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Movement and habitat use of two aquatic turtles (*Graptemys geographica* and *Trachemys scripta*) in an urban landscape

Travis J. Ryan & Christopher A. Conner & Brooke A. Douthitt & Sean C. Sterrett & Carmen M. Salsbury

Abstract Our study focuses on the spatial ecology and seasonal habitat use of two aquatic turtles in order to understand the manner in which upland habitat use by humans shapes the aquatic activity, movement, and habitat selection of these species in an urban setting. We used radiotelemetry to follow 15 female *Graptemys geographica* (common map turtle) and each of ten male and female *Trachemys scripta* (red-eared slider) living in a man-made canal within a highly urbanized region of Indianapolis, IN, USA. During the active season (between May and September) of 2002, we located 33 of the 35 individuals a total of 934 times and determined the total range of activity, mean movement, and daily movement for each individuals. We also analyzed turtle locations relative to the upland habitat types (commercial, residential, river, road, woodlot, and open) surrounding the canal and determined that the turtles spent a disproportionate amount of time in woodland and commercial habitats and avoided the road-associated portions of the canal. We also located 21 of the turtles during hibernation (February 2003), and determined that an even greater proportion of individuals hibernated in woodland-bordered portions of the canal. Our results clearly indicate that turtle habitat selection is influenced by human activities; sound conservation and management of turtle populations in urban habitats will require the incorporation of spatial ecology and habitat use data.

Introduction

Negative effects of urbanization on riparian systems are evident at a range of spatial and temporal scales and on a variety of organisms, such as algae (e.g., Hall et al. 1999), invertebrates, (e.g., Morley and Karr 2002), fishes (e.g., Onorato et al. 2000), and amphibians (e.g., Willson and Dorcas 2003; Price et al. 2006). Damage to these ecological systems is primarily through habitat conversion, but also through increased stormwater runoff and other physical changes that alter natural hydrological patterns, geomorphology, thermal regimes, and biological parameters (e.g., presence or absence and abundance of species; reviewed in Paul and Meyer 2001). Because the consequences of urbanization are broad, no single taxon or ecological response (e.g., changes in demography, behavior, species interactions) is adequate to characterize the effects of urbanization.

Because turtles inhabit a diversity of habitats, ranging from deserts to tropical forests terrestrially and ponds to oceans aquatically, the effects of urbanization on turtles are potentially very broad. For example, sea turtles (families Cheloniidae and Dermochelyidae) are influenced by urbanization with regards to nesting. Sea turtle nests are vulnerable to nest predators that are associated with high density human populations (Zeppelini et al. 2007), and incubation times may be longer in nests on urbanized beaches due to the effects of shading by condominiums, hotels, and other large built structures (Mrosovsky et al. 1995). Furthermore, artificial lights in urbanized areas influence the orientation of hatchling turtles upon emergence (Witherington and Bjorndal 1991; Ryan, personal observation). Nest poaching by humans is also a problem that threatens the long term stability of sea turtle populations (Lagueaux and Campbell 2005).

Non-marine turtle species face a different suite of threats due to urbanization. Several recent studies point to the potential impact that motor traffic can have on turtle populations (Steen et al. 2006). In populations affected by road mortality, the sex ratio may be skewed towards males, indicating that females are more likely to fall victim to vehicular collision, and these ratios are more strongly skewed towards males in areas with greater road density and in species that are more aquatic (Gibbs and Steen 2005). In addition to direct mortality, urbanization can result in changes in distribution, movement, home range and/or activity of native species (Mader 1984; Formann et al. 2002) and thus understanding anthropogenic effects on activity and habitat use is essential for developing sound conservation and management plans in urban areas. Because of its threatened and endangered status, Blanding's turtle (*Emydoidea blandingii*) has been studied in urban areas more than most other species. These studies have focused on habitat use and movement (Rubin et al. 2001a), survival and population structure (Rubin et al. 2004), and conservation genetics (Rubin et al. 2001b; Mockford et al. 2007). Most other studies of terrestrial and freshwater turtles in urban habitats have covered natural history and basic population traits (Mitchell 1988; Spinks et al. 2003; Conner et al. 2005; Budischak et al. 2006).

