

## DIET OF RADIOTRACKED MUSK TURTLES, *STERNOTHERUS ODORATUS*, IN A SMALL URBAN STREAM

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**Abstract.**—We used radiotelemetry to assess the diet of *Sternotherus odoratus* in Gin Creek, Arkansas, USA. Gin Creek is a small, frequently disturbed, urban stream in which the invasive Asiatic Clam, *Corbicula fluminea*, has attained high densities. Turtles foraged in small, well-defined home ranges within which we sampled the substrate for potential food items. The diet of *S. odoratus*, as determined by analysis of fecal samples, compared favorably to prey availability in the creek. The diet was similar to that found in previous dietary studies of typically omnivorous *S. odoratus* except that clams were eaten much more frequently. An Index of Relative Importance (IRI) revealed the most important prey in both the fecal samples and substrate was *C. fluminea*. We suggest the diet of *S. odoratus* in Gin Creek has shifted toward molluscivory as the result of a probable 40-year presence of *C. fluminea*.

**Key Words.**—*Corbicula*; diet; invasive clams; Musk Turtle; radiotelemetry; *Sternotherus odoratus*; stream

### INTRODUCTION

The diet of bottom-feeding freshwater turtles often reflects the composition of the benthic macroinvertebrate communities where they feed, which in turn may be strongly affected by the presence of certain bivalve mollusks (Newell 2004). For example, the recent invasion of North American streams by the Asiatic Clam (*Corbicula fluminea*) often results in the clam being a dominant community influence (McMahon 1982; Karatayev et al. 2003; Karatayev et al. 2005). *Corbicula* is thought to affect ecosystem nutrient cycles and energy flow (Sousa et al. 2008), community composition (Werner and Rothhaupt 2008), and competitive interactions of native macroinvertebrates (Kraemer 1979). It also may affect dietary diversity of turtles (Lindeman 2006a). For example, map turtles (*Graptemys* spp.) respond to high densities of invasive clams (*Corbicula*, *Dreissena*) by feeding heavily on the clams instead of other food items typically found in the diet (Shealy 1976; Moll 1980; Lindeman 2006a, 2006b; Ennen et al. 2007).

The Common Musk Turtle (*Sternotherus odoratus*) is a widely-distributed freshwater turtle, which prefers relatively shallow waters with abundant submerged vegetation and woody debris; it rarely leaves the water even under drought conditions (Gibbons et al. 1983; Ernst et al. 1994; Rowe et al. 2009). Generally considered a bottom-feeding omnivore, *S. odoratus* has been reported to feed on crayfish, insects, mollusks, fish, amphipods, arachnids, algae, seeds, and other plant material throughout its range (e.g., Berry 1975; Marion et al. 1991; Ernst et al. 1994; Ford and Moll 2004).

Gastropod mollusks have occasionally been reported as frequently eaten. For example, snails were found in 96% of *S. odoratus* stomachs in Oklahoma (Mahmoud 1968) and constituted 94% of the dietary animal biomass in Florida (Bancroft et al. 1983). When given a choice among five prey types in the laboratory, *S. odoratus* preferred snails (Mahmoud 1968). In contrast, rarely have bivalve mollusks been dominant in the diet (Patterson and Lindeman 2009).

Our objective is to describe the diet of *S. odoratus* in a small, frequently disturbed urban stream in which invasive *Corbicula fluminea* has attained high densities. We reasoned that because the diet of a generalist omnivore should reflect availability of food items in the habitat, *S. odoratus* would feed heavily on the *Corbicula*. Our methods were distinctive among dietary studies of turtles in that we assessed diet by resampling individual radio-tracked turtles. This procedure permitted us to compare dietary food items with food items available in the turtles' home ranges to determine if the food eaten was actively selected or simply reflected what was available to turtles.

### MATERIALS AND METHODS

We collected turtles by hand from 12 May - 23 June 2010 in Gin Creek, White County, Arkansas, USA. The entire 6 km length of Gin Creek is included in the town of Searcy and provides the major drainage for the southern part of the city (Anonymous 1975; Muncy 1976). We caught turtles in a 600 m section of the creek located between 15S UTM 3901000 N, 616850 E and UTM 3901600 N, 616850 E. Gin Creek at our study

area varies in width from approximately 5.0–9.5 m with riffles and pools ranging in depth from approximately 2–100 cm. Riffle substrate is mostly hard clay whereas pools contain unconsolidated sediments (silt, gravel, organic debris) up to ~25 cm in depth. Emergent vegetation is limited to narrow bands along shoreline banks and isolated small islands. Pockets of submerged woody and leafy debris are common. Suspended and attached algae are seasonally common throughout the creek. Muskrat (*Ondontra zibethicus*) burrows are common in the creek banks.

