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Diet of Bog Turtles (*Glyptemys muhlenbergii*) from Northern and Southern New Jersey, USA

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***Abstract*.—We tracked Bog Turtles (*Glyptemys muhlenbergii*) using radio-telemetry equipment to obtain fecal samples. We analyzed fecal samples to determine the identity of food items in both northern and southern populations in New Jersey, USA. Food items identified included: beetles, millipedes, ants, flies, caddisfly larvae, snails, and plant material, including seeds. While we found no significant differences between the diets of the two populations, fecal samples from the northern population contained more millipedes, caddisfly larvae, flies, and snails. Conversely, fecal samples from the southern population contained more beetles and seeds. This work adds to the basic life-history data on *Glyptemys muhlenbergii*, and may be valuable to conservation efforts.**

Key Words.—fecal samples; latitude; macroinvertebrates; populations; radio-telemetry

Introduction

Throughout the world, habitat loss and fragmentation has led to a significant decline in reptile populations (Gibbons et al. 2000). In the northeastern United States, for example, some regions retain < 20% of their original wetlands (Gibbons et al. 2000) due to drainage for development and agriculture. The loss of these wetland habitats has led to a decrease in turtle populations (Mitchell 1994), including the endangered Bog Turtle (*Glyptemys muhlenbergii*). Though previous research on *G. muhlenbergii* has provided an understanding of their seasonal activity, hibernation, home range, and growth patterns (Zappalorti 1976a; Ernst 1977; Arndt 1986; Chase et al. 1989; Zappalorti 1997), one important aspect of their life history that is underrepresented in the literature is information regarding their diet (Zappalorti 1976b; Gemmell 1994). Understanding their diet, and the diets of other imperiled species, may allow conservationists to identify critical food resources, which themselves may be disappearing, and guide decisions regarding captive management or head-starting programs (Bjorndal 1999).

Glyptemys muhlenbergii (Fig. 1) is a federally listed threatened species (U.S. Fish and Wildlife Service 2001), whose northern population ranges from Maryland to Massachusetts, USA (U.S. Fish and Wildlife Service 2001). The species has declined by 50% between 1977 and 1997 (U.S. Fish and Wildlife Service 2001). Not surprisingly, suitable habitat has declined at the same rate and, in 2011, the International Union for Conservation of Nature (IUCN) classified this species as critically endangered (Van Dijk 2013). In addition to habitat loss, illegal collection for the pet trade has become a contributing threat to the sustainability of their populations (Copeyon 1997).

Suitable habitat for *G. muhlenbergii* is freshwater wetlands characterized as spring-fed wet meadows and seepages (Zappalorti 1997; Haas and Mitchell 1999). Natural plant succession in these habitats can lead to a rapid transition to drier habitats (Ernst and Lovich 2009), which do not provide the soft mud substrates needed for predator avoidance and thermoregulation (Haas and Mitchell 1999). While New Jersey currently has a number of suitable areas for this species, our survey focused on a limestone calcareous fen in the northern region of the state and an agricultural wetland, fed by headwater seeps, in the southern region (Fig. 2).

Our current knowledge of the diet of *G. muhlenbergii* indicates that it is omnivorous, and feeds both on land and in the water (Ernst and Lovich 2009). Food items include a variety of small vertebrates and invertebrates, carrion, and vegetation such as seeds, fruits, and grasses (Bury 1979). Diet literature on *G. muhlenbergii* is scarce, with only two known studies in New Jersey, USA: Sussex County (Zappalorti 1976b) and central New Jersey (Gemmel 1994). The objectives of our study were to: (1) document the diet of *G. muhlenbergii* from northern and southern New Jersey populations; (2) compare our data to the findings of the study by Gemmel (1994); and (3) compare and contrast the diets of the male and female turtles. Our data will assist

Figure 1. Bog Turtle (*Glyptemys muhlenbergii*) from New Jersey, USA. (Photographed by George Cevera).

conservation programs for *G. muhlenbergii* by providing a better understanding of their dietary choices.

