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Development of a rapid-assessment technique for diamondback terrapin (*Malaclemys terrapin*) populations using head-count surveys

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Abstract
Although diamondback terrapins appear to be declining throughout much of their geographic range, more information is required to evaluate population trends. Unfortunately, sampling terrapin populations is both time and labor intensive. We initiated studies to examine the efficacy of using head counts in tidal creeks as a rapid-assessment technique for monitoring terrapin populations. From 2005 to 2007, we conducted head-count surveys in conjunction with regular aquatic sampling. Head-count surveys consisted of recording the number of terrapins we observed from a boat going up (run 1) and down (run 2) tidal creeks. These surveys were conducted before aquatic sampling (i.e., low tide) as well as other times (e.g., high tide). We found the strongest positive relationship between the number of terrapins observed in run 1 combined with run 2 and the number of terrapins captured ($R^2 = 0.538$). We examined the effects of variables such as day of year, time of day, cloud cover, and creek location on the number of heads seen. Such models will allow effective monitoring of terrapin population trends and improve implementation of appropriate conservation measures. We recommend a refinement of head-count surveys and the involvement of citizen scientists to aid in the establishment of a range-wide monitoring program that will greatly increase survey effort while saving time and money.

Key words
Diamondback terrapin, head-count surveys, *Malaclemys terrapin*, population trends, rapid-assessment.

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Introduction

Monitoring populations of marine organisms to estimate their abundance can be difficult because an unknown proportion of the population can remain undetectable to the observer (Bowen and Siniff, 1999; Kendall and Nichols, 2002). Mark-recapture studies are often used to monitor such elusive species and to estimate population size (McDonald, 2004). Unfortunately, mark-recapture studies are often time and labor intensive. Such studies also require substantial knowledge of species locations and activity patterns to optimize capture probability (McDonald, 2004). Alternatively, a more rapid type of systematic sampling, such as visual encounter surveys, can be used to estimate relative abundances of species and, ultimately, evaluate population trends over time (Campbell and Christman, 1982; Crump and Scott, 1994). Visual encounter surveys are an active method of monitoring populations of many surface-active animals, or animals that use particular habitats (Dorcas and Willson, in press). Variants of visual encounter surveys (e.g., transect, quadrat, randomized) have been used to provide information on abundances, population estimates, and distribution data of terrestrial reptiles (Sun et al., 2001; Enge and Wood, 2002; Gibbs and Steen, 2005; Rodda et al., 2005) and amphibians (Hairston, 1980; Campbell and Christman, 1982; Pough et al., 1987; Nishikawa, 1990), as well as surfacing marine organisms such as sea turtles (Epperly et al., 1995).

Diamondback terrapins (*Malaclemys terrapin*) are a candidate species to monitor using visual encounter surveys because they are aquatic reptiles that surface frequently to breathe and bask. Terrapins are estuarine turtles endemic to coastal salt marsh ecosystems from Cape Cod, Massachusetts to the Gulf Coast of Texas (Ernst et al., 1994). Although scientists have documented declines in local populations for over a decade and have begun to identify some of the causes behind these declines (Seigel, 1993; Seigel and Gibbons, 1995; Dorcas et al., 2007), the status of terrapins across most of their range is completely unknown. Historically, terrapin populations declined because of commercial harvesting (Gibbons et al., 2001) but now, threats to terrapin populations are commonly attributed to crab trap mortality (Wood, 1997; Hoyle and Gibbons, 2000; Dorcas et al., 2007), road mortality (Wood and Herlands, 1997; Szerlag and McRobert, 2006), nest predation of human-subsidized predators (Butler et al., 2004), habitat loss and degradation (Seigel, 1993; Gibbons et al., 2001), and motorized watercraft mortality (Burger and Garber, 1995; Cecala et al., 2008). However, the impact of these anthropogenic pressures on terrapin populations remains essentially unknown because of the lack of long-term population studies in most areas.

