APPENDIX 1. Prey items identified from the alimentary canals of *Egernia coventryi* (*N* = 54) examined in this study. The alimentary canals of seven specimens were empty. The number of times each prey item was recorded in the remaining 47 specimens is shown. The bold numbers represent overall totals for particular taxonomic groupings (e.g., insect orders), with the numbers of *E. coventryi* alimentary canals with specific prey types (e.g., insect families) also provided. Prey items for *E. coventryi* identified by Douch (1994) are also shown (based on stomach flushing and scat analysis).

Prey type	This study	Douch (1994)
Arthropods		
Class Insecta		
Order Blattodea (cockroaches) 15 mm long	2	X
Order Coleoptera (beetles)	**12**	X
Family Carabidae (ground beetles) 8–12 mm long	3	
Family Scarabaeidae 15–25 mm long	2	
Family Tenebrionidae (Darkling beetles) larvae 10–20 mm long	2	
unidentified larvae 6 mm long	3	
unidentified pupae 15 mm long	**1**	
Order Diptera (flies) 6 mm long	3	X
Order Hemiptera (true bugs)	**4**	X
Family Cicadellidae *Paracephaleus* sp. ~10 mm long	**1**	
Family Coreidae (heteropteran bugs) 7–15 mm long	**1**	
Family Enicocephalidae (gnat bugs) 6 mm long	**1**	
Order Hymenoptera (wasps, ants, bees)	**6**	X
Unidentified wasp	1	
Family Apidae honey bee (*Apis mellifera*)	1	
Family Formicidae (ants) *Iridomyrmex* sp., *Pheidole* sp.	5	
Order Isoptera (termites)		X
Order Lepidoptera (moths, butterflies)	**8**	X
Family Noctuidae? larvae	**1**	
unidentified adult moth (and scales)	3	
unidentified larvae 1–30 mm long	**4**	
Order Neuroptera Antlion larvae	1	
Order Odonata (dragonflies, damselflies)	**2**	X
nymph (aquatic; mudeye) 15 mm long	1	
Order Orthoptera (crickets, grasshoppers)		X
Order Trichoptera (caddlis-flies)	1	
Unidentified insect	**6**	
Unidentified insect pupae	**1**	
Unidentified egg mass	**1**	X
Class Arachnida		
Order Araneae (spiders)	**16**	X
Family Gnaphosidae (ground spiders)	1	
Family Lycosidae (wolf spiders) 5–10 mm long	3	
Class Chilopoda (centipedes)		X
Order Scolopendrida 40 mm long	2	
Class Diplopoda (millipedes)	1	
Subphylum Crustacea (Crustaceans)		
Class Malacostraca		X
Order Amphipoda (amphipods)		X
aquatic 10 mm long	**4**	
Order Isopoda (Isopods)		X
terrestrial 8–12 mm long	3	
Mollusca		
Class Gastropoda (snails)	1	X
Plant Material	**31**	
Fruit (including Epacridaceae) ~3 mm diameter	8	X
Seeds (including Epacridaceae and grass seeds)	7	

APPENDIX 1. Continued.

Prey type	This study	Douch (1994)
Stamens	1	
Pollen	1	
Leaves, flowers grass fragments	7	X
Other (e.g. twigs, branches)	15	
Other		
Slough	12	
E. coventryi tail fragment (7 × 2.5 mm)	1	
unidentified small skink		X (also Schulz, 1985)

Predation on Hatchling and Juvenile Diamondback Terrapins (*Malaclemys terrapin*) by the Norway Rat (*Rattus norvegicus*)

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ABSTRACT.—The Norway Rat (*Rattus norvegicus*) was a major predator on hatchling and juvenile Diamondback Terrapins (*Malaclemys terrapin*) in a New York population during three years (2001–2003). Rats killed young terrapins by evisceration through the plastron or carapace, exclusively at night, and during two distinct periods: (1) at emergence from nests in August and September; and (2) at emergence from hibernation in April. Predation rates were highest during peak emergence from nests and hibernacula. In the fall, hatchlings were mainly preyed upon within intertidal high marsh vegetation, where hatchlings normally occur after emergence from nests. We found no evidence of rat predation on eggs or hatchlings in nests. Predation in the spring also occurred in the intertidal high marsh, but rats killed juveniles in adjacent terrestrial habitats as well. We used data from a telemetry study of 24 wild hatchlings to estimate rat predation rates. Between 13 September and 22 October 2003, 16 of 24 (67%) radio-tracked hatchlings were killed by rats.

