of Duck Island, and accounted for 38.4 ± 20% of total detections for those individuals. The maximum percent of transmitter detections at a single receiver significantly (F_{20} = 32.98, P<0.001, adj. (r^2) = 0.62) declined as the number of different receivers an individual was detected at increased (Figure 16).

Peak detection at a single acoustic receiver was significantly different (F_3 = 10.28, P<0.001) among capture habitats and terrapin sexes; river-captured males were associated with the greatest percent of detections at a single receiver, whereas creek-captured females were associated with lower levels of detection across multiple receivers.

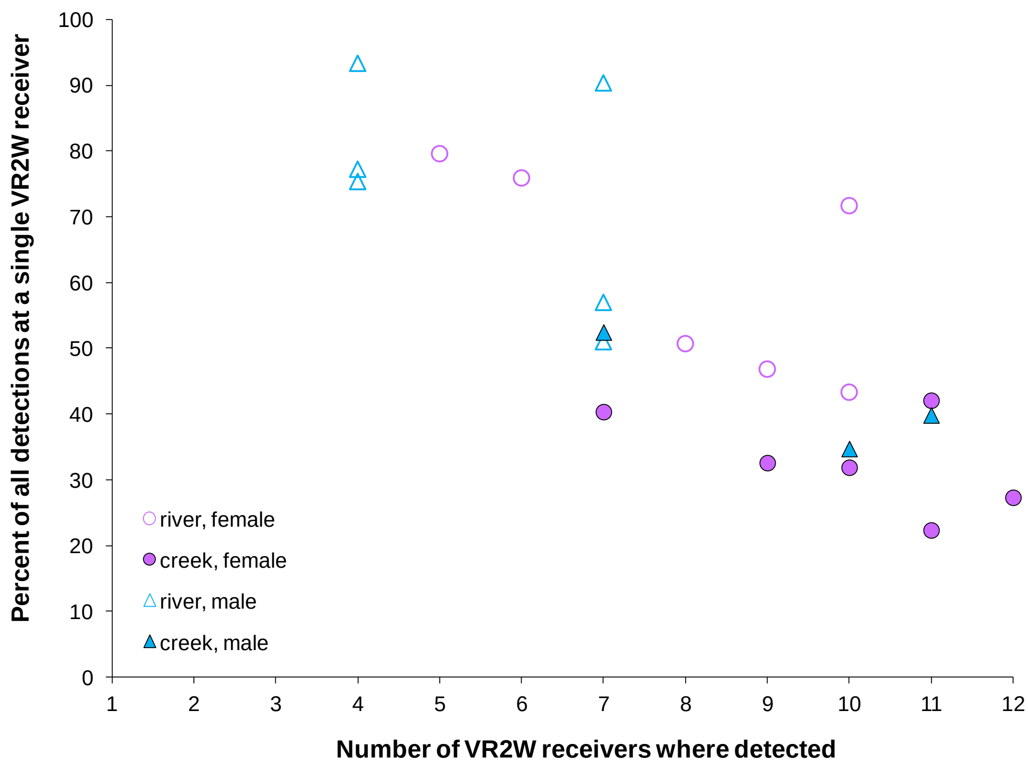

Figure 16. Acoustically-tagged diamondback terrapins were detected by at least four and up to 12 VR2W receivers at the Duck Island study area. Detection frequency at a single receiver was greater for diamondback terrapins detected at fewer receivers, which was also significantly (P<0.05) different among terrapin sex and capture habitat.

A total of 11,423 unique detection visits were observed between April and November 2013, with between 91 (November) and 3,189 (May) unique visits recorded in a given month. A significant ($F_7 = 15.02$, $P = 0.008$, adj. $(r^2) = 0.67$) and systematic increase in the proportion of visits that comprised just one detection in a fifteen minute period was noted between April (24%) and November (48%; Figure 17). Only 23% of all unique visits were associated with >5 detections, of which 47% (n = 1,247) occurred during April and May (Figure 17).

