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Cover Photograph: Basking adult *Trachemys scripta* (Red-eared box turtle). Photograph © Todd Pierson.

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Diet of *Trachemys scripta* (Red-eared Slider) and *Graptemys geographica* (Common Map Turtle) in an Urban Landscape

Jessica D. Stephens[1,2] and Travis J. Ryan[1,*]

Abstract - Urban environments present many challenges for aquatic turtle species. Here, we investigated whether the diets of *Trachemys scripta* (Red-eared Slider) and *Graptemys geographica* (Common Map Turtle) may help explain the spatial ecology of these 2 species in a pair of constructed aquatic habitats in Indianapolis, IN, USA. We conducted stomach flushings on 43 turtles from 2 sites (Central Canal, n = 33; IMA Lake, n = 10). Common Map Turtles from the Central Canal (n = 27) consumed mostly mollusks and crayfish, which comprised ~86% of the volume of stomach contents. We captured no adult Common Map Turtles at IMA Lake, likely due to the lack of mollusks within this habitat. There was considerable variability in the diet of Red-eared Sliders between the 2 habitats, with 98.8% of the diet contents comprised of plant material in the Central Canal (n = 6) and only 67% plant material in IMA Lake (n = 10). This difference in diet may have been due to the lower abundance of vegetation found in IMA Lake compared to the Central Canal, or possibly a diversification of diet in response to decreased interspecific competition in IMA Lake. Diet comparison between species in the Central Canal shows almost no overlap, which may partially explain habitat association and movement differences between the 2 species documented in a previous study. The descriptions of Red-eared Slider and Common Map Turtle diets presented here are the first to be described from an explicitly urban landscape. Further understanding of the ecology of these species in urban habitats can aid city planners and managers with the goal of maintaining species diversity in urban landscapes.

Introduction

Aquatic systems are extremely sensitive to urbanization. These systems are challenged by surface runoff (via impervious infrastructure), bank erosion, and changes in nutrient loads, while also supplying cities with potable water (Faulkner 2004, Paul and Meyer 2001). These apparent threats to aquatic ecosystems have prompted rigorous research in riparian systems examining microbial (Gibson et al. 1998, Zuma 2010), algal (Patrick 1973), and invertebrate (Thorne et al. 2000, Wright et al. 1995) responses as indicators of water quality and measures of biodiversity declines. Underrepresented in riparian urban ecology, however, is research examining community interactions, population dynamics, habitat distribution, and behavioral ecology of larger-bodied taxa (discussed in Walsh et al. 2005, but see Mitchell et al. 2008). This gap in understanding is dismaying given that larger animals are thought to be more susceptible to the negative effects of urbanization because of their larger ranges (Ryan et al. 2008, 2014), smaller population sizes (Woodroffe and Ginsberg 1998), and road fatalities (Steen and Gibbs 2004).

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In recent years, ecological investigations of freshwater turtle responses to urbanization have provided new insight. These studies have documented skewed sex ratios resulting from road mortality (Gibbs and Steen 2005), changes in nest distribution (Marchand and Litvaitis 2004a), and non-random spatial distribution along aquatic gradients with varying degrees of urbanization (Harden et al. 2009, Marchand and Litvaitis 2004b). Similar patterns have been detected in turtles within human-made habitats located in Indianapolis, IN, USA. Ryan et al. (2008) noted non-random habitat association and hibernacula selection across the Central Canal within Indianapolis for both *Trachemys scripta elegans* Wied-Neuwied (Red-eared Sliders) and *Graptemys geographica* Le Sueur (Common Map Turtles). In addition, there were differences in spatial ecology between the 2 species, with females of these species exhibiting similar distances for daily movements, although the female Common Map Turtles had significantly larger home ranges. Furthermore, Conner et al. (2005) noted a difference in the relative abundance of these species in the Central Canal and a human-made lake located ~165 m away, with Common Map Turtles the most abundant species in the canal and Red-eared Sliders the most abundant species in the lake.

