Post-emergent movements and survivorship of diamondback terrapin (*Malaclemys terrapin*) hatchlings in Bermuda: the role of predation by herons

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Introduction

Diamondback terrapins (Fig. 1) are emydid turtle residents of coastal brackish environments along the Atlantic and Gulf coasts of the USA. They are extremely tolerant of saline water and can survive for weeks in sea water. Nesting occurs in sandy soil environments located above high tide (Butler *et al*. 2006; Ernst & Lovich, 2009). After emerging from the nest, hatchlings seek refuge within the nearest vegetation, and show avoidance of open water (Burger 1977; Lovich *et al*. 1991; Butler *et al*. 2004; Coleman *et al*. 2014). Growth is rapid, but slows after sexual maturation (Tucker *et al*. 1995; Roosenburg & Kelley 1996); adult females are much bigger than males (Fig. 1). Terrapin hatchlings in the USA are preyed on by small mammals, birds and crabs (Ernst & Lovich 2009), but quantifying predatory impact has been rare.

Bermuda is a British Overseas Territory, 1000km east of the USA mainland. Diamondback-terrapins have lived there (the only population outside the USA) since long before people colonized the remote archipelago (in 1609 CE); they arrived by drifting from the USA east coast. They have been reduced in number by habitat loss and environmental contamination (Outerbridge *et al*. 2016) to a small population (about 100 adults/large juveniles; Outerbridge 2014) that uses the sand bunkers of the Mid Ocean golf course (Fig. 2) as its nesting habitat (Davenport *et al*. 2005; Parham *et al*. 2008). Surveys in 2010 and 2011 showed that 97% of nesting (between March and August) happened in 11 bunkers, mostly located near brackish ponds (Mangrove Lake and South Pond; Outerbridge 2014) that hold the adult population. Hatchling emergence from the nest occurs during two distinct periods in the calendar year; summer/autumn (July–October) and winter/spring (January–March). There was concern that hatchlings might be preyed upon by

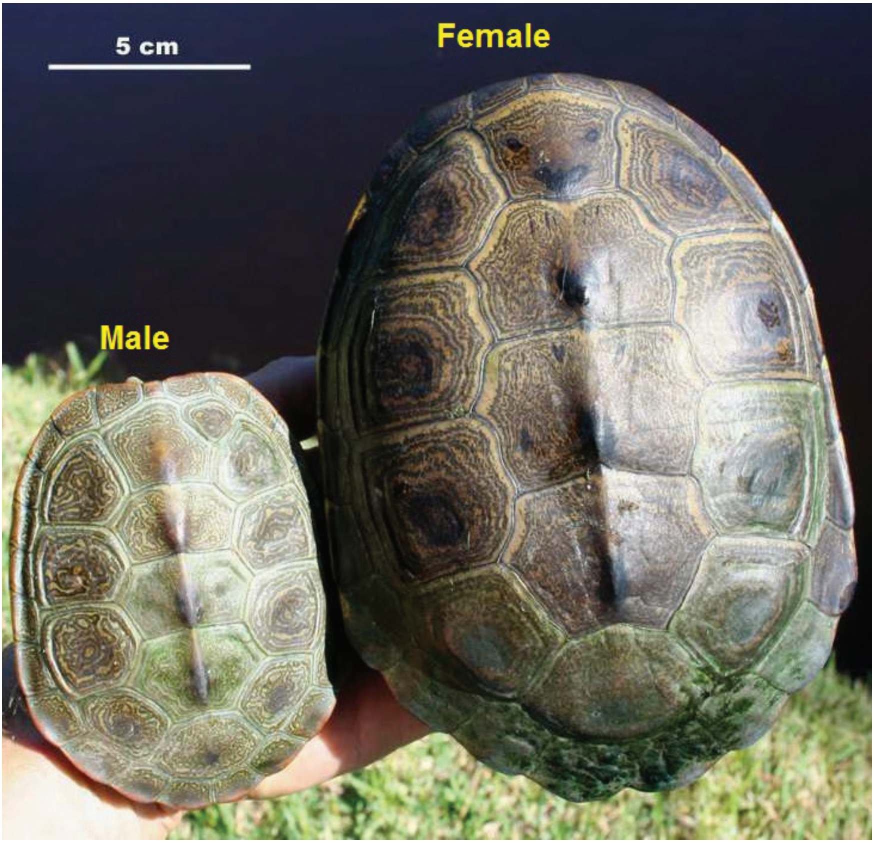

Fig. 1. Photograph of adult male and female Bermudian specimens of *Malaclemys terrapin.* Note pronounced sexual dimorphism.