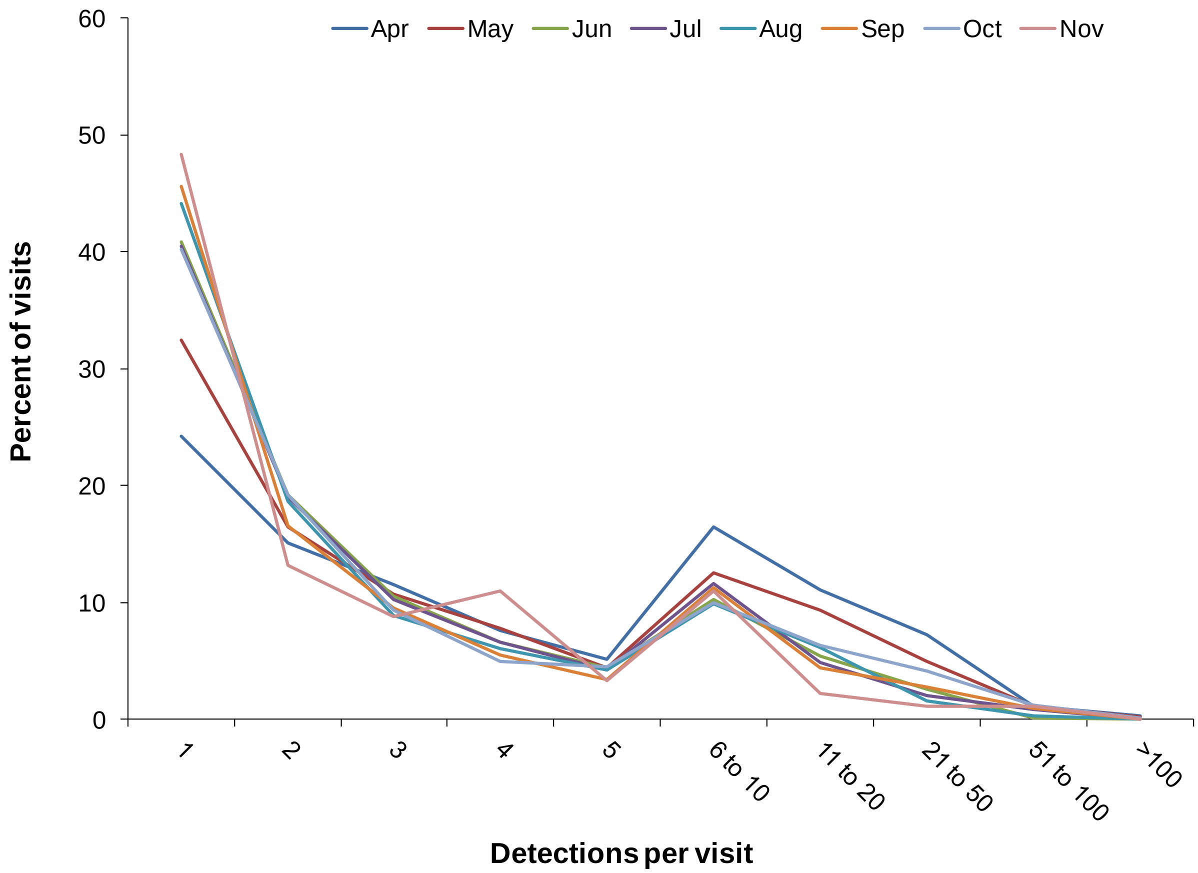

Figure 17. A total of 11,423 unique detection visits were documented for diamondback terrapins through 8 November, of which 77% consisted of five or fewer detections.

Monthly variability in detection area distribution (Figure 18) reflected a systematic reduction in the number of different transmitters detected and their inherent detection area bias. Monthly percent detection trends for three receivers associated with the cove were significantly correlated (P<0.001, Pearson r = 0.984) with the percent of monthly detections from transmitters for which the receiver of greatest detection was located in the cove. Monthly percent detection trends for the hybrid area including the cove and the north side of the island were significantly correlated (P<0.001, Pearson r = 0.943) with the percent of monthly detections from transmitters for which the receiver of greatest detection was located on the north side of the island. However, monthly percent detection trends for two receivers associated with the north side of the island were significantly correlated (P<0.001, Pearson r = 0.978) with the percent of monthly detections from transmitters for which the receiver of greatest detection was located on the east side of the island.