Although these differences in movement and relative abundance may be attributed to a variety of factors, chief among them may be contrasting feeding preferences between the 2 species (Conner et al. 2005, Ryan et al. 2008). In particular, the Central Canal supports a more robust population of several aquatic snail species and aquatic vegetation than the lake habitat, potentially influencing turtle assemblages (Conner et al. 2005, Ryan et al. 2008). Previous studies of chelonian diets have suggested that food preference can impact species' habitat selection (Hart 1983, Plummer and Farrar 1981) and can influence how species respond to habitat alteration (Lindeman 2013, Richards-Dimitrie et al. 2013). Given habitat variability in prey items, our aim in this study was to describe the diets of Red-eared Sliders and Common Map Turtles in Indianapolis, IN, across these 2 human-made aquatic habitats in the context of the hypothesis presented in Conner et al. (2005) and Ryan et al. (2008), that food availability may be a contributing factor influencing differences in habitat association, movement, and turtle assemblages.

Methods

Study area

We conducted our fieldwork at 2 sites in the northwest corner of Marion County (Fig. 1), which is home to Indiana's largest city, Indianapolis, and is in the top 2% of most populated counties in the US (human-population density = 857 inhabitants/km^2; US Census 2018). The Central Canal is a human-made waterway created in the 1830s, originating at the White River and extending 11.2 km before it enters a water-treatment facility. The Central Canal provides the city of Indianapolis with ~60% of its annual water use, and therefore, efforts are made to control water level, flow rate, vegetation, and debris. The banks of the canal vary considerably, with turf grass, riprap, native plantings, and forest edge as the most common groundcovers. The canal is no more than 25 m wide and 2 m deep and is bordered by a habitat matrix composed of commercial, residential, and recreational areas (Ryan et al. 2008, 2014).

The Virginia B. Fairbanks Art and Nature Park, owned by the Indianapolis Museum of Art (IMA), is adjacent to the Central Canal. It comprises 40.5 ha of woodlands, lake, and mown lawn ~30 m from the White River on the northern edge and 165 m from the Central Canal on the southern edge. The park was an agricultural field in the 1920s and was later converted into a gravel pit used to excavate material for the construction of an interstate in the 1960s. The resulting borrow pit was then converted into IMA Lake, which is roughly 14.7 ha in size with a maximum depth of more than 15 m. Narrow strips of wooded areas surround the lake along most of its shoreline. There has been recent effort to inventory taxa and promote reestablishment and restoration of native species (Dolan et al. 2011).

Turtle capture and diet assessment

Although there are 6 species of turtles in the Central Canal and IMA Lake (Conner et al. 2005), we conducted diet assessments on 2 of the largest and most common species, the Common Map Turtle and the Red-eared Slider. We captured turtles used for this study between July and August 2004 with aquatic hoop traps (76.1-cm–diameter hoops, 30 cm x 30 cm coated nylon mesh with a funnel at one end and a closed bag at the other) baited with sardines as part of a co-occurring study of population and community ecology in both the canal and lake habitats; see Conner et al. (2005) for additional details regarding trapping. The turtle assemblages within