yellow-crowned night herons (*Nyctanassa violacea*). These were introduced to Bermuda in 1976-78 as a substitute for an extinct night heron that was exterminated soon after humans colonized Bermuda. Kushlan *et al*. (2011) reported that the golf course and its water traps provided optimal habitat for the herons.

Radio-telemetry was chosen to investigate the behaviour and survivorship of hatchlings that had newly emerged from natal nests. This was required to (1) inform effective conservation and management planning for the species in Bermuda, (2) to identify sources of predation, especially by herons, (3) to identify areas of residency for hatchlings and small juveniles, and (4) to compare hatchling activity levels and movement patterns between those emerging in summer and those emerging in spring. Its extent was necessarily constrained by the small size of the Bermudian terrapin population.

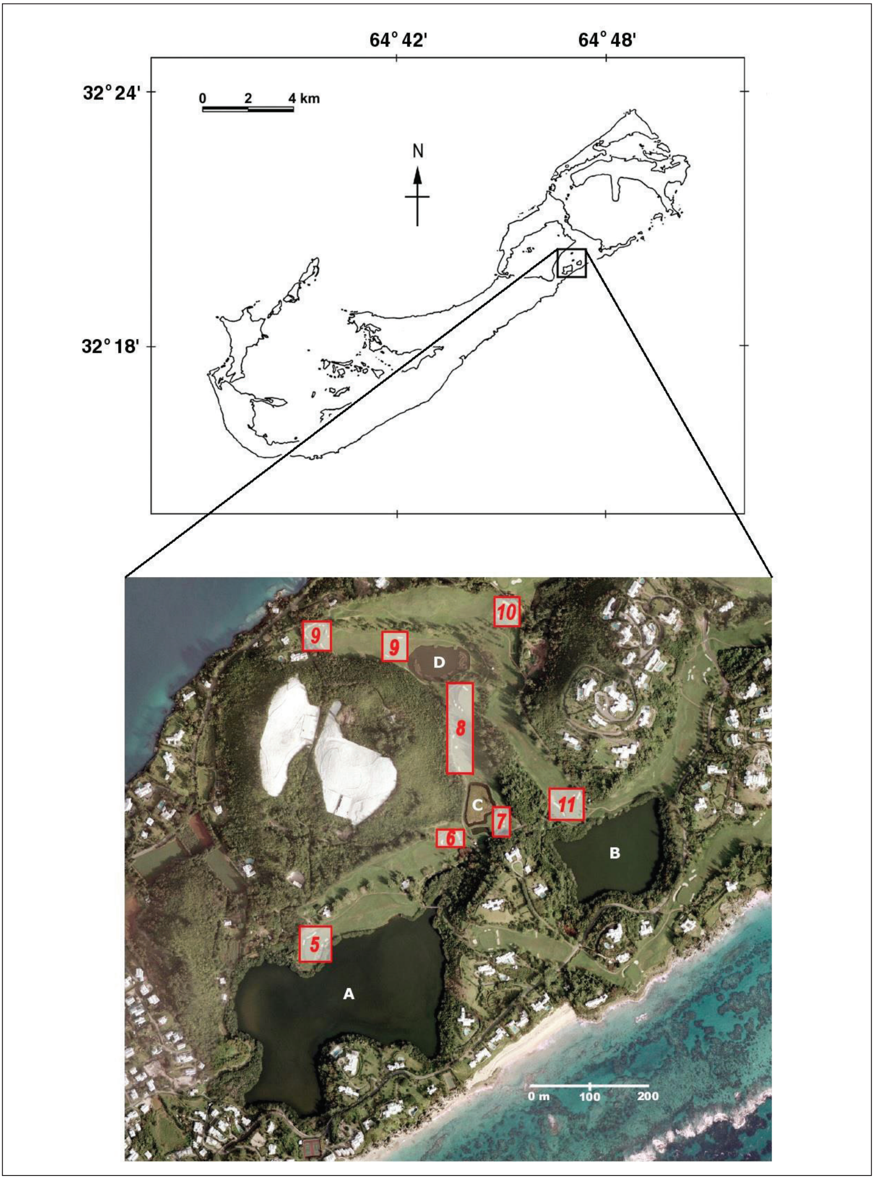

Fig. 2. **Above:** Map of Bermuda showing the location of the *Malaclemys terrapin* population. **Below:** Aerial photograph from 2003 showing the four terrapin ponds situated on the Mid Ocean golf course (A = Mangrove Lake, B = Trott's Pond, C = South Pond, D = North Pond). Generalized locations of the numbered sand bunkers associated with 97% of nesting are indicated by red-bordered translucent boxes.

Materials and methods

Ten diamondback terrapin hatchlings were captured in 2010 after newly emerging in summer from 10 different nests. Radio-transmitters (model BD-2, Holohil Systems Ltd.) with a nominal 28-day battery life were attached to their carapaces following Draud *et al*. (2004). Hatchling mass ranged from 7-10g (mean 8.4g; SD 0.8g) and straight carapace length (SCL) ranged from 31.1-34.4mm (mean 32.9 mm; SD 1.0mm). The transmitters weighed 0.7g and were therefore within the 10% recommended limit for telemetry packages (Beaupre *et al*. 2004). Hatchlings were subsequently released in sand bunkers on the fifth hole (n = 5) and seventh hole (n = 5) on the Mid Ocean golf course and tracked once or twice daily from 31st July to 8th September 2010 using a telemetry receiver (R-1000, Communications Specialists, Inc.) fitted with a hand-held radio antenna (RA-2AK, Telonics Inc.).