Previously we described the assemblage of freshwater turtles (e.g., relative abundance, sex ratios, sizes) inhabiting a man-made riparian system within an urban landscape (Conner et al. 2005). The turtle assemblage consists of six aquatic and semi-aquatic species inhabiting an approximately 11-km long canal that flows through urban Indianapolis, IN, USA. The canal was constructed beginning in the 1830s as part of a planned inner coastal waterway, but construction faltered with the rise of railroads and a lack of funding from the Indiana state government (Bakken 2003). Since 1881, the canal has been owned by the Indianapolis Water Company, and it is used to move 70% of the municipal drinking water supply from the White River to a downtown water treatment facility. The canal is used by fishermen and is bordered by a greenway path that is used for recreation throughout the year.

Two of the most abundant species in the canal and nearby urban wetlands are the common map turtle (*Graptemys geographica*) and the red-eared slider (*Trachemys scripta*). These turtles are primarily aquatic, though they leave the water to bask on trees and limbs that have fallen into the Central Canal and on riprap that borders and reinforces the canal walls in some sections. Because the canal was constructed for inner coastal travel, it features a common width (ca. 15.25 m) and depth (ca. 1.6 m) throughout its length. While the aquatic habitat is relatively unchanging, in the more than 170 years of the canal's history, the 12th largest city in the USA developed around it. Presently, the canal is surrounded by several residential neighborhoods and commercial districts, with heavily trafficked roads bordering and crossing it, and scattered woodlots found adjacent to it. We conducted this study on the spatial ecology of *G. geographica* and *T. scripta* in the Central Canal in order to determine whether the urban landscape surrounding the canal influences movement and habitat selection of these species.

Materials and methods

Study area

We conducted this research in the Central Canal in Indianapolis, IN, USA (39.83 N, 86.17 W). The canal was built in the 1830s for transportation, and is currently used by the Indianapolis Water Company to provide more than half of the water supplied to the metropolitan area. The canal is fed by the White River remains close to it (<15 m at the closest point) for 11.2 km before terminating at a water treatment plant in downtown Indianapolis. The canal flows to the south through heavily trafficked commercial and residential districts of the city. The majority of our research was conducted in the northern 8.5 km section of the canal which is bordered on one side by a towpath. The canal is narrow (15–25 m wide) with little shoreline and steep banks 0.5–2.5 m above water level. Submerged and emergent vegetation are regularly maintained by the water company to ensure adequate flow rates. Likewise, fallen trees and other large snags are removed by the water company during routine maintenance.

Radiotelemetry

We collected turtles using baited 0.76-m hoop traps during the course of a longterm mark-recapture study of the turtles inhabiting urban wetlands (Conner et al. 2005). Each turtle collected was measured for straight line carapace length (CL, to the nearest mm) and mass (to the nearest g). Between 10 May and 15 July 2002, we fitted 16 *G. geographica* and 20 *T. scripta* with radiotransmitters (ATS Inc., Isanti, MI, USA; Table 1). To minimize the effect of the transmitters on locomotion, we ensured that the radiotransmitters were <5% of each turtle's body mass. We were thus limited to outfitting only female *G. geographica* with radiotransmitters, as all males in our population were too small (i.e., <400 g). We divided the 20 *T. scripta* transmitters evenly among males and females. Transmitters were set on an 18-h duty cycle, functioning between 06:00 and 24:00 hours; therefore, no locations were made at night. The transmitters were attached to the posterior marginal scutes of the carapace with aluminum machine bolts and reinforced with plumber's epoxy (Bodie and Semlitsch 2000). We searched each transmitter frequency every 24–72 h between 14 May and 27 September 2002. Locations were recorded using handheld Global Positioning System (GPS) units (Garmin GPSIII+) to within 5 m of the true location. To