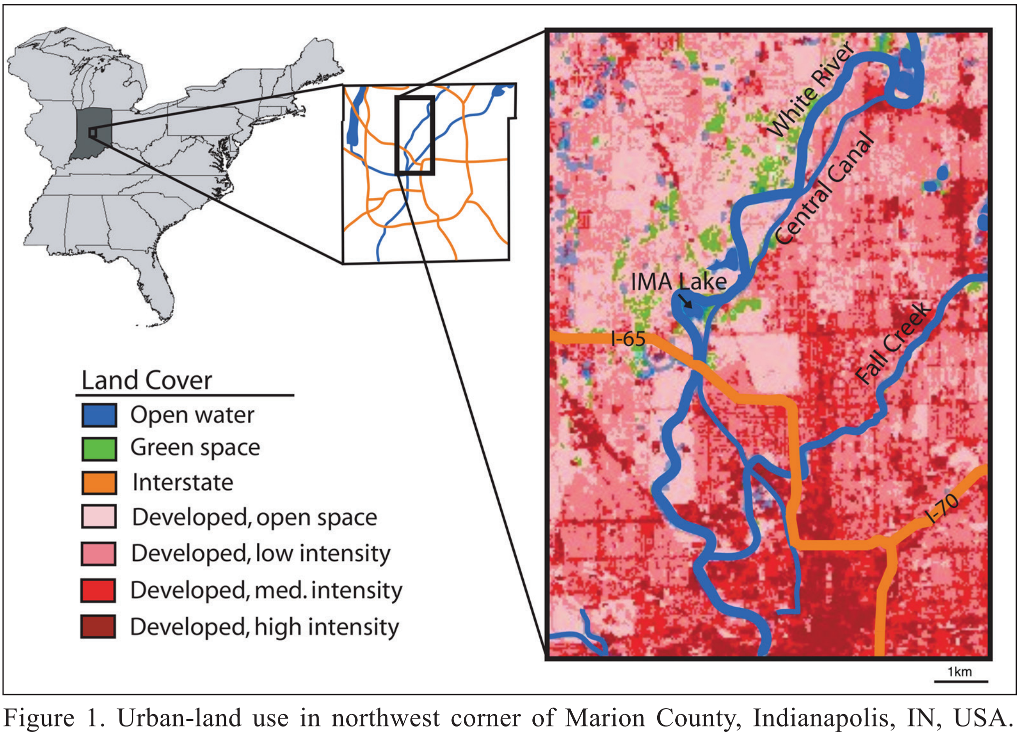

Figure 1. Urban-land use in northwest corner of Marion County, Indianapolis, IN, USA. Turtles were collected along the Central Canal and Indianapolis Museum of Art (IMA) Lake.

these habitats are described in further detail in earlier papers (Conner et al. 2005; Peterman and Ryan 2009; Ryan et al. 2008, 2014). We opened sardine cans <1 cm to ensure that turtles would not ingest the bait and skew analyses of stomach contents. We checked traps daily, refreshed bait every few days, and relocated traps weekly. Although the sampling period represented only a portion of the active period of Red-eared Sliders and Common Map Turtles, previous diet studies have relied on a similar temporal range (e.g., Demuth and Buhlmann 1997), and the diet of female Common Map Turtles seems to vary little across a wider range of the active period (Richards-Dimitrie et al. 2013).

Turtles collected from traps were immediately taken to the lab to be measured and marked (see Cagle 1939), and we placed those to be used for the stomach-flushing procedure (≥15 cm in carapace length) in a cold room (~2 °C) in order to slow digestion and allow for easier manipulation (Ford and Moll 2004). Common Map Turtles demonstrate strong sexual size dimorphism (Lindeman 2013); thus, only females were large enough to be included in our analysis. We followed the procedure described by Legler (1977) to flush the stomach contents of collected turtles. This procedure has been successful in a number of studies on diets (Fields et al. 2003, Legler and Sullivan 1979) with a very low risk of harm or death (Legler 1977, but see Lindeman 2006). We returned all turtles to their collection sites within 48 h of capture. We collected stomach contents in a 0.5-mm–mesh sieve and preserved them in 70% ethanol. We examined stomach contents under a dissecting microscope to identify food items to the lowest taxonomic level possible. Plant material was difficult to distinguish, except for *Lemna* (duckweed), therefore we used plant-anatomy categories (e.g., flowers, seeds, bark) for all plant material other than duckweed.

We used frequency of occurrence (% FO) for each identification level to describe diets, which is presented as the number of turtles that contained a given item (Bowen 1983). We also measured the abundance of each food item in diet by measuring the total volume of each diet item using water displacement for all samples from each site/species divided by total volume across those samples. We determined diet-taxon richness for each location and turtle species. We used the vegan package (Oksanen et al. 2010) in R v2.6.2 statistical software environment (R Development Core Team 2008) to calculate diversity of prey taxa in each sample using the Simpson (D') and Shannon diversity (H') indices, which account for the number of taxa and abundance of each species. We calculated Horn–Morisita dissimilarity indices in the vegan package (Oksanen et al. 2010) to compare how similar the diets were between the same species across location and different species within location. The Horn–Morisita dissimilarity index varies between 0 and 1, with values close to 1 indicating no overlap in diet and values close to 0 indicating no difference in diet. We chose this index over others because the Horn-Morisita dissimilarity index is better suited to handle differences in sample sizes and diversity (Wolda 1981).