Upon hand capture, we recorded location (UTM coordinates), habitat (pool, riffle), water depth (nearest 10 cm), and substrate type (hard clay, soft mud, debris, rock, leaves). In the laboratory, we determined the sex of turtles and measured their mass (g) and carapace length (CL) in mm. Because the diet of adult *Sternotherus minor* may differ from that of juveniles (Tinkle 1958), we used only adult *S. odoratus* (CL  $\geq$  79 mm; Tinkle 1961). We numbered each turtle on the second costal scute and pectoral scute with a Dremel<sup>®</sup> rotary etching tool. We adhered radio transmitters (Model LF-1; L.L. Electronics, Mahomet, Illinois, USA) to the postero-lateral edge of the carapace of 17 turtles (10 males; seven females) with Plastic Welder<sup>®</sup> and released the turtles back into the creek at the site of capture 24 h after attachment. Transmitter mass was < 6% of each turtle's body mass. We tracked turtles daily until 6 August 2010; we determined position coordinates with a Garmin eTrex<sup>®</sup> GPS.

We collected each turtle every 14–28 days to obtain fecal samples. Each turtle was brought to the lab and housed in a one gallon jar with 50 mm depth of water for 48 hours (Parmenter 1981) to obtain fecal samples. We strained fecal samples and dried each in a drying oven for 24 hours at 50 °C. We sorted and identified samples under a dissecting microscope and grouped items into one of seven categories: algae, seeds, unidentifiable plant material, clams, snails, insects, and other (primarily detritus, rocks, sand, and other inorganic matter). For each category, we counted the minimum number of items if possible and measured mass (g) and volume (ml by volumetric displacement). Small *Corbicula* were often ingested whole, facilitating counting and measuring minimum shell length. We estimated the number and maximum shell length of larger *Corbicula* based on shell fragments containing a hinge. Seeds were mostly fragmented thus preventing counting.

To determine food availability in the creek, we established nine substrate sampling stations spaced ~50 m apart throughout home ranges of turtles. At each sampling station, we took three substrate samples every two weeks, one near each bank and one in the middle of the creek. We used a bottomless 5 gal bucket to circumscribe a 530 sq. cm area at each sampling site. We collected the top 5 cm of the substrate using a small

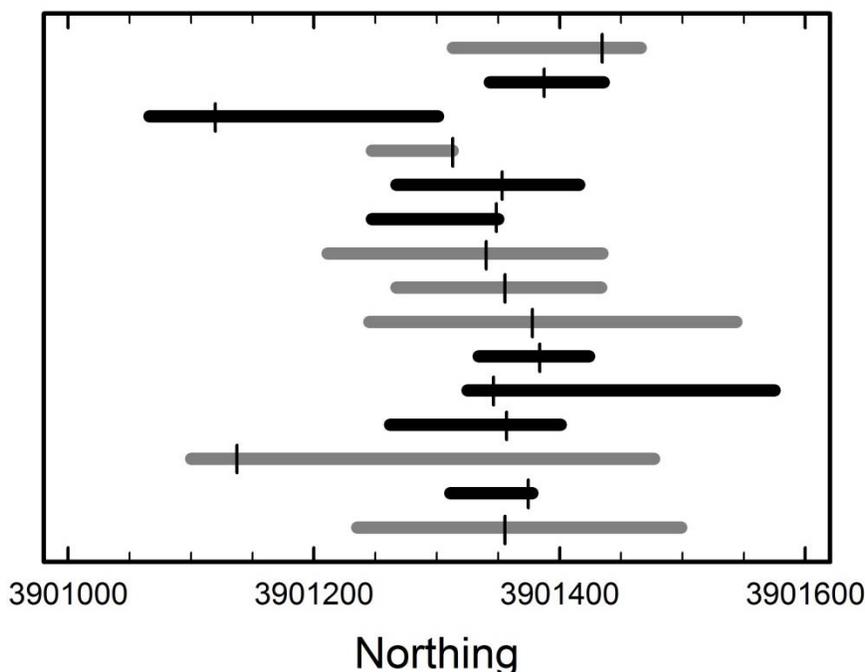
shovel and suspended material from the water column with a small net. Samples were processed as above. We determined the number of *Corbicula* by counting living individuals and/or complete shells of dead individuals. Because we did not know precisely where individual turtles fed, we compared fecal contents to a pooled sample of all sampling stations.