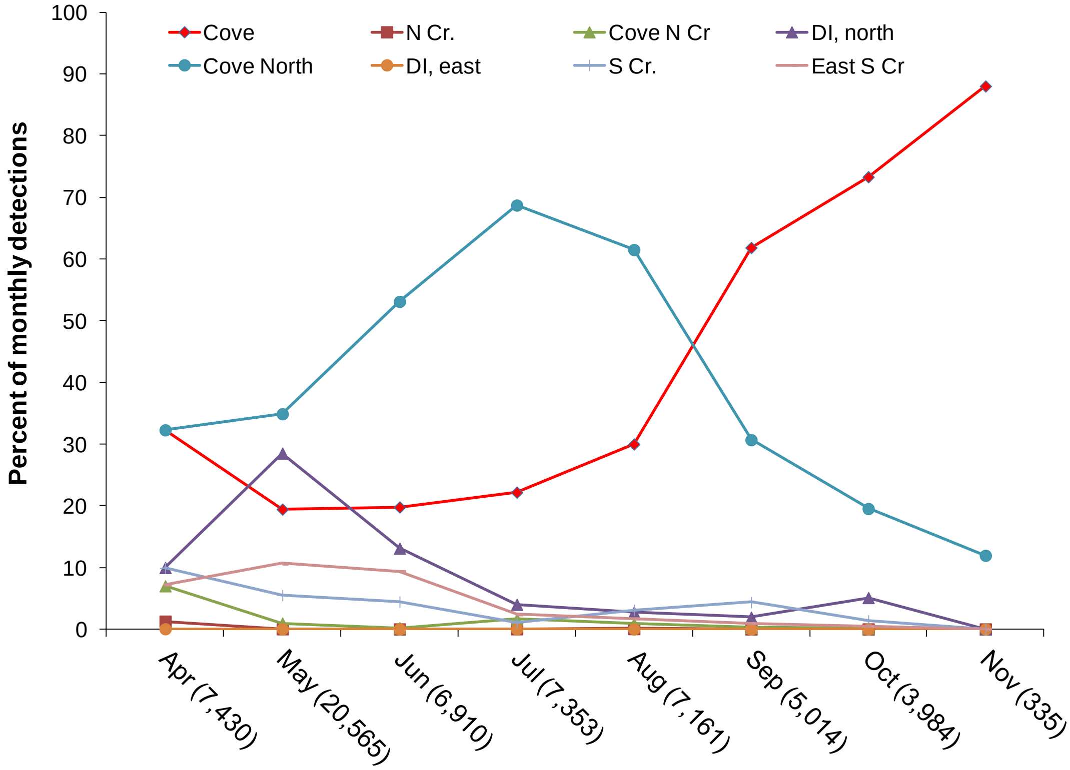

Figure 18. Monthly detection trends among receiver location areas reflected a systematic reduction in the number of different transmitters detected and their inherent location bias.

An equal number (*n* = 5) of females and males exhibited a detection bias for the north side of Duck Island; however, a slight female bias was observed for diamondback terrapins that exhibited a preference for the east side of the island (three females, two males) and the cove (four females, two males). A significant decline (F_7 = 13.10, P = 0.011, adj. (r^2) = 0.63) across months was observed in the percent of detections from females among receivers located in the cove. Significant linear trends were not detected (F_7 = 0.04, P = 0.849, adj. (r^2) = 0.00) in monthly variability in the percent of detections from females among receivers located on the north side of the island; however, a significant decline (F_7 = 17.02, P = 0.006, adj. (r^2) = 0.70) in the percent of detections from females simultaneously recorded by receivers in the cove and on the north side of the island was observed. Significant correlations were not observed between monthly variability in overall percent detection and the proportion of detections associated with female diamondback terrapins at the cove (P = 0.104, Pearson r = -0.615), on the north side of the island (P = 0.574, Pearson r = 0.236), or simultaneous detection by acoustic receivers located on both the north side of the island and the cove (P = 0.201, Pearson r = 0.506).

Influences on detection patterns

Across 19 acoustically-tagged diamondback terrapins for which emigration away from Duck Island was not documented, a total of 82,726 unique combinations of transmitter ID, day, and hour were generated to denote monitoring hours after the first detection of each transmitter. Twenty-three percent (*n* = 18,619) of all monitoring hours were associated with dry water levels in the bend of the south creek, and 237 detections (including 20 near the south creek entrance) were recorded across transmitters and dates during monitoring hours associated with these dry water levels. Of the remaining monitoring hours, a similar proportion was associated with ebb (38%; *n* = 31,343) and flood (40%; *n* = 32,764) water levels.