Materials and Methods

Study sites.—The northern study site was located in Sussex County, New Jersey, USA, and the southern study site was located in Salem County, New Jersey, USA. The distance between these sites was approximately 227 km (140 mi). Specific site locations are not disclosed to protect against the illegal exploitation of the species. Within the northern region, we obtained the majority of samples from two sites, referred to as HUNJ258 and HUNJ296. These sites are 2.4 km (1.5 mi) apart. Within the southern region, we obtained samples from one location, designated as DENJ442.

Capture techniques.—We captured turtles by hand, weekly, from 14 April to 30 September 2014. Upon initial capture, we examined turtles for previous markings (notching of marginal scutes in the carapace) and, if marked, we sharpened the notches. If the turtle was not marked previously, we notched marginal scutes using a triangular file following the unique New Jersey Endangered and Nongame Species Program notching code (unpubl. report).

Glyptemys muhlenbergii are difficult to locate because they often burrow into the mud substrate. Consequently, we used radio-telemetry equipment to recapture subjects in our study (Goodlett et al. 1998). We fitted five turtles from each site with small (< 6% of the body mass of the turtle) radio transmitters (model SOPB-2190 Wildlife Materials, Murphysboro, Illinois, USA) on the posterior right of the carapace, using a two-part quickset epoxy. We relocated turtles using a handheld digital scanning receiver, model TRX-1000S (Wildlife Materials, Murphysboro, Illinois, USA) and a three-piece directional antenna.

Fecal samples.—For fecal sample collection, we relocated turtles and recorded their GPS coordinates at the point of capture by using the iPhone compass application (Apple INC, Cupertino, California, USA). We collected the turtles and flagged their point of capture to ensure that they were placed back in their original area after holding them for fecal samples. We placed the captured turtles into buckets to collect potential fecal samples. The buckets were filled with 355 ml of water from nearby rivulets to cover the turtles, and we placed each bucket in a shaded area to prevent overheating the turtles. The turtles remained in buckets for a maximum of 2 h before being returned to their point of capture. Fecal sample analysis is a challenging but extremely important method of performing diet studies, although previous studies have proposed that it may be less accurate than observing stomach content due to the physical processing of the food items in the gut (Luiselli et al. 2004). While we recognize that Bog Turtles are known to feed on soft-bodied organisms, such as slugs and earthworms, which may not be detected in this form of analysis, we determined that such an invasive technique was too great a risk when working with this imperiled species.

We placed fecal samples in cheesecloth, strained with water to remove excess debris, and placed in a small container with 70% ethanol solution. In the laboratory, we vortexed samples to allow for the fecal matter to be broken apart for further analysis without damaging macroinvertebrate body segments. We visualized components of the samples under an SZ6145 stereomicroscope (Olympus Corporation, New Orleans, Louisiana, USA). We identified, counted, and recorded the food items found. With these data, we calculated the percentage frequency of occurrence (%F) of each food item using the formula from Seminoff et al. (2002):

%F= (Number of samples containing diet item × 100) / (Total number of samples)

Figure 2. Fen habitat for a northern population of Bog Turtles (*Glyptemys muhlenbergii*) in New Jersey, USA. (Photographed by Nelson Melendez).

We classified food items into nine groups: plant material excluding seeds, seeds, beetles, millipedes, caddisfly larvae, ants, flies, snails, and unknown (Table 1). We classified the invertebrate body segments to the lowest identifiable taxonomic unit. We used a Pearson's Chi-squared test (α=0.05) to compare sex and location differences in the number of food items observed per sample (Wilhelm and Plummer 2012). Due to frequent zero values for many of the food types, which invalidates most tests of categorical data, we only used the four most frequently observed items (plant material excluding seeds, seeds, beetles, and millipedes) in this analysis. For those remaining items, we used a Fisher's exact test when counts were < five per category.