In cases where the dietary mass was < 0.001 g, we assigned the value 0.0005 g for quantitative analysis. We assigned volumes too small to measure accurately a value of 0.01 ml. Following Lindeman (2006b), we calculated an Index of Relative Importance (IRI) for each prey category  $i$  as  $IRI_i = 100 \sqrt{V_i F_i} / \sum (\sqrt{V_i F_i})$ , where  $V_i$  = mean percentage of total volume and  $F_i$  = percentage frequency for each prey category. We calculated home range length for each turtle as the linear section of the creek that extended from the extreme upstream telemetry location to the extreme downstream location for that individual. Because turtle movement was limited to the water channel, we calculated home range area for each turtle by multiplying the home range length by the average creek width. Average creek width was calculated by averaging the widths of the creek at each substrate sampling station. Distance moved each day was the difference between successive daily relocations.

We used Systat<sup>®</sup> 13 (SYSTAT Software, Inc., Richmond, California, USA) for statistical analyses. We checked for normality and homogeneity of variances and, when necessary, log-transformed data to meet assumptions of normality. We tested for sexual differences in home range size and daily movement with  $t$ -tests. We used Chi-square tests to compare habitat usage on opposite creek banks and to compare sexual differences in frequency of *Corbicula* in fecal samples. We used ANCOVA with CL as the covariate to correct for body size to test for sexual differences in fecal composition of *Corbicula* by number, volume, and mass. To assure independence, the data used in ANCOVA consisted of a single mean value calculated over all sampling periods for each turtle. Descriptive statistics reported from ANCOVA analyses are least squares means reported as mean  $\pm$  SE. For all tests,  $\alpha = 0.05$ .

## RESULTS

**Movement.**—Two of the 17 turtles fitted with radiotransmitters moved out of the study area 100–800 m upstream within four days of release and remained there for the duration of the study; they were not used in further analyses. Of the 544 telemetry relocations on the remaining 15 turtles ( $36 \pm 3$  relocations ea.), 95% were located within the central 392 m section of the 600 m study area (Fig. 1). These turtles established broadly overlapping home ranges (Fig. 1), which averaged  $176 \pm 23$  m in length and  $0.15 \pm 0.02$  ha in area. Home range



**FIGURE 1.** Extent and overlap of home ranges in 15 radiotracked *Sternotherus odoratus* in Gin Creek, Arkansas, USA using UTM coordinates. Black bars indicate males; gray bars indicate females. Vertical line on each bar represents the initial capture location for that individual.

size did not differ between males and females ( $t = 2.06$ ,  $df = 13$ ,  $P > 0.05$ ). Turtles moved an average of  $23 \pm 2.5$  m (max 279 m) per day, but frequently (41%) did not move from one day to the next. Daily movement did not differ between males and females ( $t = 0.21$ ,  $df = 13$ ,  $P > 0.80$ ). All turtles moved within home ranges, consisting mostly of shallow pools with mud, gravel, and detritus substrates. Most (86%) relocations were within 1 m of the creek bank, most often (72%) the west bank ( $\chi^2 = 156.6$ ,  $df = 1$ ,  $P < 0.001$ ), which had denser vegetation, more overhanging limbs and roots, more submerged woody and leafy debris, and more muskrat burrows compared to the southeast bank. In 30% of all relocations, turtles were inside muskrat burrows. Of the

15 tracked turtles, 13 were located inside muskrat burrows at least once. We did not observe turtles on land. Movement, and presumably foraging, of each turtle occurred in areas where the substrate was sampled for food availability.

**Diet.**—The dominant food types in fecal samples were mollusks and seeds, together constituting 89.2% by volume and 97.8% by mass of the diet of *S. odoratus* (Table 1). Mollusks, of which 72% were *Corbicula* and 28% were snails, were clearly the most important food type in terms of frequency, volume, mass, and IRI (Table 1). The mean minimum length of *Corbicula* in fecal samples was  $2.7 \pm 0.30$  mm (range 1–7 mm) and

**TABLE 1.** Dietary composition of fecal samples of *Sternotherus odoratus* and substrate samples in Gin Creek, Arkansas, USA. IRI = Index of Relative Importance. Frequency is the percentage of turtles containing a particular food item.