Excluding all detections for two emigrants, a total of 6,243 detections were recorded by the five VR2W acoustic receivers located in creek habitats. Creek detections were recorded during 2.1% of monitoring hours associated with flood and ebb water stages, but <0.1% of monitoring hours associated with dry water stages (Figure 19). Fifty-five percent (*n* = 3,449) of creek detections occurred during hours associated with flood water stages; 44% (*n* = 2,774) and 0.3% (*n* = 20) occurred during hours associated with ebb and dry water stages, respectively (Figure 19).

Excluding all detections for two emigrants, a total of 51,121 detections were recorded by seven VR2W acoustic receivers located in river habitats. Greatest frequency (19%) of detection and the greatest percent of total river detections (53%; *n* = 27,278) occurred during hours associated with ebb water stages (Figure 19). Diamondback terrapins were detected at river habitats during 15% of hours associated with flood water levels, which comprised 46% (*n* = 23, 626) of total detections in river habitats (Figure 19). During hours associated with dry water levels, 217 detections were recorded in river habitats, which represented both a detection frequency and percent of total river detections of 0.4%.

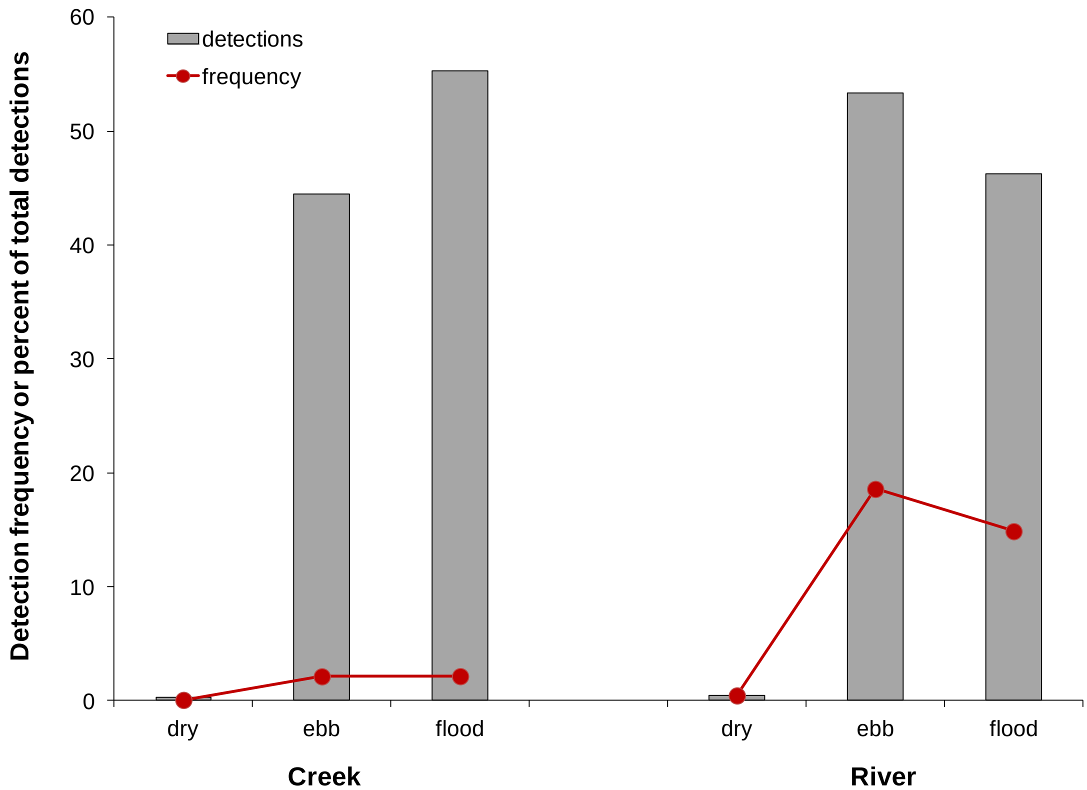

Figure 19. Nearly nine times as many detections were recorded by acoustic receivers located in river vs. creek habitats; however, variability in detection frequency (red line) and/or relative detection (gray bar) was observed within these two primary habitats with respect to water level stage (ebb, flood, dry) during 82,726 monitoring hours between 9 April and 8 November 2013.