Results

We collected 60 fecal samples: 31 samples from the northern populations and 29 from the southern population. The most common food item observed in the fecal samples was plant material, which was found in about 90% of the samples (Table 2). The most common invertebrates, in both populations, were beetles (Table 2). Turtles from one of the northern populations consumed weevils (Curculionidae), which were identified in two samples. Six of 11 samples from the southern population contained Japanese Beetles (*Popillia japonica*) while none were found in samples from the northern population. We found millipedes

Table 1. List of food items and characteristics of items used to determine food from fecal samples collected from Bog Turtle (*Glyptemys muhlenbergii*) in northern and southern regions of New Jersey, USA.

Identified Food Items	Taxonomy	Identifiable Characteristics
Plant material excl. seeds	—	Plant debris, including: leaves and stems
Seeds	—	Whole or segments of seeds
Beetles	Coleoptera	Body segments: head, legs, thorax, abdomen, and elytra
Weevils	Curculionidae	Body segments: head, legs, thorax, and abdomen
Japanese Beetles	*Popillia japonica*	Body segments: head, legs, thorax, abdomen, and elytra
Millipedes	Diplopoda	Body segments: head, legs, and thorax
Caddisfly Larvae	Trichoptera	Casings
Ants	Formicidae	Body segments: head and thorax
Flies	Diptera	Body segments: head and wings
Snails	Gastropoda	Shell segments
Unknown Arthropods	Unknown	Body segments

Table 2. Percentage Frequency of Occurrence (%F) of food items in the diet of Bog Turtles (*Glyptemys muhlenbergii*) in New Jersey, USA categorized by: northern (NP) and southern (SP) regional populations, northern population males (NM), northern population females (NF), southern population males (SM), and southern population females (SF) respectively. The number of fecal samples from the respective category (n) was used to calculate %F.

Food Items	%F NP n = 31	%F SP n = 29	%F NM n = 9	%F NF n = 21	%F SM n = 15	%F SF n = 14
Plant material excl. seeds	90.3	89.7	100	81.0	93.3	100
Seeds	61.2	69.0	66.7	52.4	66.7	85.7
Beetles	29.0	37.9	33.3	19.0	46.7	35.7
Weevils	6.4	0	11.1	4.7	0	0
Japanese Beetles	0	20.6	0	0	20.0	21.4
Millipedes	25.8	3.4	33.3	23.8	0	7.1
Caddisfly Larvae	12.9	10.3	11.1	14.3	6.7	14.3
Ants	9.7	10.3	0	14.3	6.7	14.3
Flies	6.5	0	0	9.5	0	0
Snails	6.5	0	11.1	4.7	0	0
Unknown Arthropods	3.3	6.9	0	4.7	13.3	0

more frequently in the northern populations than in the southern population (Table 2). We found a small number of samples from both populations, which contained caddisfly larvae and ants. We only observed flies and snails in the northern population samples. We observed no significant differences in the components of fecal samples between the northern and southern populations when individuals of both sexes were combined (X^2= 7.00, df = 3, P = 0.072) or when individuals were compared by sex between locations (males, Fisher exact, P = 0.233; females, Fisher exact, P = 0.366).

We included one sample from a juvenile turtle in the total northern population data and excluded it from the northern population by sex data because we could not determine its sex (Table 2). Male samples had a higher %F for plant material, seeds, beetles, millipedes, and snails than did female samples. Females had a higher %F for caddisfly larvae, ants, and flies than did male samples (Table 2). There was no difference in %F for plant material between southern males and females. Male samples had a higher %F for beetles than did female samples. Female samples had a higher %F for seeds, millipedes, caddisfly larvae, and ants than male samples. We did not identify any flies or snails in samples from the southern population (Table 2). There was no significant difference in diet when males and females from all sampling sites were compared (X^2 = 0.81, df = 3, P = 0.847).