Table 1 Descriptive statistics of turtles used in movement and habitats use study

	<i>Graptemys geographica</i>	<i>Trachemys scripta</i>	
	Female	Female	Male
Body mass (g)			
Mean±SE (range)	1,445±188 (650–2,160)	1,233±237 (410–2,240)	677±76.9 (410–1,190)
<i>N</i> used to determine range	15	9	9
Locations per individual			
Mean±SE (Min–Max)	34.3±2.16 (9–43)	26.3±1.99 (20–35)	22.4±2.54 (9–32)
<i>N</i> used to daily movement	14	9	7
<i>N</i> used to determine hibernacula	10	4	7

determine the location of hibernacula, we similarly located and recorded the position of individuals between 22 and 28 February 2003 (Table 1). When determining the location of hibernacula, each individual was located at least twice on non-successive days to ensure that they were dormant and not moving. Daytime high air temperature during this time was on -2°C on average. Survivorship for the duration of the study was 100%.

GIS and habitat classification

We plotted the locations of turtles on 2001 orthophotos using ArcGIS 8.2 software (ESRI, Redlands, CA, USA). We placed a 15-m radius buffer around each location to account for variation in GPS signal accuracy and the possibility of movement for individuals startled during locating. In order to standardize measurements between turtle locations, we created a GIS layer consisting of “channel markers” located in the center of the canal, 50 m apart beginning at the canal origin and extending the 8.5-km length of the canal we monitored (see Pluto and Bellis 1986 for a similar, non-GIS approach to standardizing measurements). We classified the upland habitats surrounding the Central Canal based on the orthophotos and ground level assessment. Our simple classification scheme was based on the predominant cover type at the 50 m channel markers as follows: commercial, residential, river, road, woodlot, and open (cleared habitat not fitting any of the other classifications). The predominant cover type was that which accounted for at least 75% of the non-canal area within a 50-m radius of a given channel marker. We classified habitat on either side of the canal at each channel marker, as upland habitats were frequently different on opposite sides of the canal at the same channel marker. All measurements were taken at the scale of 1:1,000 and measured to the nearest 10 m.

Analyses

We considered the distance between the two farthest locations of an individual as its total range of activity. We did not locate individuals an equal number of times, thus to calculate mean movement distance, we took the total cumulative distance between successive locations divided by the number of movements (i.e., the number of locations—1; see Bodie and Semlitsch 2000). For individuals located on successive days at least three times throughout the study period (Table 1), we calculated the average daily movement, with daily movement being the distance

between locations on successive 24 h periods. We compared total range of activity, mean movement, and daily movement between female *G. geographica* and *T. scripta* and also between male and female *T. scripta* using one-way analysis of variance (ANOVA). To meet the assumptions of parametric tests, mean and daily movements were log-transformed. Because preliminary linear regression analyses demonstrated that mass played no significant role in either the total range (*G. geographica*: $F_{1, 13}=0.00857$, $P=0.927$; *T. scripta* females: $F_{1, 7}=0.0335$, $P=0.860$; *T. scripta* males: $F_{1, 7}=0.172$, $P=0.691$) or daily movements (*G. geographica*: $F_{1, 12}=0.156$, $P=0.699$; *T. scripta* females: $F_{1, 7}=0.256$, $P=0.628$; *T. scripta* males: $F_{1, 5}=1.23$, $P=0.317$), we did not include mass as a covariate in these analyses (contra Bodie and Semlitsch 2000). We used linear regression to determine whether the total number of observations or the number of daily movement observations significantly influenced estimates of the total range or daily movement for each species.