Population sizes of diamondback terrapins are traditionally estimated using sampling techniques that require seines, trammel nets (Lovich and Gibbons, 1990; Dorcas et al., 2007), crab pots (Bishop, 1983; Roosenburg, 1997), and dip nets (Hart, 2005), although these techniques are intensive and require substantial time and effort. Development of a rapid-assessment technique for terrapin populations will allow researchers to assess population sizes throughout their range. Our goal in this study was to examine the utility of using head-count surveys to estimate population sizes of diamondback terrapins. Specifically, we sought to determine the relationship between number of terrapins observed and the actual number of terrapins captured via aquatic sampling, and investigate factors that affect the number of terrapins observed during surveys.

Methods

Data collection

In spring 2005, as part of a 24-year mark-recapture study of terrapins at Kiawah Island, South Carolina (Dorcas et al., 2007), we began head-count surveys in conjunction with regular aquatic sampling. Between 2005 and 2007, aquatic sampling was conducted twice per year (between 13-25 May and 5-17 October) and consisted of using seines and trammel nets at low tide to capture terrapins in tidal creeks. Our study site included five tidal creeks (Sandy, Fiddler, Oyster, Stingray, and Terrapin), which are tributaries of the Kiawah River. For a map, a more detailed description of creek locations, and information on terrapin processing see Dorcas et al. (2007). Low to high tides from the Kiawah Island Bridge (within 2 km from all sampled creeks) ranged from −0.14 m to 2.36 m for the two years we conducted head-count surveys.

Head-count surveys were conducted at low tide before each aquatic creek sampling bout but were also periodically conducted at high, ebbing, and flowing tides throughout the sampling week. Head-count surveys consisted of recording the number of terrapins observed at the surface of the water or, on rare occasion, observed on the bank that fled to the water when approached by boat. Observations were made from a 4.3-m aluminum jon boat with an outboard motor or from a 5.5-m Boston Whaler. Each head-count survey (i.e., transect) consisted of navigating up (run 1) and down (run 2) each tidal creek. We divided each of the five tidal creeks into relatively equal length sections (anywhere from 3 to 6 sections), and we recorded the number of terrapin heads seen in each section as we drove up and down the creek at approximately 8-11 km/h. Head-count surveys involved two or more participants: one who was responsible for driving the boat and at least one other who was responsible for recording the number of terrapin heads seen in addition to other variables. For each head-count survey, this observer recorded environmental variables including: air temperature (C), tide level, percent cloud cover (estimated to nearest 10%), and wind speed ($0 =$ no wind $\ldots 3 =$ extremely strong wind).

Data analysis

We used a linear regression to evaluate the relationship between the number of terrapins observed and the number captured via aquatic sampling. The independent variable was the number of terrapins observed in each creek section and the dependent variable was the number captured per creek section. We ran three regression analyses: once with number of terrapins observed in run 1 versus the number captured, once with number of terrapins observed in run 2 versus the number captured, and once with number of terrapins observed in run 1 and run 2 combined versus the number captured. We used R^2 values to compare the strengths of these relationships.

We used a stepwise multiple regression to examine how various factors affected the number of terrapins observed during head-count surveys. Independent variables included day of year, time of day, tide, air temperature, percent cloud cover, wind strength, and individual creek sampled. Terrapin Creek was not included in this analysis because of its low terrapin population size (Gibbons et al., 2001). For this analysis, the dependent variable was number of terrapins observed at each of the four creeks. We used an alpha of 0.05 for all analyses.

Results

In all analyses, we found a significant positive relationship between the number of terrapins observed and the number captured. More specifically, the number of terrapins observed during run 1 of a tidal creek combined with the number of terrapins observed during run 2 showed the strongest relationship with the number of terrapins captured ($R^2 = 0.538$, $p < 0.001$) (fig. 1). We also found that, while exhibiting weaker relationships, the number of terrapins seen in run 1 alone correlated with the number of terrapin captures ($R^2 = 0.506$, $p < 0.001$), as did the number of terrapins seen in run 2 alone ($R^2 = 0.419$, $p < 0.001$).