Discussion

Previous studies have given an indication of the diet of *G. muhlenbergii*, but most relied on very small numbers of turtles. For example, Surface (1908) reported the stomach contents of just one specimen (80% insects and 20% berries). Barton and Price (1955) noted that the stomachs of two specimens from a New Jersey site contained mostly insects, with one species of lepidopteran larvae constituting nearly half the total amount recovered. Other items found, in order of importance, were beetles, seeds of pondweed (*Potamogeton* sp.), and large numbers of sedge (*Carex* sp.) seeds. The authors stated that the specimens also consumed caddisfly larvae, snails (*Succinea* sp.), a millipede, and specifically *Popillia japonica* in August of a field period. In our study, the first to examine and compare the diet of a large sample size of this species from separate study sites, we found similar food items as above using fecal sample analysis. Further, we found that the diets of *G. muhlenbergii* from our northern and southern populations were similar, with only small differences in the %F of certain food items. Our larger sample sizes also provided the opportunity to investigate possible sex-specific diets; however, though males and females showed small differences in %F within populations, the overall pattern was not significant. Diets between sexes and between populations are the same.

Gemmell (1994) found that *Glyptemys muhlenbergii* consumed a large variety of invertebrates, which were mostly from the phylum Arthropoda. Gemmell (1994) classified the invertebrates he observed to a minimum of 15 orders and 31 families. In our study, we found that invertebrates were classified to three classes, four orders, and three families. This difference between the similar northern and southern diets, when compared with the central diet, may reflect the techniques used more than the populations themselves. We relied on analyzing fecal samples rather than stomach content and animal parts are more difficult to identify after digestion

(Caputo and Vogt 2008). This likely led to the small amount of identified invertebrate food items found in this study, compared to other studies. However, we observed that *G. muhlenbergii* consumed more vegetation than did Gemmell (1994). Our %F mean of plant material was 90% and 65.2% seeds from both populations, while Gemmell observed a %F of < 2% for plant and seed material combined.

Though the majority of our diet samples were from adults, we did obtain one fecal sample collected from a juvenile turtle from the northern population site. The fecal sample of this juvenile included plant matter, seeds, and an insect segment that was identified to the order Coleoptera, indicating that *G. muhlenbergii* are omnivorous at an early age. The data we collected in this study can be used to assist researchers and conservationists interested in this rare turtle. This study demonstrates the appropriateness and effectiveness of using the minimally invasive fecal sampling method in future diet studies with endangered turtles. Further, it is our hope that greater knowledge of the diet of *G. muhlenbergii* can give researchers insight to prey items and their habitat needs that should be considered in developing habitat management plans.

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Literature Cited

Arndt, R.G. 1977. Notes on the Bog Turtle, *Clemmys muhlenbergii*, in Warren County, New Jersey, USA. Bulletin of the Maryland Herpetology Society 22:56–61.

Barton, A.J., and J.W. Price. 1955. Our knowledge of the Bogturtle, *Clemmys muhlenbergi*, surveyed and augmented. Copeia 1955:159–165.

Bjorndal, K.A., F.A. Abreu-Grobois, and M. Donnelly. 1999. Research and Management Techniques for the Conservation of Sea Turtles (No. 4). International Union for Conservation of Nature and Natural Resources / Species Survival Commission, Marine Turtle Specialist Group, Washington, D.C., USA.

Bury, B.R. 1986. Feeding ecology of the turtle, *Clemmys marmorata*. Journal of Herpetology 20:515–521.

Caputo, F.P., and R.C. Vogt. 2008. Stomach flushing vs. fecal analysis: the example of *Phrynops rufipes* (Testudines: Chelidae). Copeia 2008:301–305.

Chase, J.D., K.R. Dixon, J.E. Gates, D. Jacobs, and G.J. Taylor. 1989. Habitat characteristics, population size, and home range of the Bog Turtle, *Clemmys muhlenbergii*, in Maryland, USA. Journal of Herpetology 23:356–362.

Copeyon, C.K. 1997. Endangered and threatened wildlife and plants: Final rule to list the northern population of the Bog Turtle as threatened and the southern population as threatened due to similarity of appearance. Federal Register 62:59605–59623.

Ernst, C.H. 1977. Biological notes on the Bog Turtle, *Clemmys muhlenbergii*. Herpetologica 33:241–246.

Ernst, C.H., and J.E. Lovich. 2009. Turtles of the United States and Canada. 2nd Edition. Johns Hopkins University Press, Baltimore, Maryland, USA.