The early life history of the Diamondback Terrapin (*Malaclemys terrapin*) is largely unknown (Gibbons et al., 2001). Predation on nests (e.g., Burger, 1977; Roosenburg, 1992) and adult terrapins (e.g., Seigel, 1980) is well documented from throughout the range of the species, with Raccoons (*Procyon lotor*) considered to be the major predator. Considerably less is known about the predators on hatchling and juvenile terrapins, and virtually nothing is known about mortality rates of these early life-history stages.

As is true for most Chelonia, Diamondback Terrapins are long lived with delayed sexual maturity, and as such their populations are less capable of responding to chronic high juvenile mortality (Iverson, 1991; Congdon et al., 1993). There are good data relating to survivorship of adult terrapins, but much less is known about survivorship of hatchlings and juveniles, and this

has prevented accurate demographic modeling of terrapin populations (Gibbons et al., 2001). This is of particular concern because terrapin populations in some parts of its range are at risk. Therefore, data on the significance of various predators on early life-history stages is essential to the formulation of effective conservation and management plans for this and other chelonian species. To this end, we documented predation on hatchling and second-year juvenile Northern Diamondback Terrapins (25–41 mm carapace length) by the Norway Rat (*Rattus norvegicus*) in three consecutive field seasons (2001–2003) in Oyster Bay Harbor (OBH), Bayville, Nassau County, New York.

MATERIALS AND METHODS

The study site was a 0.15-ha stretch of intertidal high marsh on the shores of Oyster Bay Harbor, approximately 190 m long and 3–10 m wide, adjacent to a public beach in an urban setting (40°54′10″N, 73°32′54″W). The shorelines of Oyster Bay are highly developed and the

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FIG. 1. Carcass of a Northern Diamondback Terrapin hatchling, approximately 28-mm carapace length, killed by Norway Rat. Note the transmitter still affixed to the carapace.

FIG. 2. The frequency of live and depredated hatchling and juvenile Diamondback Terrapins collected during Fall 2001 (A) and during Spring 2002 (B).

high marsh vegetation is patchy and narrow. Daily searches were conducted throughout August and September in 2001, 2002, and 2003 and throughout April and May in 2002 and 2003. Terrapin carcasses were recovered by searching through the intertidal high marsh vegetation and the adjacent terrestrial habitat. Carcasses were preserved in 10% formalin and later transferred to 70% ethanol for permanent storage.

Three times during September and August 2003, five snap traps were set 20–30 m apart in the intertidal vegetation of the high marsh. Traps were baited with peanut butter, set at 2100 h, and checked at 0700 h the following morning. Captured rats ($N = 4$) were taken back to the lab for dissection. Alimentary canals, esophagus through colon, were removed intact. The contents of esophagus and stomach were extracted and preserved in 10% formalin. Contents of the intestines were extracted, preserved, and stored separately. Gut contents were examined under stereo microscope and pieces of terrapin shell were removed and preserved separately. Fragments were confirmed as belonging to terrapins by comparison of their pigment patterns with the preserved carapaces and plastrons of carcasses collected in the study site. Rat heads were removed so that bite marks on the carcasses could be compared with rat dentition.

Twenty-four hatchlings (6.04–8.14 g; 28.3–32 mm carapace length) were captured in the intertidal vegetation of the high marsh in 2003. They were immediately transported to the lab where a radio transmitter was affixed to the vertebral scutes of the carapace with super glue. Transmitters weighed either 0.69 g (14-day battery life) or 1 g (30-day battery life) and thus were 8.5–11.5% of hatchling body mass. Hatchlings were then transported back to the study site and released at the exact point of initial capture. The total time from capture to release was 2–6 h. In cases where the battery life expired on a hatchling that was still active (prior to hibernation), the expired transmitter was carefully removed, residual glue wiped away with an acetone-soaked cotton swab and a new transmitter affixed as above.

Hatchlings were tracked 1–3 times daily from 13 September to 22 October, when the last hatchling was fully buried for hibernation. Tracking sessions were conducte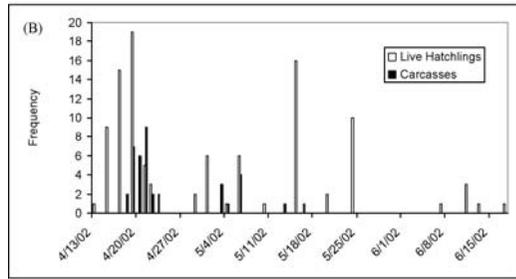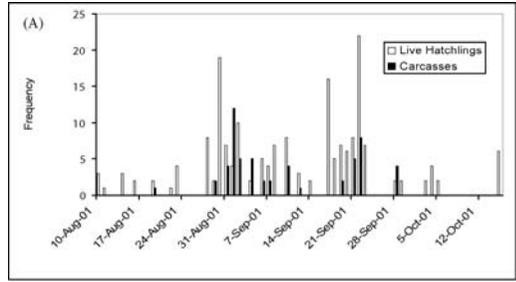d so that some data were collected during all hours of the day and night and during all tidal conditions. Hatchlings were visually observed during each tracking session, noting behavior (such as buried in substrate, motionless at surface, moving along surface, etc.) and microhabitat characteristics. Depredated hatchlings bearing transmitters were taken back to the lab, photographed, transmitter removed, preserved in 10% formalin, and stored in 70% ethanol.

