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NOTES AND FIELD REPORTS

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Changes in Raccoon (*Procyon lotor*) Predation Behavior Affects Turtle (*Malaclemys terrapin*) Nest Census

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ABSTRACT. – Turtle researchers often use depredated nest surveys as an index of the total number of turtle nests laid. However, it can be difficult to determine whether an empty nest hole indicates a depredated nest or not. In such cases the presence of depredated egg shells clearly indicates that a nest was present; similarly, absence of eggshells may be interpreted to mean that no nest was present. We measured the amount of calcium in raccoon (*Procyon lotor*) scats at depredated nests of diamondback terrapins (*Malaclemys terrapin*) at Jamaica Bay Wildlife Refuge, New York, and found that during the first half of the nesting season, raccoons ingested egg contents without their shells, but during the second half of the season they ate whole eggs with shells. Researchers who use the presence of egg shells during depredated nest surveys should be aware that their counts may be affected by this change in predation behavior by raccoons.

Turtle nests are often thoroughly camouflaged and usually very difficult to detect visually, making counts of undisturbed nests difficult unless females are observed in the act of oviposition. Therefore, many turtle biologists (e.g., Burger 1977; Congdon et al. 1987) estimate the number of turtle nests in an area by measuring predation rates by counting depredated nests and estimating the percentage of nests predators miss. This method is often the easiest way to determine the size and stability of nesting turtle populations, as censusing adult turtles is sometimes very difficult. For example, Feinberg and Burke (2003) and Giambanco (2003) relied in part on counts of depredated nests to estimate the total number of diamondback terrapin (*Malaclemys terrapin*) nests at their study site. As previous researchers have done, Feinberg and Burke (2003) and Giambanco (2003) only considered each nest hole to be acceptable evidence of the location of a depredated nest when piles of eggshells were found nearby, so as to distinguish between depredated nests and other similar-looking holes. Using this technique, Feinberg and Burke (2003) estimated that approximately 2053

terrapin nests were laid in 1999 on Ruler's Bar, a 362-ha island in Jamaica Bay Wildlife Refuge, part of Gateway National Recreation Area in New York.

Raccoons (*Procyon lotor*) are by far the most important predator on terrapin nests on Ruler's Bar, and Feinberg and Burke (2003) documented rates of raccoon predation on terrapin nests as high as 92.2%. The number of nests and nest predation rates remained approximately the same in annual censuses through 2003 (Giambanco 2003) but the number of nests has been declining since then (R.L. Burke, unpubl. data, 2003-2007). Most of the information concerning the number of terrapin nests in Feinberg and Burke's (2003) and Giambanco's (2003) studies came from observations of nests after predation, while some data were available concerning nests discovered by watching nesting females. Feinberg and Burke (2003) noted that predation by raccoons nearly always occurred within 2 days of oviposition. When raccoons depredate nests at this site, they typically open up the nest from directly above, and eat all eggs within the nest chamber (Feinberg and Burke 2003).

These authors also noticed an unusual pattern of raccoon foraging behavior. During the first half of the terrapin nesting season (from the end of May through the end of June), raccoons excavated nests and left consolidated piles of cleaned eggshells within 15 cm of nests. During the second half of the nesting season (beginning July through early August), sometimes no eggshells were found adjacent to holes that otherwise appeared to be the result of raccoon predation. Furthermore, raccoon scat was found commonly in the terrapin nesting area, and the appearance of the scat changed concurrently with the change in eggshell remains. In the first half of the nesting season, the scat was typically dark brown. Later in the nesting season, the scat was usually white because of a large quantity of terrapin eggshells in it. Thus it appears that raccoons switched from consuming only terrapin egg contents without shells early in the nesting season, to eating entire eggs with shells later in the season. However, Feinberg and Burke (2003) did not quantify this apparent relationship nor attempt to explain why it might occur.

The apparent change in predator behavior is important because if a significant number of holes without eggshells nearby were actually the result of predators consuming nests, but leaving no eggshell remains, then this method of counting nests would routinely underestimate the true number of turtle nests. Thus we sought to determine whether Feinberg and Burke's (2003) observation of the changing amount of eggshell in raccoon scat was real and biologically significant; in other words, whether raccoon foraging behavior changed during the terrapin nesting season. We did this by investigating whether the calcium content of raccoon scats changed through the terrapin nesting season.