To determine the distribution of an individual's locations throughout the observed range of activity, we calculated a skewness index (after Lair 1987). A skewness index is a relative measure of the evenness of the spread of locations, with a value equal to 0 indicating a perfectly even spread of an individual's locations throughout its total range. The skewness index was calculated as:

$$\text{distance between MDPT and MCA/SDMDPT}$$

where MDPT was the midpoint (linear center) of the range of activity, MCA was the modal center of activity, and SDMDPT was the standard deviation of the mean distance of locations from the midpoint. The modal center of activity (MCA) was the segment of the habitat with the highest number of observations. For the purpose of determining MCAs, we divided the canal in non-overlapping 300-m segments (e.g., 0–300 m from canal origin, 300–600 m from canal origin, etc.). For each individual, the segment with the highest number of observations was considered the MCA. We determined the habitat classification for each individual at the center of the MCA segment. Because the canal is essentially a linear habitat (i.e., the width of the canal is not a considerable distance) and we were not always capable of determining whether individual locations were on one side of the canal or the other, the habitat of each individual's MCA was scored twice, once for habitat on either side of the canal. We found that for all but one individual this classification was the same as the most common habitat at all channel markers within the 300-m segment of the canal that comprised the MCA; thus our classification scheme accurately reflects the broader habitat experienced by turtles at those locations. We took the absolute value of the skewness index for each individual and used a one-sample *t* test to determine whether the mean skewness index for *G. geographica* and male and female *T. scripta* differed significantly from 0. In order to determine whether turtle locations were distributed randomly throughout the canal (i.e., without regard to the surrounding upland habitats), we used a goodness-of-fit test comparing the number of MCAs in each habitat versus the expected values given a random distribution of MCAs.

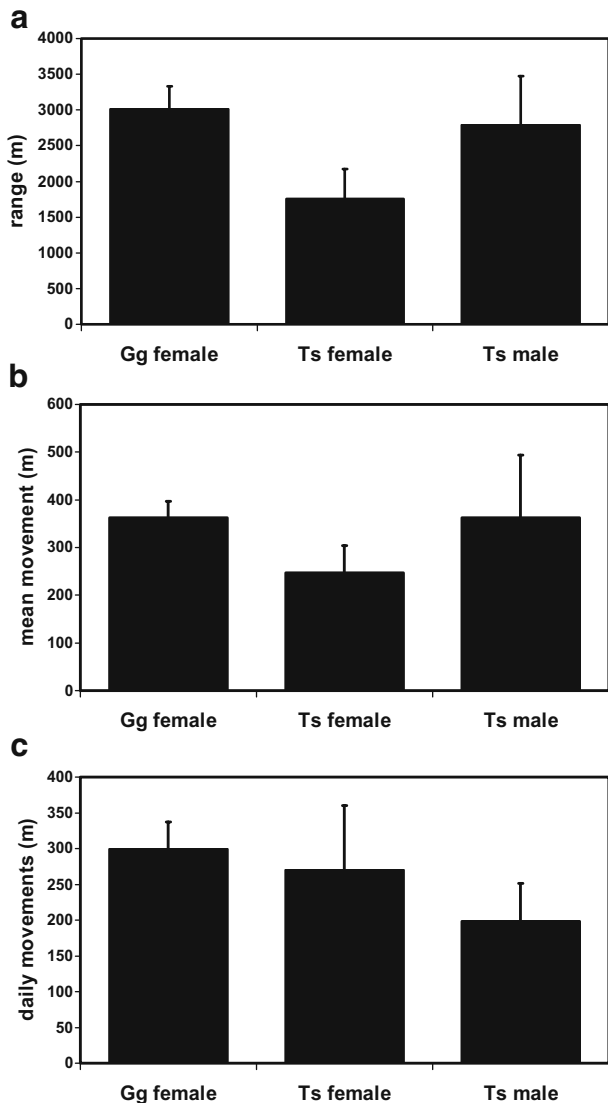
To determine whether hibernacula were randomly distributed with regard to upland habitats, we performed a goodness-of-fit test similar to the MCA analysis above. We also repeated the goodness-of-fit test using the location of MCA as expected values to determine whether the location of hibernacula was coincident with active-season habitat use. Furthermore, we calculated the distance between each individual's MCA and its hibernaculum, and used a one-way ANOVA to evaluate the difference between the species.