RESULTS

We estimate 400–700 hatchlings are produced in our study area annually. Rat predation on hatchlings occurred mainly during (1) emergence from nests in August and September and (2) emergence from hibernacula in April. All recovered hatchlings had been completely eviscerated through either the carapace or plastron and had their limbs and head gnawed or completely consumed. The tail was usually left intact (Fig. 1). Notches in the shell remains of many of the carcasses were consistent, both in size and shape, with rat incisors. Furthermore, fragments of terrapin shell were found among the stomach contents of each of the four dissected rats.

After emergence from nests in August and September we collected 57 depredated hatchlings in 2001 and 38 in 2002. Carcasses were recovered under intertidal high marsh vegetation such as salt-hay grass (*Spartina patens*) and salt grass (*Distichlis spicata*) or on top of rocks and debris in the same zone. Commonly we found several (usually 3–4) carcasses together and once a group of 11 carcasses in a 0.25-m² plot of *S. patens*. It is not known whether these groupings resulted from a clumped distribution of hatchling terrapins or by the foraging behavior of the rat. Predation on hatchlings mainly occurred during times of peak emergence from nests (Fig. 2A).
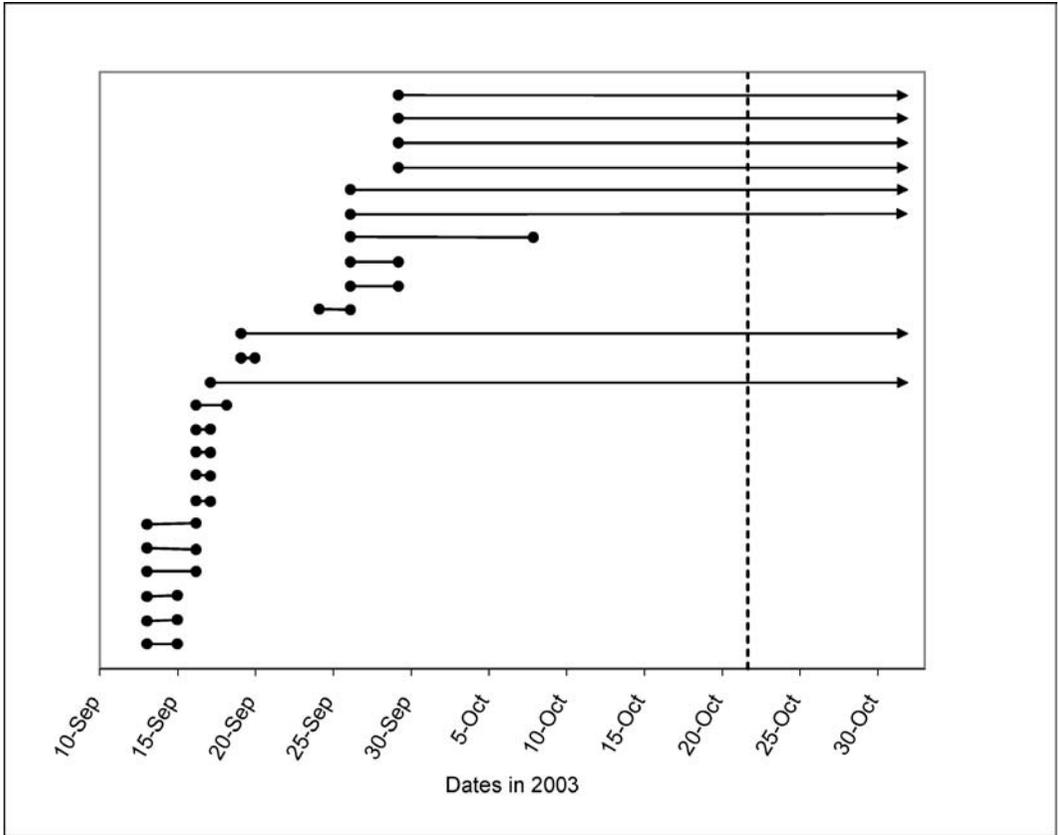
FIG. 3. Time line of tracked hatchling terrapins showing that vulnerability to rat predation was greater earlier in the season. Overall, eight of 24 (33%) hatchlings survived to hibernate (noted by horizontal lines terminating in arrows) and all were buried by 22 October 2003 (demarcated by dotted vertical line). Sixteen of 24 (67%) hatchlings were killed by rats (noted by horizontal lines terminating in dots).