Methods. — Diamondback terrapins often dig multiple "test-holes" before beginning the hole where

oviposition actually occurs (R.L. Burke, *pers. obs.*). In addition, terrapins are easily disturbed while in the process of excavating nest holes, and they quickly abandon excavations, even if the nest chamber is complete (R.L. Burke, *pers. obs.*). Thus, nesting areas may contain numerous partially or fully excavated nest chambers in which eggs were not laid (R.L. Burke, *pers. obs.*). However, once begun, successful oviposition takes only about 25 minutes for terrapins (Feinberg and Burke 2003). The completed nests are flask-shaped, and the bottom of the nest is typically 10–12.5 cm deep (R.L. Burke, *pers. obs.*). We surveyed terrapin nesting areas on Ruler's Bar at approximately weekly intervals in June, July, and early August 2002, collecting all raccoon scat we found. Vegetation in this area was sparse, and much of the ground was exposed. Therefore, scats were readily visible. Scats were placed in plastic bags, labeled, and frozen prior to measurement of the calcium content of each sample.

We were unable to count the number of depredated nests without eggshells because there were many sources of holes that were similar in appearance to those of completed and depredated nests, including test holes, holes left by terrapins that were disturbed while nesting, holes made by other animals, and holes made by human visitors.

When collections were complete, scats were weighed, air-dried for 2 weeks, and then oven-dried at 24°C to a constant mass. They were then dried in crucibles at 600°C for 2 hours to reduce them to ash. The ashed samples were allowed to cool overnight, then homogenized to a fine powder and reweighed. Samples were reheated to 600°C for 2 hours, cooled overnight, and reweighed.

We measured the amount of calcium in each sample using standard techniques (Harris, 2003; experiment #11). We digested each ashed sample into 2 mL of concentrated nitric acid. The resulting solution was adjusted with sodium hydroxide to pH 6–8. The undigested solid was filtered out and the filtrate was diluted with nanopure water to yield a 100-mL sample solution. Between 1–5 mL of the sample solution was transferred into a clear flask, along with 3 mL of pH 10 ammonia buffer and 42–46 mL of nanopure water. The pH 10 ammonia buffer was prepared by adding 284 mL of 28 wt% aqueous NH_3 to 35 g of NH_4Cl . This was diluted to 500 mL with nanopure water. A trace of Erichrome Black T indicator was added to the solution to yield a pink-purple-colored solution. Sample solutions were then titrated with a 0.0010 M Na_2EDTA solution to a final blue color. The amount of calcium detected in each sample was compared to the initial mass of each scat in order to estimate the percentage of calcium originally contained in the scat. A control experiment with dried turtle eggshell was completed, which showed that whole eggshell is 29% calcium by mass. We used one-tailed statistical tests because we suspected that egg shell and

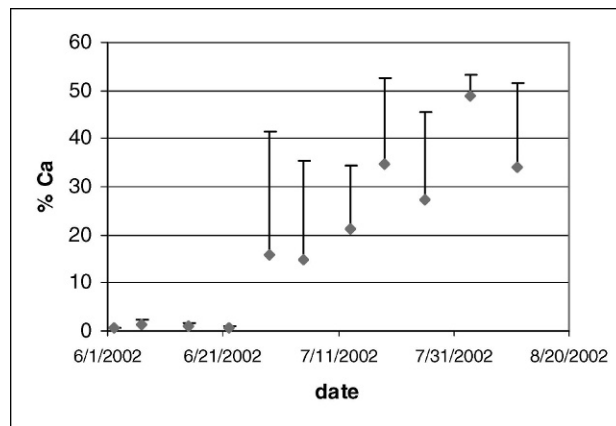


Figure 1. Relationship between percentage of calcium in scat samples collected over terrapin nesting season. Diamonds indicate means, error bars are standard deviations. See text for sample sizes.

calcium contents of raccoon scats would be higher later in the terrapin nesting season, based on the earlier observations of Feinberg and Burke (2003).

Results. — We collected 70 scat samples over 70 days from 2 June to 11 August 2002, sample sizes were 3, 7, 12, 7, 6, 6, 4, 6, 9, 2, and 8 in weeks 1–11, respectively. We observed a dramatic change in the appearance of the raccoon scats in June (approximately the first half of the terrapin nesting season) compared to July (approximately the second half of the terrapin nesting season). The July samples were clearly made up of varying amounts of turtle eggshells, and often nearly entire eggshells were observed in scats from July, while none were observed in June. In addition, we measured a large increase in calcium content in the scats (Fig. 1). Sixty percent of the samples overall had < 10% calcium, yet some ranged as high as 70% and appeared almost completely white. Scat samples containing > 10% calcium were much more common in July and August than in June (Fig. 2). The calcium levels in scats (pooled by sample date) collected in June were significantly lower than those collected in July and August (one-tailed $t = 4.63$, 8 df, $p = 0.008$).