A significant correlation ($P = 0.004$, Pearson $r = 0.569$) was observed between the percent of detections recorded during ebb ($n = 2,647$) and flood ($n = 3,868$) water stages in creek habitats. Overall, 0.5 to 7.3% of creek detections were associated with one of 24 hourly bins. Given an expected value (if distribution across bins was equal) of 4.2%, the proportion of all detections recorded between 22:00 and 07:00 hours was less than expected, and thus the proportion of detections recorded between 08:00 and 21:00 hours was greater than expected (Figure 20a).

A significant correlation ($P<0.001$, Pearson $r = 0.808$) was observed between the percent of detections recorded during ebb ($n = 26,527$) and flood ($n = 25,621$) water stages in river habitats. Overall, 1.9 to 7.0% of river detections were associated with one of 24 hourly bins. Given an expected value (if distribution across bins was equal) of 4.2%, the proportion of all detections recorded between 07:00 and 20:00 hours was less than expected, and thus the proportion of detections recorded between 21:00 and 06:00 hours was greater than expected (Figure 20b).

A significant negative correlation ($P<0.001$, Pearson $r = -0.778$) was observed between the percent hourly detection distributions in creek vs. river habitats (Figure 20c). Hourly detection distribution in river habitats was significantly correlated ($P = 0.001$, Pearson $r = 0.620$) with ebb tide stages, but not with flood tide stages ($P = 0.355$, Pearson $r = -0.197$). Hourly detection distribution in creek habitats was not significantly correlated with either ebb ($P = 0.379$, Pearson $r = -0.188$) or flood tide stages ($P = 0.058$, Pearson $r = 0.392$).