Results

We obtained stomach contents from 43 turtles from the 2 sites (Central Canal, n = 33; IMA Lake, n = 10). We captured a total of 6 Red-eared Sliders from the

Central Canal and 10 from IMA Lake, while all the Common Map Turtles (n = 27) were from the Central Canal. We captured only juvenile Common Map Turtles at IMA Lake, which were not of sufficient size to conduct stomach flushings. The average carapace length of Common Map Turtles and Red-eared Sliders was 160.8 mm and 133.4 mm, respectively.

Stomach contents displayed a wide variety of prey, comprising 7 phyla and 5 classes. We were also able to identify taxa belonging to 6 orders, 4 families, 2 genera, and 1 species (Table 1). Two-thirds of Common Map Turtle samples from the Central Canal contained snails (Gastropoda), whereas we found no snails within the stomach contents of Red-eared Sliders in either the Central Canal or IMA Lake. Red-eared Sliders consumed large amounts of plant material, with 100% of individuals in the Central Canal and 60% in IMA Lake consuming plants. Although

Table 1. Stomach contents of Common Map Turtles and Red-eared Sliders from the Central Canal and IMA Lake, Indianapolis, IN. Only Common Map Turtle juveniles were captured in IMA Lake, and therefore, were not of sufficient size to conduct stomach flushings. Sample size is indicated by n; %FO is the percent frequency of occurrence of each respective taxon.

	Central Canal				IMA Lake	
	Common Map Turtle (n = 27)		Red-eared Slider (n = 6)		Red-eared Slider (n = 10)	
Prey taxon	n	%FO	n	%FO	n	%FO
Plantae						
Total plant material	8	30	6	100	6	60
Duckweed	4	15	3	50	0	0
Flowers	0	0	2	33	0	0
Seeds	0	0	0	0	3	30
Bark	0	0	0	0	1	10
Animalia						
Gastropoda (snails)	18	67	0	0	0	0
Decapoda						
Cambaridae (crayfish)	8	30	2	33	0	0
Odonata						
Total Anisoptera	0	0	2	33	0	0
Larvae	0	0	1	17	0	0
Adult dragonflies	2	7	1	17	1	10
Zygoptera nymphs	1	4	0	0	0	0
Nematoda	2	7	1	17	7	70
Arachnida (spiders)	2	7	0	0	0	0
Annelid (Hirudinea)	1	4	0	0	0	0
Hemiptera (Corixidae)	1	4	0	0	0	0
Diptera (Culicidae larvae)	5	19	0	0	0	0
Ephemeroptera (Baetidae)	3	11	0	0	0	0
Coleoptera (*Popillia japonica*)	2	7	0	0	5	50
Osteichthyes	0	0	0	0	1	10
Styrofoam	0	0	1	17	0	0
Unidentifiable	4	15	0	0	1	10
Unidentifiable animal	2	7	0	0	2	20

some Common Map Turtle samples contained vegetable matter, it may have been coincidental by-catch, as it was exclusively duckweed, a small, surface-floating plant. The samples from Red-eared Sliders contained not only duckweed (in canal samples), but also structures from other plant species.

Common Map Turtles consumed 92% of the total taxonomic groups (not including unidentifiable and styrofoam categories) identified in this study, giving a species richness value of 11 (Table 1). The species richness of Red-eared Sliders across both the IMA Lake and Central Canal was 6 (50% of the total taxonomic groups identified). More specifically, prey taxon richness values for Red-eared Sliders at IMA Lake and Central Canal were 4 and 5, respectively. It should be noted that species richness can be influenced by sample size, and therefore the difference in taxon richness may be explained in part by the higher capture-frequency of Common Map Turtles. The Shannon index value was accordingly higher for Common Map Turtles ($H' = 0.721$) than for Red-eared Sliders ($H' = 0.088$) in the same habitat. However, $H' = 1.83$ for Red-eared Sliders found in IMA Lake, indicating a much higher dietary diversity than in the Central Canal. The results were similar using the Simpson index values of 0.331, 0.029, 0.511 for Common Map Turtles, Central Canal Red-eared Sliders, and IMA Lake Red-eared Sliders, respectively.