Results

Movement

We located 33 of the 35 radio-tagged turtles a total of 934 times during the 2002 field season. Female *G. geographica* had a significantly greater total range of activity than female *T. scripta* ($F_{1, 22}=5.54$, $P=0.028$; Fig. 1a). While male *T. scripta* had a tendency for a larger total range of activity than female *T. scripta*, (Fig. 1a), the sexes were not statistically different ($F_{1, 15}=3.05$, $P=0.10$). Likewise, there was a significant difference between females of the two species for mean movement ($F_{1, 22}=6.55$, $P=0.018$) but there was no difference between the sexes of *T. scripta* ($F_{1, 15}=0.07$, $P=0.79$; Fig. 1b).

Fig. 1 Mean (± 1 SE) **a** total range, **b** mean movement, and **c** daily movement of *G. geographica* (Gg) and *T. scripta* (Ts). See text for significance of comparisons



For both species the woodlot habitat was the preferred location of hibernacula, with residential being the only other common habitat for overwintering turtles (Fig. 2a). The distribution of hibernacula was significantly different from random ($\chi^2=22.68$, $df=5$, $P=0.00039$) and from summer MCAs ($\chi^2=12.87$, $df=5$, $P=0.025$), indicating that turtles seek locations different from their active season in order to overwinter. The distance between summer MCAs and hibernacula was considerable for both species, with a mean (SE) distance of 1,290 m (445.6) for *G. geographica* and 825 m (222.6) for *T. scripta*. The difference between species was not significant ($F_{1, 19}=0.923$, $P=0.349$).

Discussion

Range and movement

Our data from the 2002 active season showed that female *G. geographica* had larger ranges of activity than female *T. scripta*. Furthermore, we found that the average distance between locations was greater for *G. geographica* than for *T. scripta*, although females of these two species did not differ with regard to daily movement. These results indicate that while individuals move about the same amount in a 24-h period, *T. scripta* females tend to linger in a particular area whereas *G. geographica* females are more likely to move in a constant direction for several days in succession. While male *T. scripta* had mean values similar to those of *G. geographica* for total range and mean movement, neither of these variables were significantly different from female *T. scripta*. We had low power in the tests between the sexes of *T. scripta* (power=0.15 and 0.12 for the total range and mean movement ANOVAs, respectively) as a result of high variances (particularly in males) and relatively low sample sizes (Table 1). The *T. scripta* in our study had mean movement values comparable to those monitored in the Missouri River reported by Bodie and Semlitsch (2000). This overall similarity is not necessarily expected, given that we conducted our study within a single urban water way and theirs was conducted among several different aquatic habitats in the Missouri River floodplain, including the river, scour holes, flooded agricultural fields, and sloughs. However, *T. scripta* is not habitat specific (Gibbons 1990), and the similarity in movement patterns in two drastically different systems (i.e., narrow, urban canal versus a large-river floodplain) may be due to this species' generalist nature. In a study of *G. geographica* movement, Pluto and Bellis (1988) found the mean range of activity for females to be 1,210.7 m, less than half the range we observed in our study, despite overall similarity in the size of the riverine segment studies (6.6 km for their study, 8.5 km for ours). The Pluto and Bellis (1988) study inferred movements based on recapture of marked individuals captured by hand or in basking traps, rather than following individuals through radiotelemetry, and thus differences in methodology may account for some of the differences in movement estimates.