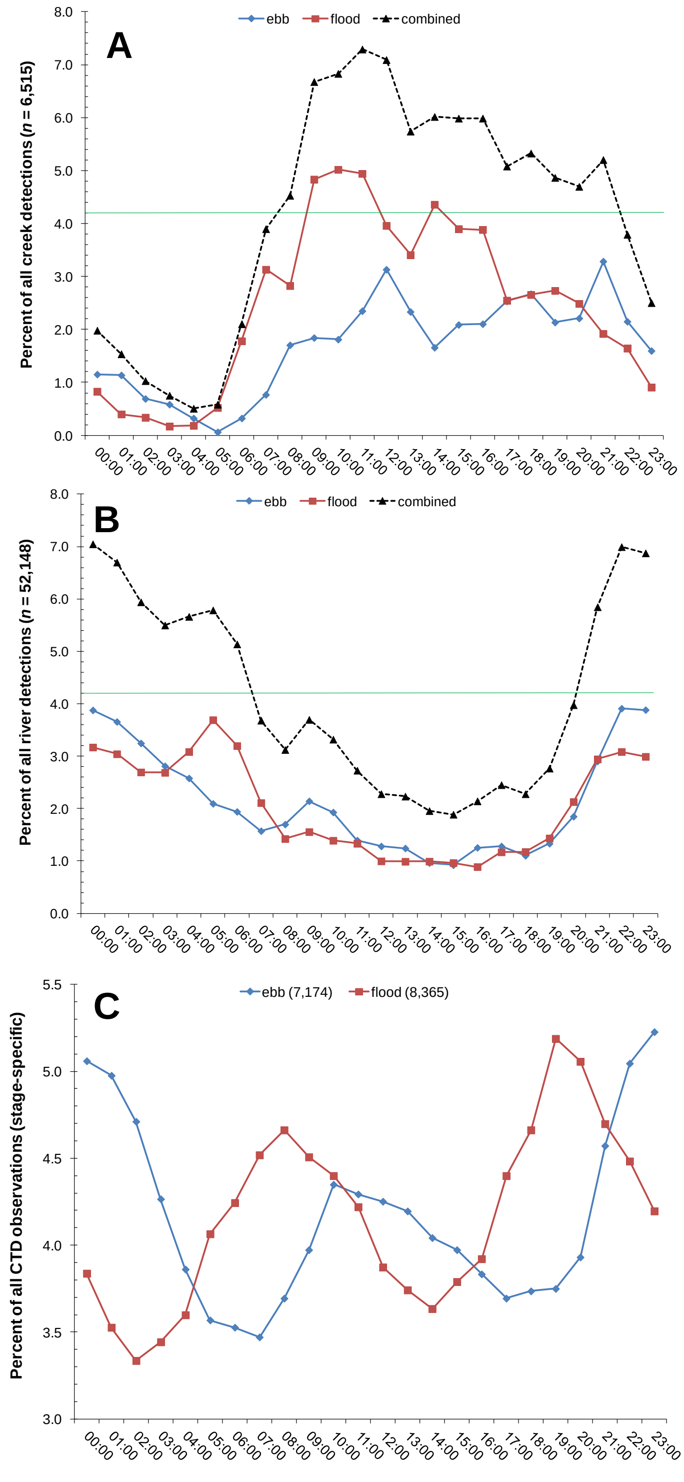

Figure 20. The distribution of detections across hourly bins in creek (A) and river (B) habitats was significantly correlated between ebb (blue line) and flood (red line) tide stages within these habitats, and also overall (black lines) with tide stage (C; total CTD observations in parentheses). The green line in panels A and B denotes the 4.2% expected distribution if detections were equal across all hourly bins.

Discussion

A moderate sample size and the use of automated acoustic monitoring resulted in a large and potentially unprecedented number of total detections for this species from which temporal and spatial distribution patterns were evaluated. Prior to the present study, we are aware of only four other studies that have used acoustic telemetry to collect similar data for diamondback terrapins elsewhere in their range. Estep (2005) deployed 13 acoustic transmitters on adult female diamondback terrapins and remotely collected 21,848 detections over a 16-month period using four acoustic receivers that provided episodic bouts of monitoring at 10 locations in a cove and creek system located near the mouth of Charleston Harbor, SC. In Virginia, Tulipani (2013) attached transmitters to 10 male and six female (including two presumably immature individuals) diamondback terrapins in 2011 and 2012 and recorded ~26,000 detections using five acoustic receivers for the purpose of developing a model for predicting residence vs. emigration. In New Jersey, nine acoustic receivers deployed at selected creek mouths in the salt marshes of the Cape May, NJ peninsula during 2005–2009 generated an undisclosed amount of acoustic telemetry data for 65 diamondback terrapins (http://www.terrapinconservation.org/home.htm). This technique has also been used to investigate home range for an undisclosed number of adult female diamondback terrapins (and unknown number of receivers) in Barnegat Bay, New Jersey (http://dspace.library.drexel.edu/bitstream/1860/3505/1/Winters_2009.pdf).

Prior studies which have utilized manual radio telemetry produced vastly smaller data sets on order with acoustic detection data generated during mobile searches employed in the present study, reinforcing the need for automated data collection for this cryptic species. Estep (2005) reported 348 detections across 10 adult female diamondback terrapins between May and December 2001, with mean detection for individual terrapins spanning 10.1 days that occurred 78.9 days apart. Perhaps related to nesting activity, radio transmitter detections were greatest during June and August (Estep, 2005). Harden and Southwood Williard (2012) reported 362 detections for 24 female and five male diamondback terrapins in southeastern North Carolina based on one to three search efforts per week between June 2008 and May 2009. Lowest radio detection frequency was reported when tagged terrapins were dormant and buried in mud (Harden and Southwood Williard, 2012), a behavior also reported that also occurs in summer (Spivey, 1998; Tucker et al., 1995; Butler, 2002).

Automated data collection also revealed greater localized movement patterns for this species than is reported in the published literature. Acoustically-tagged diamondback terrapins were detected by a minimum of four and upwards to all 12 remotely deployed receivers in the present study; however, fidelity to specific areas by individuals was also observed which in turn greatly influenced spatial detection patterns. These findings were consistent with a high degree of individual variability in residence and localized movement patterns reported for this species in previous telemetry studies (Estep, 2005; Tulipani, 2013), and suggest the need to reevaluate the mantra of strictly localized populations (Tucker et al., 2001). Although only two of 21 terrapins in the present study were documented to emigrate away from Duck Island and genetic diversity and divergence for this species is “exceptionally low” (Lamb and Avise, 1992), we hypothesize that movement within and among waterways contributed to the inability of Hauswaldt and Glenn (2005) to differentiate population structure within the Charleston Harbor estuary. Individual variability in distribution patterns contributes to inter-annual variability in detection patterns (Tulipani, 2013), and has considerable ramifications for analyzing catch rate data for this species.

Accordingly, we recommend continued and expanded telemetry data collection until sufficient sample sizes and observation years enable appropriate generalizations for analyzing catch data.