We found that during low tide, more terrapins were observed in the tidal creeks than at high tides ($p < 0.001$) (fig. 2). More terrapins were observed when clouds were limited ($p = 0.021$) than when it was cloudy. We observed more terrapins

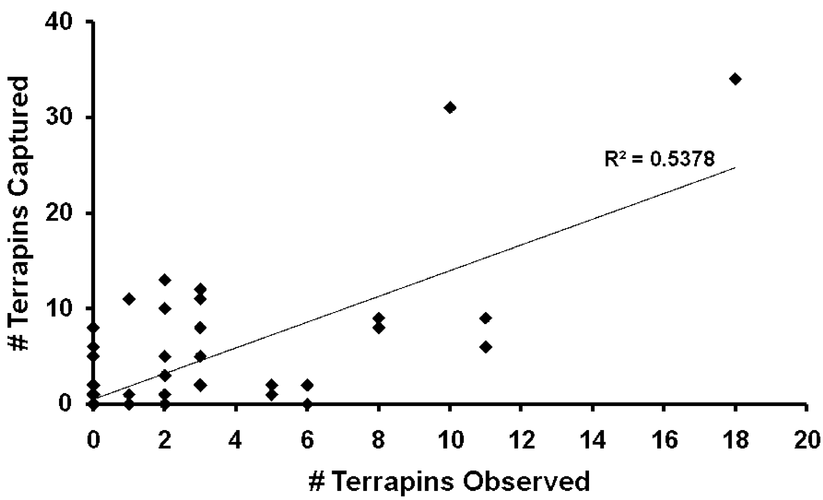

Figure 1. The number of terrapins observed during pre-sampling head-count surveys (run 1 + run 2) versus the number of terrapins captured by seine at low tide in all five creeks.

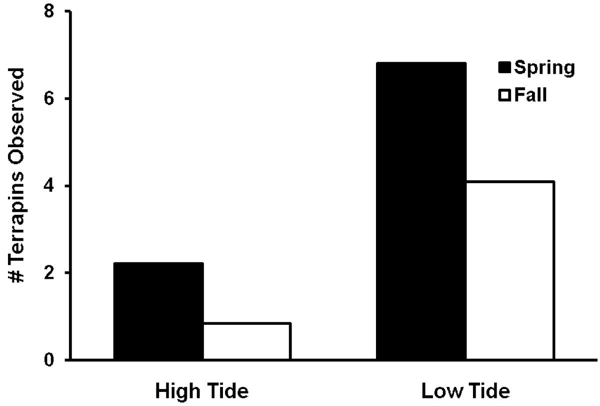

Figure 2. The number of terrapins observed during spring (closed bars) and autumn (fall — open bars) head-count surveys at low tide and high tide. Head-count surveys for this analysis included all creeks except Terrapin Creek and consisted of terrapins observed during run 1 + run 2.

during the spring sampling period than during the autumn sampling period, but this variable (i.e., day of year) was not statistically significant ($p = 0.153$).

Discussion

Currently, the overall status and trends of terrapin populations remain uncertain because few researchers have established estimates of population sizes (Bishop, 1983; Tucker et al., 2001; Mitro, 2003; Avissar, 2006). Consistent, long-term monitoring is needed to detect temporal changes in population sizes (Avissar, 2006), but using intensive present-day methods requires too much time, money, and sampling effort. Based on our results, we therefore recommend the development of an alternative monitoring program that relies on systematic head-count surveys to evaluate diamondback terrapin population trends over time.

Based on three years of head-count survey data, we found that combining the number of terrapins observed during run 1 and run 2 of the pre-sampling survey was more strongly correlated with the number of terrapins captured than using only the results of run 1 or run 2 separately. In other words, the number of terrapins observed during the combined runs is the best predictor of the number of terrapins that will be captured from that same creek at low tide. Head-count survey protocol in other estuarine regions within the terrapin's geographic range may need adjusting because of differences in salt marsh habitats along the East and Gulf Coasts (e.g., inability to navigate creeks at low tide in some regions).