In 2011, ten hatchlings (mass range 7-10g; mean 8.3g; SD 1.2g and SCL range 30.3–34.5mm; mean 32.3mm; SD 1.6mm) which had recently emerged from over-wintering in 10 different nests were captured, fitted with new transmitters and released in their sand bunkers. They were tracked once or twice daily from 27th March to 28th April 2011. All tracking sessions were conducted between 08:00 and 24:00.

Hatchlings were observed during each tracking session; stakes were used to mark tracks for distance estimations. Searches continued for three days after loss of a radio-transmitter signal. Presence of herons (suspected to be likely predators as described in the Introduction) was also documented.

Results

Summer surveys 2010

Mean transmitter battery life was 33.5 days (range 23-40 days). Hatchling movement was detected in only 11% of tracking sessions. Mean daily distance travelled per hatchling was 0.8m (range 0-60m). Upon release, all 10 hatchlings crawled immediately to the edge of the bunkers and either buried themselves in the sand, or burrowed into the grass growing at the edge of the bunkers. Only three were observed to leave the bunkers later. One hatchling departed the bunker by the second day following its release, travelled a straight line distance of ca. 15m and entered a mangrove swamp where it remained until the transmitter signal was lost 35 days later. A second hatchling travelled a straight line distance of ca. 60m and entered a saw-grass marsh in the centre of South Pond where it remained until the transmitter was removed 12 days later. The third hatchling travelled a straight line distance of ca. 16m and crawled into grass bordering the fairway where it remained until the transmitter was removed 10 days later. The remaining seven hatchlings stayed concealed at the margins of their respective bunkers throughout the survey period; most were buried in the sand to depths ≤10cm. Thirty-three yellow-crowned night heron sightings were recorded on 15 separate days over the 40-day survey period in 2010, supporting the finding of Krushlan *et al*. (2011) that the golf course was good heron habitat.