Food type	IRI	No.	Fecal samples			No.	Substrate samples		
			% Frequency	% volume	% mass		% Frequency	% volume	% mass
Mollusks	71.4	2136	80.0	61.6	90.3	884	100	93.7	94.2
<i>Corbicula</i>	58.9	1535	56.7	58.3	--	881	100	93.4	94.1
Snails	12.5	601	55.0	3.3	--	3	2.7	0.3	0.1
Seeds	22.9	--	48.3	27.6	7.5	--	15.7	< 0.01	< 0.01
Insect parts	4.4	--	53.0	4.8	0.8	--	16.7	0.2	< 0.001
Plant parts	1.2	--	31.7	1.9	0.5	--	45.4	2.1	1.8
Algae	0.1	--	8.3	1.0	0.4	--	33.3	4.0	4.0
Other	< 0.1	--	48.3	3.1	0.5	--	0.9	< 0.01	< 0.001

the mean estimated maximum length was  $7.9 \pm 0.49$  mm (range 3–14 mm). The frequency of fecal samples containing *Corbicula* was similar in females (83%) and males (75%;  $\chi^2 = 3.35$ ,  $df = 1$ ,  $P > 0.60$ ). The number of *Corbicula* in fecal samples ranged from 0–86, except for female no. 26 who defecated 864 very small (1–2 mm) clamshells. For comparisons of *Corbicula* feeding between the smaller ( $85 \pm 2.4$  mm CL) males and larger ( $104 \pm 2.5$  mm CL) females, we treated the no. 26 sample as an outlier based on the extreme number and small size of the ingested clams. ANCOVA revealed that CL affected the mass ( $F_{1,13} = 5.49$ ,  $P < 0.05$ ) but not the number ( $F_{1,13} = 0.46$ ,  $P > 0.50$ ) or volume ( $F_{1,12} = 3.19$ ,  $P > 0.10$ ) of *Corbicula* in fecal samples. Sex affected the volume ( $F_{1,12} = 4.87$ ,  $P < 0.05$ ) and mass ( $F_{1,13} = 7.77$ ,  $P < 0.05$ ) of *Corbicula* in feces, but not the number ( $F_{1,13} = 0.48$ ,  $P > 0.50$ ). Female feces contained  $34\times$  the volume (females  $0.68 \pm 0.155$  ml, males  $0.02 \pm 0.210$  ml) and  $2.8\times$  the mass (females  $22.3 \pm 2.64$  g, males  $8.1 \pm 3.67$  g) of *Corbicula* compared to males. Mollusks had the highest IRI in the diet with a value  $> 3\times$  that of seeds, the next highest category (Table 1). For all mollusks (clams and snails), summed IRI values were females = 67.5 (*Corbicula* 59.2, snails 8.3) and males = 61.7 (*Corbicula* 36.6, snails 25.1).

**Substrate samples.**—As in the fecal samples, mollusks were the dominant food type in substrate samples, constituting  $> 90\%$  by volume and mass (Table 1). All substrate samples contained mollusks, of which 99.8% were *Corbicula*. Other dietary components were each  $< 5\%$  by volume and mass. The mean minimum length of *Corbicula* in substrate samples was  $10.5 \pm 0.62$  mm (range 4–20 mm) and the mean maximum length was  $23.8 \pm 0.55$  mm (range 19–32 mm). Density of individual *Corbicula* (living individuals + complete shells) in 36 substrate samples ranged 0–3,453  $m^{-2}$  (mean  $452.8 \pm 95.8$   $m^{-2}$ ). Except for *Corbicula*, all substrate dietary components constituted  $< 5\%$  of substrate samples by volume and mass; some components, such as snails, seeds, and insects, occurred more frequently in feces than in the environment (Table 1).

### DISCUSSION

Our results are largely consistent with previous movement and dietary studies on *S. odoratus*. Data from mark-recapture (Holinka et al. 2003; Smar and Chambers 2005; Andres and Chambers 2006) and radiotelemetry (Belleau 2008; Rowe et al. 2009) studies of *S. odoratus* have shown that individuals are relatively sedentary and move within discrete aquatic home ranges to which they return if displaced. Our radiotelemetry data indicated less daily movement and smaller home ranges than radio-tracked *S. odoratus* in larger habitats

(Belleau 2008; Rowe et al. 2009). Small home ranges in a small creek also characterized radio-tracked *Sternotherus depressus* (Dodd et al. 1988). Having small home ranges facilitated our sampling efforts as all turtles foraged within well-defined areas of mostly comparable habitat where we systematically sampled potential food items.