Most of stomach-content volume consisted of plant material (99%) for Red-eared Sliders in the Central Canal (Fig. 2). Plant material made up < 1% of the total stomach contents in Common Map Turtles within the same habitat. Additionally,

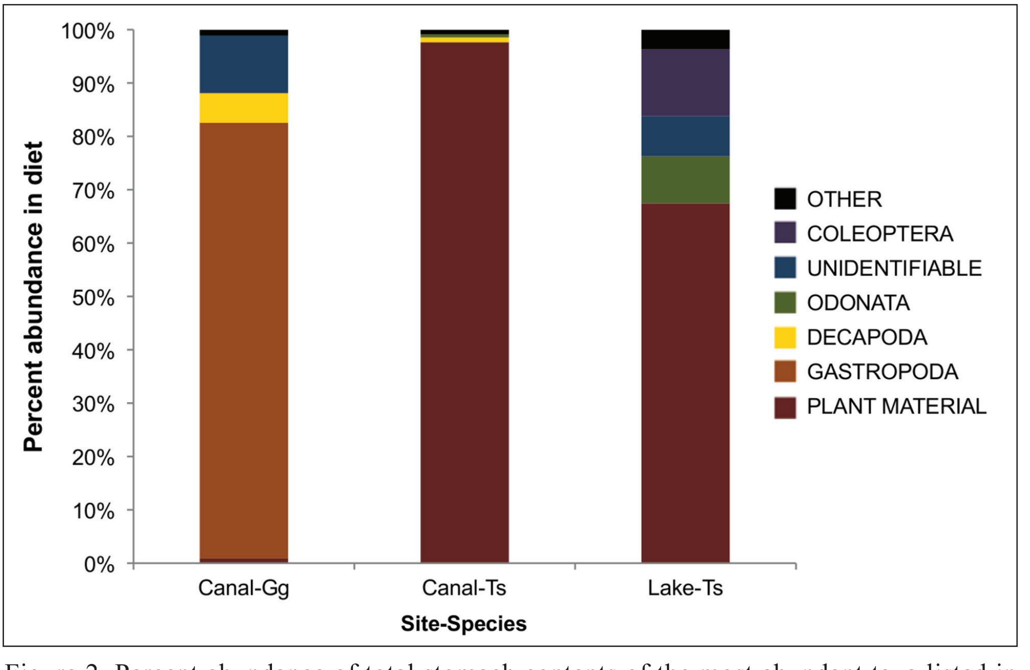

Figure 2. Percent abundance of total stomach contents of the most abundant taxa listed in the diet of Common Map Turtles (Gg) and Red-eared Sliders (Ts) from the Central Canal and IMA Lake, Indianapolis, IN, USA. "Other" includes all taxa, other than those listed here, from Table 1.

the Common Map Turtle diet was primarily composed of snails (Gastropoda; 81%), with Red-eared Sliders showing no consumption of this prey in either habitat. The Horn–Morisita index value was 0.989 between Common Map Turtles and Red-eared Sliders in the Central Canal. This finding indicates very little dietary overlap between the 2 species. Comparisons of Red-eared Sliders between the 2 habitat types show similar preferences, as the Horn–Morisita index value was 0.085.

Discussion

We were unable to capture Common Map Turtles at IMA Lake that were of sufficient size (carapace length >15 cm) to conduct stomach flushing (see also Conner et al. 2005), therefore we could not make diet comparisons between the 2 habitats for this species. However, the stomach contents of Common Map Turtles from Central Canal indicate a predominately molluscivore diet, which is consistent with other diet studies for this species (Gordon and MacColluch 1980; Lindeman 2006, 2013; Richards-Dimitrie et al. 2013; Vogt 1981; White and Moll 1992). The lack of adult Common Map Turtles at IMA Lake may be attributed to the relatively low abundance of snails in this habitat (T.J. Ryan, pers. observ.). The Central Canal supports a robust population of several aquatic snail species; IMA Lake lacks these populations (Conner et al. 2005; T.J. Ryan, pers. observ.). The absence of snails may be a result of the characteristics of this type of human-made aquatic habitat. Freshwater snails typically prefer lake bottoms covered with leaf litter and other plant detritus (Dillon 2000, Spyra 2010). IMA Lake, however, is a converted gravel pit with a deep, rock basin and steep-banked slopes. Our results, together with the lack of adult Common Map Turtles at IMA Lake (Conner et al. 2005), indicate that the difference in abundance of Common Map Turtles between the 2 habitats may be attributed to preferred food availability.