Spring surveys 2011

Mean transmitter battery life was 29.3 days (range 28-31 days). Hatchling movement was detected in 59.3% of tracking sessions. Mean distance travelled per hatchling was 6.2m (range 0-122.5m). All 10 hatchlings released in 2011 crawled immediately to the edge of the bunkers and buried themselves in sand or burrowed in the grass edge. By the end of the first week following release, all terrapins had left their bunkers. Five hatchlings entered nearby mangroves and dispersed within them. They were frequently observed seeking refuge within the mangrove leaf litter close to the water's edge, or in shallow water among mangrove prop roots. Two hatchlings moved to dense mats of sheathed *Paspalum, Paspalum vaginatum* that border South Pond on the first day following release, travelling straight line distances of 22.6m and 35m respectively across a putting green. One of these remained hidden within the *Paspalum* for the following 26 days; the other remained within the grass for a two week period before taking up residency within the 0.3 hectare saw-grass *Cladium jamaicense* marsh at the centre of South Pond. This latter individual was tracked for an additional 13 days during which it was repeatedly observed sheltering under dense saw-grass foliage, often partially buried in the marsh substratum. An eighth hatchling could not be located on the second day despite a thorough search of the area, though its transmitter (without terrapin) was found on the third day 160m from the original release location (see below). The final two hatchlings left their bunker within three days and travelled straight line distances of 92.4m and 122.5m across the fairway. One crawled to the base of a tree where it remained until it disappeared on the sixth day following its release; the other entered the mangrove swamp adjacent to Mangrove Lake where it continued to move along the fringe of the swamp. It also disappeared on the sixth day following its release.

A total of 49 heron sightings were recorded on 22 separate days. There were five species: the yellow-crowned night heron *N. violacea*, the little blue heron *Egretta caerulea*, the great egret *Ardea alba*, the snowy egret *E. thula*, and the tricoloured heron *E. tricolor*. One hatchling heron predation event (not of a transmitter-equipped specimen) was directly observed at South Pond (Fig. 3A).