Gemmell, D.J. 1994. The natural history and ecology of the Bog Turtle, *Clemmys muhlenbergii*. PhD. Dissertation, Rutgers University, New Brunswick, New Jersey, USA. 428 p.

Gibbons, J.W., D.E. Scott, T.J. Ryan, K.A. Buhlmann, T.D. Tuberville, B.S. Metts, J.L. Greene, T. Mills, Y. Leiden, S. Poppy, et al. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50:653-666.

Goodlett, T., G. Goodlett, and P. Hamilton. 1998. Review of radio transmitter attachment techniques for turtle research and recommendations for improvement. Herpetological Review 29:26–33.

Haas, C.A., and J.C. Mitchell. 1999. Home range and habitat selection of Bog Turtles insouthwestern Virginia, USA. Journal of Wildlife Management 63:853–860.

Lindeman, P.V. 2006a. Diet of the Texas Map Turtle (*Graptemys versa*): relationship to sexually dimorphic trophic morphology and changes over five decades as influenced by aninvasive mollusk. Chelonian Conservation and Biology 5:25–31.

Lindeman, P.V. 2006b. Zebra and Quagga mussels (*Dreissena* spp.) and other prey of a Lake Erie population of Common Map Turtles (Emydidae: *Graptemys geographica*). Copeia 2006:268–273.

Luiselli, L., G.C. Akani, E. Politano, E. Odegbune, and O. Bello. 2004. Dietary shifts of sympatric freshwater turtles in pristine and oil-polluted habitats of the Niger Delta, southern Nigeria, Africa. Herpetological Journal 14:57–64.

Mitchell, J.C. 1994. The Reptiles of Virginia. Smithsonian Institution Press, Washington, D.C., USA.

Richards-Dimitrie, T., S.E. Gresens, S.A. Smith, and R.A. Seigel. 2013. Diet of Northern Map Turtles (*Graptemys geographica*): sexual differences and potential impacts of an altered river system. Copeia 2013:477–484.

Seminoff, J.A., A. Resendiz, and W.J. Nichols. 2002. Diet of east Pacific Green Turtles (*Chelonia mydas*) in the central Gulf of California, Mexico. Journal of Herpetology
36:447–453.

Surface, H.A. 1908. First report on the economic features of the turtles of Pennsylvania, USA. Zoology Bulletin 6:105–196.

U.S. Fish and Wildlife Service. 2001. Bog Turtle (*Clemmys muhlenbergii*), Northern Population, Recovery Plan. Hadley, Massachusetts, USA. 103 pp.

Wilhelm, C.E., and M.V. Plummer. 2012. Diet of radiotracked Musk Turtles, *Sternotherus odoratus*, in a small urban stream. Herpetological Conservation and Biology 7:258–264.

Van Dijk, P.P. 2013. *Glyptemys muhlenbergii*. International Union for Conservation of Nature and Natural Resources. http://www.iucnredlist.org/details/4967/0

Zappalorti, R.T. 1976a. The status of the Bog Turtle (*Clemmys muhlenbergii*), in North Carolina, USA. Bulletin of the Maryland Herpetological Society 12:69.

Zappalorti, R.T. 1976b. The Amateur Zoologist's Guide to Turtles and Crocodilians. Stackpole Books, Harrisburg, Pennsylvania, USA.

Zappalorti, R.T. 1997. Turtles of New Jersey and the Bog Turtle in the Northeast. Pp. 15–22 *In* Status and Conservation of Turtles of the Northeastern United States. Tyning, T. (Ed.). Serpent’s Tale Natural History Book Distributers, Lanesboro, Minnesota, USA.

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(Photographed by Tyler Degener).

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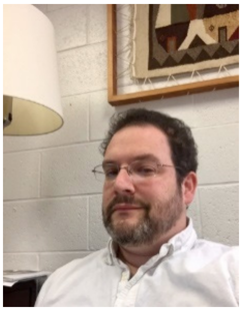

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