The difference in movement between *G. geographica* and *T. scripta* females is likely attributable to feeding preferences. Adult *G. geographica* prey predominantly on mollusks (Gordon and MacColluch 1980; Vogt 1981; White and Moll 1992) whereas *T. scripta* adults are generally considered omnivorous (Ernst et al. 1994; Minton 2001). These dietary characterizations appear to hold true in our populations, based on gut content analysis (Conner and Ryan, unpublished data). We have suggested previously that the dietary difference between these species may explain, in part, the differential abundance of *G. geographica* and *T. scripta* in the Central Canal versus a nearby man-made lake (Conner et al. 2005). The canal supports seasonally robust populations of several aquatic snail

species (e.g., *Pleurocera* sp., *Goniobasis* sp., *Vivaparus* sp.), whereas none of these are commonly found at the lake. The specific diet of *G. geographica* likely necessitates active foraging and movement from one area to the next as preferred food items become scarce following prolonged foraging or because of natural variability in prey availability (Pluto and Bellis 1988; Vogt 1981). In the absence of specific food preferences, *T. scripta* can stay within an area feeding on whatever food is available.

Habitat associations

The urban landscape surrounding the Central Canal is a complex matrix of residential, commercial, road, open, wooded, and other terrestrial habitats. Our data clearly show that the distribution of *G. geographica* and *T. scripta* in the Central Canal was non-random with regard to the surrounding terrestrial habitats. About 20% of the MCAs for each species were in sections of the canal associated with residential habitat. However, fewer of the locations were in residential and road-associated portions of the canal than would be expected by chance. The negative association with road and (to a lesser degree) residential habitats does not hold for all of the human-dominated regions of the canal. More than 30% of the MCAs for *G. geographica* were in parts of the canal surrounded by commercial upland habitat. Roughly an equal amount of MCAs were found in woodlot habitats. More than half of the MCAs of *T. scripta* were associated with woodlots, the least human-impacted habitat type in the urban landscape.

The terrestrial woodlot habitat surrounding the canal is clearly important to these species, as nearly 50% of all individuals had their MCA associated with this habitat type. The woodlots themselves vary considerably along the canal, with some as narrow as 25 m and others extending more than 100 m from the canal edge. It is difficult to surmise at present whether the specific quantity or quality of the woodlot matters as much as the simple presence or absence of the woodlot. The absence of a woodlot has several direct consequences, such as the elimination of basking sites and allochthonous input, the latter serving as a substrate and food source for the prey of omnivorous and carnivorous turtles (Bodie 2001). Woodlots also maintain the integrity of the banks of riparian systems with a thick, stabilizing root structure, thus reducing erosion and siltation, and they may reduce or remove pollutants. The availability of adequate basking sites may also explain the positive association with commercial upland habitat. In the most heavily used commercial zone, the banks of the canal are high (about 2.5 m), steep, and reinforced with large rocks (rip-rap) that are used by *G. geographica* and *T. scripta* as basking sites (Peterman and Ryan, in review). The density of *Graptemys* species is often positively associated with deadwood used for basking (Lindeman 1999a). When basking sites are in short supply, emydid turtles may actively compete for access to them (Ernst et al. 1994; Lindeman 1999b; Cadi and Joly 2003) indicating the importance of this resource.

More than 70% of the locations of overwintering turtles in our study were associated with woodlots. The root systems of trees in this habitat invade the bank of the canal and frequently penetrate the canal substrate, creating some of the hummock characteristics that many emydid species prefer in hibernation sites (Ernst et al. 1994). The absence of significant root systems in other parts of the canal—with the exception of residential areas where some large trees persist near the canal banks—likely accounts for the decrease in turtles relative to the active period. While the majority of MCAs and hibernacula were both located in areas bordered by woodlots, the considerable distance between MCAs and hibernacula for both species (slightly >1 km on average) suggests that the presence of woodlots alone does not suffice for an adequate hibernation site. These urban woodlots are

likely more heterogeneous than we have considered to this point, with some areas being superior for basking (i.e., sites with deadwood, snags, and emergent trunks and branches) and others possessing characteristics better suited for hibernation (e.g., subsurface root systems that facilitate burrowing). Fine scale analysis (e.g., Fuselier and Edds 1994; Shiveley and Jackson 1985) of the woodlot microhabitats may explain differences between active-season MCAs and hibernacula.