Common Map Turtles in the Central Canal preyed on a high diversity of prey items besides mollusks, especially compared to Red-eared Sliders in that habitat. Specifically, ~30% of Common Map Turtles captured consumed decapods (i.e., crayfish), though they made up only 5.5% of total prey volume. This finding is not unusual, as Common Map Turtles, while mollusk specialists, have also been known to feed on crayfish (Ernst and Lovich 2009, Lagler 1943, Penn 1950). Excluding unidentifiable material, all other items combined made up the remaining 2% of total prey contents, most of which may have been consumed incidentally. The continued presence of Common Map Turtles within the urban landscape appears to be largely dependent on the fact that the biota of the Central Canal, despite its anthropogenic origins, approximates that of more natural habitats, like the nearby White River, which is also inhabited by Common Map Turtles (T.J. Ryan, pers. observ.).

Despite the wide breadth of food items available in the Central Canal, it is interesting to note that Red-eared Sliders were specializing on vegetation. Vegetation accounted for 98.8% volume and occurred in all individuals sampled. In more natural settings, Red-eared Sliders tend to be opportunistic omnivores, consuming vegetation and soft-bodied insects (Ernst and Lovich 2009, Minton 2001, Parmenter and Avery 1980). However, changes in diet are well documented for this species, whereby juvenile Red-eared Sliders tend to have a more carnivorous diet with a shift towards herbivory coming with maturation (Clark and Gibbons 1969, Hart 1983, Marchand and Litvaitis 2004b). To prevent possible harm to small turtles, we did not conduct stomach-flushing procedures on juveniles, which may have biased our analyses relative to Red-eared Sliders. Another possible interpretation for the high abundance and volume of vegetation in the Central Canal Red-eared Sliders' diet may be the overall plant abundance in the Central Canal. Previous research in the Central Canal found that this turtle species non-randomly associates with areas lined by woodlots (Ryan et al. 2008), where vegetation is more prevalent. In addition, Parmenter and Avery (1990) hypothesized that Red-eared Sliders may consume vegetation in areas with greater plant abundance due to the ease of foraging compared to available animal matter; our findings were consistent with their hypothesis. In the lake habitat, Red-eared Sliders appeared to be generalists, with vegetation only making up 67% of food content volume. While this result may be due in part to there being less aquatic vegetation in IMA Lake compared with the Central Canal (T.J. Ryan, pers. observ.), Red-eared Sliders at IMA Lake may be experiencing a release from competition for food with the other species, which are typically more abundant in the Central Canal.

The populations of Red-eared Sliders and Common Map Turtles located in the Central Canal show a high degree of resource partitioning with almost no overlap in prey. This difference in diet may help explain the differences in movement patterns between these 2 species in the Central Canal. We found that Red-eared Slider and Common Map Turtle females moved the same distance on a daily basis, but female Common Map Turtles tended to have larger ranges than female Red-eared Sliders (Ryan et al. 2008). While these 2 species move amongst basking sites throughout the day (Peterman and Ryan 2009), the basking-related movements did not adequately account for the movement difference between species. The difference in range size may be attributed to a preference for snails by Common Map Turtle, necessitating active foraging over a larger area as local prey availability becomes scarce (Pluto and Bellis 1988, Vogt, 1981).

Studies of diet differences have aided in elucidating life history (Ford and Moll 2004) and habitat selection (Hart 1983, Plummer and Farrar 1981) for many populations of turtles in natural settings. This study is, to our knowledge, the first to describe the diets of Red-eared Sliders and Common Map Turtles in explicitly urban habitats. Our results suggest that within an urban landscape, diet may help shape turtle assemblages and it may account for differences in home ranges and habitat selection for these species, although other factors are likely important as well (e.g., water depth and buffer-zone width; see Elston et al. 2016). We found no significant deviation from patterns reported in previous diet studies conducted in more natural habitats, which underscores the fact that urban planners should consider all facets of species' ecology—including the needs of both dietary specialists and generalists—when creating or altering urban aquatic habitats to promote and sustain diversity.

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