We collected 41 carcasses in April 2002 and 27 carcasses in April 2003 during the time period of hatchling emergence from individual terrestrial hibernacula, which were 0.5–35 m inland from the mean high tide line. Hatchlings seemed to be most vulnerable within a few days of emerging from hibernation when hatchling density in the marsh was highest because of synchronous emergence (Fig. 2B). Many of the carcasses (nine in 2002 and seven in 2003) collected during spring were found in the terrestrial vegetation as far as 10 m beyond the mean high tide line.

Sixteen of the 24 radio-tracked hatchlings were depredated (67% predation rate), whereas eight survived to hibernate in late October. There were no significant differences between carapace lengths (t_{22} = 0.13, P = 0.9) or masses (t_{22} = 0.28, P = 0.8) of depredated and surviving hatchlings. The mean life of released hatchlings that were killed was 2.6 days (median = 2 days; range: 1–12 days; Fig. 3). Each of the 16 depredated hatchlings was recovered by telemetry and had the same kill pattern described above. All predation occurred between 2100 h and 0600 h.

The overall predation rate of 14 hatchlings released between 13 and 19 September was 86% (12 of 14 killed), whereas the predation rate of 10 hatchlings released between 24 and 29 September was lower at 40% (four of 10 killed; χ^2 = 2.06, df = 1, P < 0.2). Increased predation rates corresponded with peak emergence from nests, which was between 11 and 21 September. During this same period, we recovered 39 additional carcasses of hatchlings without transmitters.

DISCUSSION

Lack of hatchling and juvenile survivorship data is hampering the development of accurate population demography models for Diamondback Terrapins (Gibbons et al., 2001). Besides Raccoons, which have been reported to prey upon terrapin hatchlings in nests just prior to emergence (Burger, 1977), only the Ghost Crab (*Ocypode quadrata*) has been reported to be a potentially significant predator on wild terrapin hatchlings (Arndt, 1991, 1994). Predation by Norway Rats on captive terrapin hatchlings in outdoor enclosures was previously noted by Barney (1922) and Hildebrand (1929, 1933), but our report is the first of extensive rat

predation on terrapin hatchlings in the wild. Other small mammals are also known as major predators on the hatchlings of many chelonians, both in natural and artificial settings (e.g., Black Rat [*Rattus rattus*] MacFarland et al., 1974; Short Tailed Shrew [*Blarina brevicauda*] Standing et al., 2000; Chipmunk [*Tamias striatus*] Belzer et al., 2002).

Increased rat predation with peak emergence of hatchlings from nests and hibernation suggests that rats may become more efficient hunters once they acquire a search image (visual or olfactory). In such a case, rats would be expected to exploit hatchlings as long as prey density was high enough. Once hatchling density drops below a critical threshold rats would be expected to switch to alternate prey sources. This may account for lower predation rates later in the fall and spring.

Although we have evidence that suggests Fish Crows (*Corvus ossifragus*), Yellow-Crowned Night Herons (*Nycticorax violacea*), and Raccoons (*P. lotor*) also hunt and kill hatchlings and juveniles in our study area, the main predator is the Norway Rat. Approximately 400–700 terrapin hatchlings emerge from nests in this study site annually (MD, unpubl. data). Because we found 38–57 carcasses each fall, and probably did not find others, we believe that as many as 10–20% of newly emerged hatchlings are eaten by rats each fall. In addition, discovery of between 20 and 41 depredated hatchlings in April and May indicates that a significant fraction of the same cohort is lost the following spring. This is probably a relatively conservative estimate, given the 67% predation rate on radio-tracked hatchlings. We are confident that the transmitters did not attract rats or make hatchlings more vulnerable to predation for some other reason, because we often found carcasses of hatchlings without transmitters in the immediate vicinity of other live hatchlings with transmitters. The transmitters were relatively light, weighing about 10% of hatchling body mass and the antennae were short and blended in with the vegetation used by hatchlings.

Burger (1977) calculated only about 18% survivorship from egg to emerged hatchling (157 successfully emerged hatchlings from 883 eggs) in a New Jersey terrapin population, and Feinberg and Burke (2003) calculated that less than 8% of nests in a southern New York population produced hatchlings. These estimates of survivorship from egg to hatchling along with our conservative estimate of predation on emerged hatchlings and juveniles, suggests that survivorship through the first year may be less than 10%. Rats should be considered a major predator on the early life-history stages of the Diamondback Terrapin, and rat removal should be considered where appropriate.

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