Our dietary results are consistent with other dietary studies on *S. odoratus*, with one notable exception. The species has been described as an omnivore whose diet includes crayfish, mollusks, insects, fish, amphipods, arachnids, algae, seeds, and other plant material (Mahmoud 1968, 1969; Berry 1975; Marion et al. 1991; Ernst et al. 1994). A recent dietary analysis of a *S. odoratus* population in a lake located within 250 km of Gin Creek is generally typical of the species with a *Corbicula* frequency of approximately 17% and a proportion by volume of  $< 2\%$  (Ford and Moll 2004). The major dietary difference we found was a pronounced frequency and proportion by volume of *Corbicula* compared to previous studies, which indicates a more molluscivorous diet. Our results suggest females eat more bivalves than do males and males eat more snails than females, as indicated by the IRI. This pattern of sexual dimorphism in diet, as well as greater body size and relative head width in females, has been reported previously in *Graptemys* spp. (Lindeman 2006a, 2006b) and other *Sternotherus* spp. (Berry 1975), but not in *Sternotherus odoratus*.

The methods of diet determination we used by examining feces may have limited our data compared to dissection or stomach flushing techniques. For example, it may be difficult to detect soft-bodied organisms and measure the original volume and mass ingested when analyzing only feces (Marion et al. 1991; Lindeman 2006a). Despite these limitations, dietary results for *S. odoratus* determined by fecal analysis (Marion et al. 1991), gut dissection (Berry 1975), and stomach flushing (Ford and Moll 2004) have yielded similar qualitative results.

Our study provides interesting dietary results in a small, frequently disturbed, urban stream in which maximum *Corbicula* density (3,453 clams  $m^{-2}$ ) compares favorably with maximum densities reported from other localities such as Virginia (2,990 clams  $m^{-2}$ ; Hornbach 1992), central Europe (3,520 clams  $m^{-2}$ ; Werner and Rothhaupt 2008), and the Iberian Peninsula (2,152 clams  $m^{-2}$ ; Sousa et al. 2008). Because the composition of our fecal samples tracked that of the substrate samples in Gin Creek, the molluscivorous diet likely resulted from the abundance and availability of *Corbicula* rather than a physiological molluscan preference.

The recent invasion of North American streams by *Corbicula* (McMahon 1982; Karatayev et al. 2005) appears to have altered the diet of some populations of *S. odoratus* as has been suggested for *Sternotherus*

*depressus* (Marion et al. 1991) and some map turtles (Shealy 1976; Moll 1980; Shively and Vidrine 1984; Porter 1990; Lindeman 2006a). Similar results have been reported for map turtles and the invasive Zebra and Quagga Mussels (*Dreissena* spp.; Lindeman 2006b). *Corbicula* was first detected in the Arkansas River in Arkansas in the mid-1960s and was considered ubiquitous in the Arkansas River by 1979 (Kraemer 1976; 1979). *Corbicula* seems to reach its highest densities in highly managed harsh environments (Kraemer 1979) such as Gin Creek, which has been channelized and repeatedly disturbed since the early 1970s to facilitate urban runoff (Plummer and Mills 2008). Assuming *Corbicula* invaded Gin Creek (~70 km northeast of the Arkansas River) in the early 1970s and that its steady increase in density was reflected in the diet of *S. odoratus*, it is possible that the diet of Gin Creek *S. odoratus* has been influenced by the presence of *Corbicula* for 30–40 years.

Being able to exploit rapidly invading exotic mollusk populations could have favorable population consequences for the mostly widespread and common *S. odoratus* throughout its North American range and possibly also in Iowa, Maine, Vermont, Quebec, and Ontario, where it is of conservation concern (NatureServe. 2012. NatureServe Explorer: An online encyclopedia of life. Version 7.1. NatureServe, Arlington, Virginia. Available from <http://www.natureserve.org/explorer>. [Accessed 14 July 2012]). A possible mechanism for this scenario is that the trophic apparatus of various freshwater turtles (e.g., *Sternotherus minor*, *Graptemys* spp.) is known to respond morphologically to a durophagous diet of thick-shelled bivalves by increasing head width and jaw breadth (Berry 1975; Lindeman 2006a). The biomechanical changes involved in developing bigger heads are known to increase gape and bite force in turtles (Herrel et al. 2002; Bulté et al. 2008), which could free a gape-limited predator to feed on larger, energetically unfavorable prey (such as mollusks) and thus increase energy intake. In turn, greater fitness could be achieved through better body condition and greater reproductive success (Bulté et al. 2008). Whether the head morphology of *S. odoratus* from Gin Creek is responding similarly to eating the hard and thick-shelled (Cloe et al. 1995; Zhou et al. 2011) *Corbicula* is currently under investigation.

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ASIH “Guidelines for Use of Live Amphibians and Reptiles in Field and Laboratory Research” (<http://www.asih.org/files/hacc-final.pdf>). This research was conducted under Scientific Collecting Permit #020120101 from the Arkansas Game and Fish Commission and was supported by a grant from the Margaret M. Plummer Research Fund of Harding University.

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