We found that certain environmental factors can serve as predictors of the number of terrapins observed during head-count surveys. In our study, the primary factor affecting number of terrapins observed was tide level; our data show that an observer is likely to see more terrapins at low tide than at high tide. Our results also indicate that more terrapins are likely to be observed when skies are clear than under cloudy conditions. Finally, although not a statistically significant effect, day of year appeared to be negatively correlated with head counts, suggesting that an observer would detect more terrapins in the spring (i.e., May) than autumn (i.e., October).

A population ecology study on the Carolina Diamondback terrapin (*Malaclemys terrapin centrata*) in northeast Florida documented similar results on effects of head counts. Butler (2002) found that during his year-round head-count surveys in 1997-1998 and in 2000-2001, the highest head count was recorded on 19 May 1998 and on 5 May 2001. Terrapins may be more active during the late spring versus autumn as a result of mating activity (Seigel, 1980; Hauswaldt and Glenn, 2005; Brennessel, 2006).

Although Butler (2002) did not find tide to be a main effect on head counts as observed in our study, he did find that tide level was correlated with water temperature ($p = 0.039$) and water temperature was a main effect on head counts ($p = 0.03$). Therefore, if low tides result in warmer water and warmer water results in more terrapins observed, then a combination of these two environmental factors may result in a higher head count.

Finally, our results indicate that more heads are observed during periods of low cloud cover, which may indicate increased basking behavior during periods of direct sunlight and thus, warmer temperatures at the water's surface. Basking is a type of thermoregulation that increases body temperature and accelerates metabolism, growth, and activity (Congdon, 1989; Harden et al., 2007), all of which are necessary for foraging, digestion, and reproduction (Krawchuk and Brooks, 1998). Furthermore, although we did not measure water temperature, warmer water may increase the amount of time terrapins spend at the surface as a result of increased oxygen requirements because of elevated metabolic rate. Essentially, any conditions that increase terrapin activity within creek channels will influence the number of terrapins counted during a head-count survey.

Mark-recapture studies are essential to monitor terrapin population demographics and trends (Seigel, 1993; Hart and Lee, 2006), but less intensive assessment techniques are also crucial to help evaluate terrapin populations across their range. Our results indicate that when conducted under the recommended environmental conditions of low tide and low cloud cover, head-count surveys can be used to estimate relative abundances of terrapins in Kiawah Island salt marsh tidal creeks and likely other parts of the species range where habitats and conditions are similar. We recommend consideration of including other environmental variables such as water temperature, salinity, and tidal fluctuations. Additionally, we recommend consideration of maintaining consistency when conducting head-count surveys such as using the same watercraft and same number of observers for every survey. Tide level is a critical component to head-count surveys because it varies substantially along the east and gulf coast and thus, should be taken into consideration when establishing local head-count survey protocols (e.g., choosing an ideal tide level to successfully navigate a boat through a tidal creek). Once head-count surveys are refined, we recommend testing these models at additional sites within the terrapins' geographical range and finally, establishing a range-wide terrapin monitoring program to evaluate the status and trends of terrapin populations.

In order to facilitate the development and expansion of such an extensive monitoring program, we propose to involve community members in the collection of long-term head-count data. Not only will researchers benefit from an increase in survey effort, data, and public awareness, but citizens also benefit. Citizen scientists gain a hands-on approach and appreciation for scientific research and become familiar with local conservation matters (Brewer, 2002; Pittman and Dorcas, 2006), which can lead to a better sense of stewardship over animal populations they are monitoring (McCaffrey, 2005). Our rapid-assessment technique lends itself to citizen science by the ease in which surveys are conducted and because of the charismatic nature of diamondback terrapins, which can serve as a great outreach tool to capture the interest of the public. The incorporation of citizen science will ultimately expand the terrapin population monitoring program spatially and temporally with the goal of becoming a range-wide long-term monitoring program such as The Great Backyard Bird Count (http://www.birdsource.org/gbbc/), The North American Amphibian Monitoring Program (http://www.pwrc.usgs.gov/naamp/), or the Monarch Larva Monitoring Program (http://www.mlmp.org/).

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