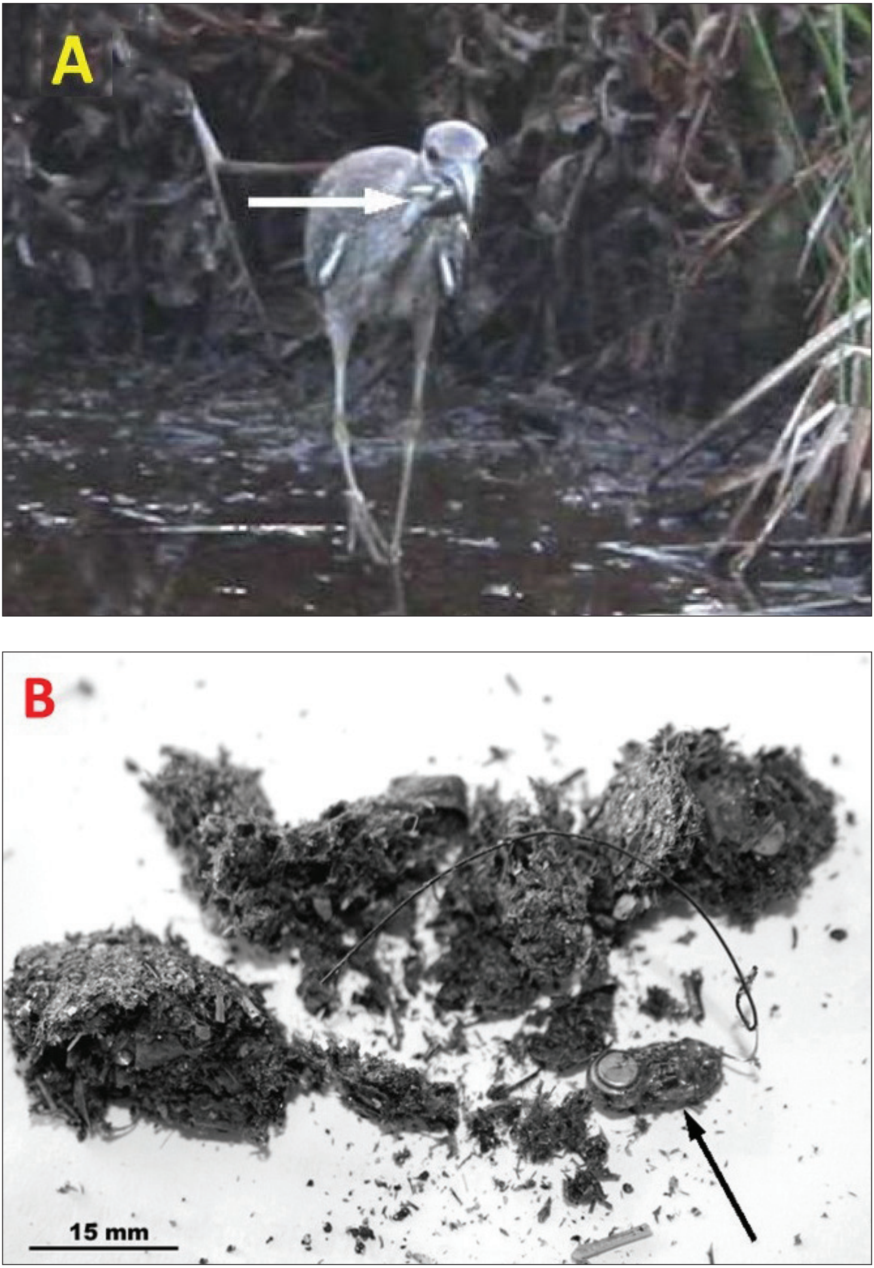

Fig. 3.
A. Yellow-crowned night heron with a dead juvenile diamondback terrapin in its bill (arrowed).
B. Regurgitated heron pellet showing a BD-2 radio transmitter unit (arrowed).

Hatchling survivorship

Nine of the 10 radio-transmitters were recovered from their respective hatchlings in summer 2010. Only one hatchling vanished during this study due to loss of transmission signal 37 days after release, well after expected battery exhaustion. Survival was therefore high, probably total.

Only three radio-transmitters were recovered in spring 2011. The remaining seven transmitters (and hatchlings) were not recovered due to loss of radio signal. Four of these disappeared within one week of deployment (range 2-6 days, mean 4.75 days), well before expected battery exhaustion. Predation is assumed in these cases and the loss of signal suggests avian predation as it implies removal from the 1km^2 area of study. One of these transmitters was located 160m from its last known location after vanishing for a 24-hour period. This unit was recovered from a regurgitated heron pellet which contained chitinous fragments of terrestrial arthropods and carapace scutes from a diamondback terrapin hatchling (Fig. 3B). Clearly this hatchling had been eaten; it had probably been transported outside the transmitter reception area before the bird returned and disgorged the pellet. The final three hatchlings disappeared 17, 20 and 28 days following release.

Discussion

Our results showed that the mangrove swamp and grass-dominated marshes adjacent to the saline ponds on the Mid Ocean golf course are important habitats for the early development of diamondback terrapins in Bermuda. Young diamondbackterrapins (≤75mm SCL) in the USA are similarly cryptic, hiding under surface debris, low vegetation, rocks and matted *Spartina* grass on tidal mud flats (Pilter 1985), burrowing into the tidal wrack at the high tide line in salt marshes (Lovich *et al*. 1991) or within the intertidal vegetation of the high marsh zone (Draud *et al*. 2004; King 2007).

Bermudian hatchlings avoid open water and crawl to the nearest vegetation. This is consistent with earlier USA studies (Burger 1976; Lovich *et al*. 1991; Butler *et al*. 2004). We also found that hatchlings that emerge in summer are much less mobile and more terrestrial than those that emerge after remaining in their nests ('brumation') over the winter period; the latter disperse more rapidly and further and enter shallow, vegetation-shielded water. This finding is novel, although Muldoon & Burke (2012) reported that post-emergent hatchling terrapin movements in the autumn were typically upland, away from water, a trend reversed in the spring.

The mangrove swamps and grass-dominated marshes of Mangrove Lake and South Pond offer ample food resources, particularly in the form of small gastropod molluscs (Outerbridge *et al*. 2017) and the plant cover provides concealment from predators. The grass-dominated marshes in South Pond and North Pond are significantly smaller in area than the mangrove swamps

(0.3 and 0.04 hectares respectively), while the *Paspalum* mats that fringe these two ponds are frequently cut back or removed entirely as part of the maintenance programme of the golf course.

The limited battery life of the transmitters did not permit long term (months-years) monitoring of hatchling movement, but it is reasonable to assume that these grass/mangrove areas are not temporary microhabitat choices; no hatchling-sized or small juvenile terrapins (<81mm SCL) were encountered in the open water habitat of the ponds during a three year mark-recapture study of the Bermuda population (Outerbridge 2014).