One generalization that can be made at this time is that movement throughout the study area was facilitated using both creek and marsh corridors as well as along-shore movement in the river. Although the majority of this movement appeared to correspond to tidal movement into the marsh as water levels rose and flushing back into the river as water levels receded, movement was not always tidally-mediated as evidenced by the onset of emigration of female 25234 against the tide. Routine tidally-mediated movements have also been reported elsewhere in South Carolina estuaries. For example, Estep (2005) reported directional movement of acoustically-tagged diamondback terrapins between creek and cove habitats near the entrance to Charleston Harbor. Estep (2005) also reported that a greater proportion of radio detections occurred on ebb tide stages, presumably due to improved signal reception as tagged terrapins moved away from marsh grass and into open water systems. Tucker et al. (1995) also reported directional movement away from flooded marsh grass habitats as waters receded, with less predictability associated with habitat use during low water. Conversely, terrapins have also been observed walking in grass habitats (Butler, 2002); thus, their use of habitats may also reflect time of year, sex, and reproductive condition. Tulipani (2013) also reported tidally-mediated movement, especially by large females, between shallow near-shore waters at high water levels and egress to deeper waters further from shore at low water levels. Tulipani (2013) also suggested that these localized movements serve as vectors for eel grass (*Zostera marina*) seed dispersal, an ecological role akin to serving as vector for Digenean trematode life cycles (Byers et al., 2013).

Strong correlation between seasonal detection patterns and seasonal capture rates in the trammel net survey bode well for use of this data set for monitoring population trends for this species. Within-season spatial distribution patterns largely reflected variability among individual diamondback terrapins; however, detection frequency during April and May suggests aggregation behavior and therefore more consistent behavior among individuals. Accordingly, it may be most appropriate to restrict temporal analyses to these months, with the caveat that temporal trends reflect variation in the size of the annual spring aggregation. Given the importance of tide stage and water level, historical trammel net catch rates should also be adjusted to reflect the conditions present at the time of sampling. A multivariate analysis to develop parameter-specific correction factors is underway, but was not able to be included in this annual report due to our not having selected an appropriate model to fit the unique distribution associated with these data. Initially we had hoped to conduct this multivariate analysis to assess influences on the number of detections associated with each unique visit (Figure 15); however, the preponderance of zeros and large spread in observed values resulted in an input data set that did not statistically fit any of 16 standard distributions or data transformations available in Minitab 15® (MDA, pers. obs.). Subsequently, hourly detection summaries were computed for all but two known emigrant acoustically-tagged diamondback terrapins between the time of first detection and the last data upload. This approach reduced the binned detection range from 0 to 30 vs. 0 to 158 as well as increased the number of input rows from 11,423 (visits) to 81,756 (hourly transmitter records), which in turn resulted in a statistically viable goodness of fit with several data distributions. Thus, we are evaluating the best distribution as well as proper coding before running the multivariate model in R (Version 2.13.0; R Core Team, Vienna, Austria).

Use of the trammel net to monitor temporal trends for diamondback terrapins in river habitats is also supported by the greatest catch rates among techniques employed in the present study. Seining and trammel netting (when set perpendicular to water mass movement) have both proven effective at sampling creeks (Gibbons et al., 2001) larger than those found in our study area, when sufficient water levels for concentrating diamondback terrapins were present at current speeds that were conducive to sampling. Insight into seasonal and tidally-mediated movement patterns during year one of the present study should greatly improve capture of diamondback terrapins from creek habitats in year two. Additional transmitter testing will also be performed in year two to evaluate signal attenuation in mud vs. grass habitats, with the hope that this information will improve our ability to fine-tune terrapin distribution patterns during the winter dormant period as well as the reduced detection period in the summer. Simultaneous detection by receivers at both the north side of Duck Island and the cove at the end of ebb tide cycles suggests movement far away from shore as reported by Tulipani (2013). Because the trammel net survey only operates in the river near the marsh edge, it is important to elucidate whether river detections predominantly stem from marsh edge habitat use or from extensive use of a wide spatial range of locations in the river, most of which are not sampled by the trammel net survey. Placement of additional receivers further from shore and/or across the river, as well as the use of rapid-repeat transmitters for manual tracking, will greatly complement telemetry data efforts. Far from shore vs. marsh-edge distribution also directly relates to susceptibility to drowning in commercial crab traps, the reduction of which is also a focus of data collection in year two. Lastly, receiver data collection in creeks which remain inundated at low tide during year two will also enable assessment of whether localized movement patterns observed near Duck Island are representative of terrapin behavior elsewhere in the Ashley River and other estuary systems.