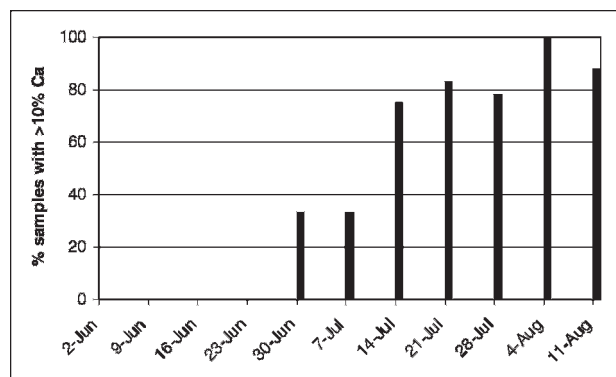


Figure 2. Percentage of scats in each sampling period that had > 10% calcium. See text for sample sizes.

Discussion. — We found clear evidence that raccoons, the major predator of turtle nests at Ruler's Bar, dramatically changed their egg consumption habits midway through the turtle nesting season. This has broad implications because raccoons are widespread in the United States, Mexico, and southern Canada, and raccoons are probably significant turtle egg predators in many, if not all, places where turtle nesting and raccoons are sympatric. As such, raccoons are considered the single most important predator of turtle eggs and turtle hatchlings in North America (Mitchell and Klemens 2000; Ver and Burke 2008). Similar changes in raccoon predation behavior could be occurring in many sites where turtle research occurs.

The change in predator behavior that we detected results in the absence of eggshell evidence after predation, and may therefore result in a significant underestimate of the number of nests initially present, as well as an underestimate of the number of nests depredated. For example, Feinberg and Burke (2003) used their nest survivorship data to estimate the total number of nests laid on Ruler's Bar, based on Burger's (1977) use of the Lincoln-Peterson index (Brower et al., 1997):

$$N_2 = \frac{N_1 P_2}{P_1}$$

where P_1 = number of unprotected, depredated, marked nests, P_2 = number of unmarked, depredated nests, and N_1 = total unprotected marked nests; therefore, N_2 can be calculated as the total number of unmarked nests. Using the data reported by Feinberg and Burke, $P_1 = 71$, $P_2 = 1822$, and $N_1 = 77$, and N_2 is calculated to be 1976; therefore, the estimate of the total number of nests laid is $N_1 + N_2 = 2053$. The data presented here suggest that P_2 can be underestimated when actual terrapin nests are misinterpreted as non-nests because of their lack of eggshell evidence and are not included in P_2 . When P_2 is underestimated, then N_2 and subsequently the total number of nests will also be underestimated. To extend this example, if raccoons consumed eggshells from 25% of the terrapin nests at the site studied by Feinberg and Burke, and therefore the correct value of P_2 was 2429, then the estimate of the total number of nests on the site should have been 2711, and the correct value would have been underestimated by 24%. This indicates that the real number of terrapin nests at Ruler's Bar was greater and the estimates were probably less precise than those reported by Feinberg and Burke (2003).

Other researchers should consider, and perhaps measure, whether similar changes in raccoon behavior occur at their sites and realize that estimates derived using techniques like Burger (1977) may be underestimates of true turtle nesting activity. It would be useful to detect nests in ways that do not influence predation, revisit these nests after predation, and observe whether eggshells are left behind. This is likely to vary by site and by year, so multiple large-scale observations would be needed.

We have been unable to develop any satisfying hypotheses to explain this change in raccoon foraging behavior. By the end of June, most young-of-the-year raccoons are newly independent, yet the scat samples found in July and August appear to be similar in size to those from earlier in the year, and we have no reason to think that these young raccoons are more likely to eat entire eggs than are older raccoons. While it is possible that consuming entire eggs may facilitate some calcium absorption, we are unaware of any reason why raccoons would suddenly develop such a need at midsummer.

We are also unaware of the generality of this phenomenon and encourage other researchers to look for similar changes in raccoon behavior elsewhere. While many North American turtle species nest over much shorter time periods than do *Malaclemys*, some quite common species (e.g., *Chrysemys*, *Graptemys*, *Trachemys*) also typically nest over a 4- to 8-week period, roughly corresponding to that of terrapins. Variation in apparent raccoon predation rates over these extended nesting seasons may indicate similar changes in raccoon behavior.

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