None of the hatchlings monitored in summer 2010 was believed to have been lost to predation, but the data for the following spring (2011) indicate that at least 40% (*n* = 4) of the hatchlings monitored were consumed (probably by herons) near South Pond and Mangrove Lake. All lost transmitter signals during the spring tracking session in 2011 were preceded by observations of herons foraging in the areas where hatchlings were being monitored, so it is likely that predation rate was actually higher. In support of the likely importance of heron-mediated predation it should be noted that 10 small diamondback-terrapins were seen to be preyed upon by yellow-crowned night herons foraging in the saw-grass marsh and *Paspalum* at South Pond during spring 2010 (Outerbridge 2014).

Skeletal remains found in Pleistocene and Holocene cave and pond deposits indicate that an endemic, crab-eating heron *Nyctanassa carcinocatactes* was present in Bermuda, but went extinct subsequent to human colonization in 1609 CE (Olsen & Wingate 2006). During the late 1970s an attempt was made to establish a breeding population of a living con-generic heron (the yellow-crowned night heron) as a potential agent of biological control of a terrestrial species of land crab *Gecarcinus lateralis* that was deemed a pest at the time. This species is now the most common heron on Bermuda, breeding has been documented island-wide and the present-day population is self-sustaining (Madeiros, pers. com.). Herons of the genus *Nyctanassa* have been described as crustacean specialists (del Hoyo *et al*. 1992) and examination of regurgitated pellets on Bermuda during the early 1980s revealed that land crabs comprised approximately 97% of their diet. Recent foraging observations, plus examination of regurgitated pellets, suggest that yellow-crowned night herons on Bermuda now feed on a much greater diversity of prey items, including various varieties of terrestrial arthropods, small fishes, marine crustaceans, small amphibians and reptiles (Outerbridge, unpubl.). Diamondback terrapins 96-137mm SCL inspected during an assessment of the Bermuda population (Outerbridge *et al*., unpubl. data) showed signs of carapace damage of a near-identical nature to those observed on a young specimen (51mm SCL) that had been killed by a yellow-crowned night heron. This suggests that yellow-crowned night herons prey on young diamondback-terrapins until the latter attain a size of at least 96mm SCL, when they are approximately three years old (Gibbons *et al*. 2001). The other heron species observed in our study are fish-eaters.

Predators of small diamondback terrapins in the North American range include raccoons, rats, ghost crabs and a variety of birds (including night herons) (Burger 1976; Arndt 1991, 1994; Draud *et al*. 2004). Rats have been seen, while feral cats are attracted to the Bermudian study area by organized feeding stations. Draud *et al*. (2004) reported rats taking 67% of terrapin hatchlings and small juveniles (25-41 mm SCL) studied in New York State. Feral cats can certainly take small chelonians; Seabrook (1989) reported that 90% of cat scats collected on a single island in the Indian Ocean contained green turtle (*Chelonia mydas*) hatchling remains. However, there is no current evidence of rat or cat predation of young terrapins on Bermuda.

Concluding comments

Delayed sexual maturity, longevity and iteroparity (repeated breeding) are key characteristics of the population biology of chelonians (Gibbs & Amato 2000), but these very characteristics also make their populations less capable of responding to elevated rates of juvenile mortality (Congdon *et al*. 1993). The observed level of heron predation on diamondback terrapin hatchlings during the first month following spring emergence in Bermuda may be partially responsible for the low levels of recruitment that have been documented in the adult population (approximately two terrapins per year) (Outerbridge 2014). Furthermore, yellow-crowned night herons appear to remain predators of small juvenile terrapins for three years following hatching. This is worrying, given the estimated average annual production of only 90 hatchlings (Outerbridge 2014; Outerbridge *et al*. 2016). High post-hatching survival rates are necessary to ensure that adequate recruitment occurs to maintain a stable population.

Continued monitoring of this vulnerable population is vital, as are further radio-telemetry studies to examine heron predation rates. It would also be prudent to control rats and to relocate the feral cat feeding stations to areas where terrapin hatchlings are absent. A limited cull of yellow-crowned night herons, particularly at South Pond, should be considered in the spring when terrapin hatchlings appear to be more conspicuous.

Postscript

Following our study, targeted culling of yellow-crowned night herons has occurred annually during the months of April and May (52 have been shot over the past five years). In addition, the feral cat feeding station has been moved to another location, while rats are being controlled using commercial rodenticides. Hopefully these measures will enhance survival of diamondback hatchlings.

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