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Appendix 1. Ultrasound examinations were performed for one male (*) and all but four of 32 female diamondback terrapins collected between April and October 2013. Follicles were evident through August, with the largest follicles observed through early May. Shelled eggs were only observed in late April and early May; however, no reproductive examinations were conducted in June or July.

TerrapinID	Day	Follicles	Size (cm)	Eggs	Size (cm)	Inconclusive
MT0002	09-Apr-13	numerous				
MT0003	09-Apr-13	numerous				
MT0004	09-Apr-13	numerous				
MT0014*	09-Apr-13					x
MT0030	18-Apr-13	numerous	1.3 to 1.6			
MT0037	18-Apr-13	x	0.7 to 1.5			
MT0038	18-Apr-13	numerous	small/atretic?			
MT0043	18-Apr-13	numerous	0.6 to 1.5			
MT0044	18-Apr-13	x	1.2 to 1.8			
MT0048	18-Apr-13	x	1.1 to 1.8			
MT0053	18-Apr-13	x	1.4			
MT0057	29-Apr-13			x	>3.5 x 2.3	
MT0059	29-Apr-13	x	1.6 to 2.0			
MT0061	29-Apr-13	x	1.8			
MT0048R	09-May-13	x	1.5 to 1.8			
MT0064	09-May-13	x	1.7	x	2.8 to 3.0	
MT0066	09-May-13	x	1.5 to 1.8	x	4.0 x 2.0	
MT0087	06-Aug-13	x	≤1.5			
MT0089	06-Aug-13	small				
MT0091	06-Aug-13					x
MT0092	06-Aug-13					x
MT0095	06-Aug-13	numerous	1.2 to 1.3			
MT0096	06-Aug-13					x
MT0097	06-Aug-13					x
MT0098	06-Aug-13					x
MT0099	06-Aug-13	atretic	0.9			
MT0101	06-Aug-13					x
MT0107	06-Aug-13					x
MT0113	04-Sep-13					n/a
MT0118	17-Sep-13					n/a
MT0120	04-Oct-13					n/a
MT0122	04-Oct-13					n/a

Appendix 2. Fecal samples were evaluated for 33 diamondback terrapins captured between April and November 2013. Snail parts were the most prevalent prey item and represented a large size range of snail sizes based on partial spires and opercula observed.

TerrapinID	Sex	Day	Habitat	crab	snail	plant	other
MT0004	F	09-Apr-13	River			x	
MT0009	M	09-Apr-13	River	x			
MT0016	M	09-Apr-13	River	x		x	
MT0018	M	09-Apr-13	River	x			
MT0037	F	18-Apr-13	River		x		
MT0040	M	18-Apr-13	River	x			
MT0044	F	18-Apr-13	Creek		x		
MT0049	M	18-Apr-13	Creek	x			
MT0051	M	18-Apr-13	Creek	x			
MT0053	F	18-Apr-13	Creek		x		
MT0064	F	09-May-13	River		x		
MT0077	M	21-May-13	River	x	x		
MT0078	M	21-May-13	River		x	x	
MT0079	M	21-May-13	River	x	x	x	
MT0080	M	21-May-13	River		x	x	
MT0081	M	21-May-13	River	x	x		
MT0082	M	21-May-13	River	x	x		x
MT0087	F	06-Aug-13	River	x	x	x	
MT0092	F	06-Aug-13	River		x	x	
MT0093	M	06-Aug-13	River		x		
MT0095	F	06-Aug-13	River		x		
MT0096	F	06-Aug-13	River		x		
MT0097	F	06-Aug-13	River		x		
MT0098	F	06-Aug-13	River	x	x		
MT0099	F	06-Aug-13	River		x		
MT0100	M	06-Aug-13	River	x	x		
MT0101	F	06-Aug-13	River		x		
MT0102	M	06-Aug-13	River	x	x		
MT0103	M	06-Aug-13	River	x	x		
MT0107	F	06-Aug-13	River	x	x		
MT0120	F	04-Oct-13	River		x		
MT0121	M	04-Oct-13	River	x	x		
MT0123	M	04-Oct-13	River		x		