The turtles in our study avoided the portions of the canal bordered directly by roads. The impact of roads on wildlife can be quite extensive, and in particular roads can have a strong effect on turtle population viability with regard to overland migration to nesting sites (Gibbs and Shriver 2002; Gibbs and Steen 2005). During the course of field work in the Central Canal urban landscape in the 2002 and 2003 field seasons, we recovered eight carcasses of *G. geographica* that were killed by automobiles during nesting forays. Additionally, we have recovered several recently emerged nestlings en route to the canal along roads, also killed by automobiles. Collision with automobiles during overland migration does not necessarily explain why both *T. scripta* and *G. geographica* avoid road-associated portions of the canal, however; frequent disturbance from pedestrians, bicyclists, and automobiles may account for the observed pattern. Increased disturbance by humans influences several aspects of wildlife behavior and habitat choice, even for groups that commonly interact or coexist with human populations (Reijnen and Foppen 1995; Slabbekoorn and Peet 2003).

Implications for conservation and management

The regulation of natural and manmade riparian systems can have negative impacts on freshwater turtles through changes in food supply, population structure, population connectivity, and nesting success (Bodie 2001). However, when these habitats are properly monitored and managed, they may function as a refuge for turtles in an otherwise inhospitable landscape. For example, the western pond turtle (*Emys marmorata*) is declining throughout its range, but its persistence in an urbanized stream in Davis, CA, USA is possible through considerable a management effort, such as a head-starting program and removal of non-native species (Spinks et al. 2003). While some authors have contended that head-starting programs are ineffective for turtle populations, whose long term persistence is more dependent on adult survival (e.g., Congdon et al. 1993), Spinks et al. (2003) demonstrated that head-starting was important in helping stem the loss of *E. marmorata* because of the loss of adequate nesting sites. Our anecdotal data suggests that female *G. geographica* preferential move towards residential areas, an upland habitat type they otherwise avoid, during nesting forays (Ryan et al., unpublished data). Because of the apparent availability of suitable nesting sites (e.g., landscaped beds) in some areas surrounding the Central Canal, a head-starting program may not be necessary. Meaningful conservation and management of urban wildlife is dependant upon understanding the specific effects that urbanization has on different resident species.

Previous studies have shown terrestrial habitat variation to have a significant influence on aquatic turtles at very broad scales. For example, Marchand and Litvaitis (2004a) found that the amount of forest cover up to 500 m from and road density within 250 m of a pond affects the population characteristics of the painted turtle (*Chrysemys picta*). While it is clear that human activity has a significant impact on turtles and other wildlife at the landscape scale, our data demonstrate that terrestrial habitats within 25 m of an urban riparian zone influence the habitat use and movement of individual *G. geographica* and *T. scripta*. While broad scale studies establish important patterns, such as presence/absence and abundance for a variety of urban-tolerant animals (e.g., Blair 1996; Marchand and

Litvaitis 2004a, b; Randa and Yunger 2006), fine scale investigations of the urban landscape and its effects on individual behavior (e.g., Miller 2006) are important for the development of urban management plans. Most conservation strategies are developed for sensitive species (those with low or declining population sizes) and wildlife management plans are most frequently employed for game species. Ditchkoff et al. (2006) recognized that urban wildlife frequently demonstrates behavior different from their rural counterparts, as may be necessary for the acclimation or adaptation to urbanization. Thus, conservation plans and wildlife management strategies based on studies of the ecology and behavior of wildlife conducted on rural populations may not be directly applicable to their urban counterparts. In order to “keep common species common” within urban ecosystems, we may best approach these urban-tolerant species as having been poorly studied heretofore.

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