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Thirteen Years of Turtle Capture–Mark–Recapture in a Small Urban Pond Complex in Louisiana, USA

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Abstract.—Turtles are one of the most imperiled vertebrate groups in the world. With habitat destruction unabated in many places, urban and suburban greenspaces may serve as refugia for turtles, at least those species able to tolerate heavily altered landscapes. In south-central Louisiana, we have conducted a turtle capture–mark–recapture effort in two ponds in an urban greenspace for 13 yr to understand species composition, survival, and individual growth rates. We had 574 total captures of 251 individuals of five species from 2009–2021, with *Trachemys scripta elegans* (Red-Eared Sliders) and *Sternotherus odoratus* (Eastern Musk Turtles) being the most common. Apparent annual survival for *T. scripta* (0.79) was similar to estimates reported in other studies in altered habitats, whereas apparent annual survival for *S. odoratus* (0.89) was slightly or much higher than other published studies. Growth rates of *T. scripta* were comparable to other studies and showed both sexes have similar rates of growth until maturity, which is earlier and at a smaller size in males. The two ponds showed marked differences in captures by size, with significantly more juvenile *T. scripta* captured in the pond with more vegetation, depth, and a softer bottom. Most *T. scripta* (78.5%) that were recaptured came from the same pond from which they were originally captured. The basic demographic data gained in this study can serve as a starting point for broader questions on urbanization effects and as a comparison to more natural populations.

Greenspaces are increasingly being designed into the planning of developed areas in urban and suburban spaces. Aydin and Cukur (2012) define greenspace as "a type of land use which has notable contributions to urban environments in terms of ecology, aesthetics or public health, but which basically serves human needs and uses." Greenspaces exist on a continuum from intensely managed areas to wild places, and may include forests, shrublands, meadows, marshes, golf courses, suburban parks, and riparian areas (Guzy et al., 2013). Ponds, rivers, lakes, and reservoirs, sometimes referred to as bluespaces, are often components of greenspaces.

There are many noted environmental benefits of greenspaces (Davern et al., 2016; Rakhshandehroo et al., 2017; Twohig-Bennett and Jones, 2018). One specific benefit that greenspaces offer is a refuge for wildlife, which has been documented in amphibians (Semlitsch et al., 2007; Bogosian et al., 2012), birds (Chamberlain et al., 2007; Fuller et al., 2009), insects (McGeoch and Chown, 1997; Baldock et al., 2015), mammals (VanDruff and Rowse, 1986; Fabianek et al., 2011; Hale et al., 2012), plants (Schwartz et al., 2002), and reptiles (Bogosian et al., 2012; Guzy et al., 2013; Price et al., 2013).

The order Testudines, to which all turtles belong, is among the most imperiled major vertebrate groups in the world today (Rhodin et al., 2018). Of six significant threats to reptile biodiversity, habitat loss (degradation, fragmentation, or conversion) is generally recognized as the most pervasive and a leading cause for noted faunal declines (Sala et al., 2000), including in many turtle taxa (Gibbons and Stangel, 1999; Stanford et al., 2020). Urbanization results in habitat loss, degradation, and fragmentation through increased road networks, increased land use, and subsidized predators, which can negatively impact genetic structure (Rubin et al., 2001), demography (Garber and Burger, 1995; Lindsay and Dorcas, 2001; Aponte et al., 2003), and movements in turtle populations (Marchand and Litvaitis, 2004; Ryan et al., 2008). Direct mortality of turtles via vehicle roadway collisions, especially adult females on nesting forays, is a common occurrence in many urban turtle populations (e.g., Gibbs and Shriver, 2002; Steen and Gibbs, 2004; Aresco, 2005; Steen et al., 2006).

Semiaquatic turtles are a common component of many aquatic greenspace habitats and play an important role as omnivores, scavengers, predators, prey, and nutrient recyclers (Dupuis-Desormeaux et al., 2018). Energetic effects of semiaquatic turtles in a system can be profound, with turtle productivity and biomass often among the highest of all vertebrates (Iverson, 1982; Congdon et al., 1986; Lovich et al., 2018). Undoubtedly, some plants and animals, including turtles, cannot survive in heavily altered urban environments; however, synanthropic species often thrive in such urban greenspaces (Mitchell, 1988; Souza and Abe, 2000; Hays and McBee, 2010; Munscher et al., 2020). Our study focuses on a freshwater turtle capture–mark–recapture effort in an urban greenspace to understand baseline information such as species composition, survival, and individual growth rates. The basic demographic data gained can serve as a starting point for broader questions on urbanization effects and as a comparison to more natural populations.

Materials and Methods

Study Site.—We conducted our study in two urban man-made ponds within the city limits of Lafayette, the fifth most populous city in Louisiana (2020 Census population: 121,374; U.S. Census Bureau, 2020). The two ponds are in the University of Louisiana at Lafayette's Research Park. One pond is adjacent to the U.S. Geological Survey Wetland and Aquatic Research Center (hereafter WARC), and the other is adjacent to the National Oceanic and Atmospheric Administration Estuarine Habitats and Coastal Fisheries Center (hereafter EHCFC). The ponds adjacent to the WARC (named the National Wetlands Research Center until 1 October 2015) and the EHCFC were built in 1992 and 1999, respectively, when the buildings were constructed (Pham et

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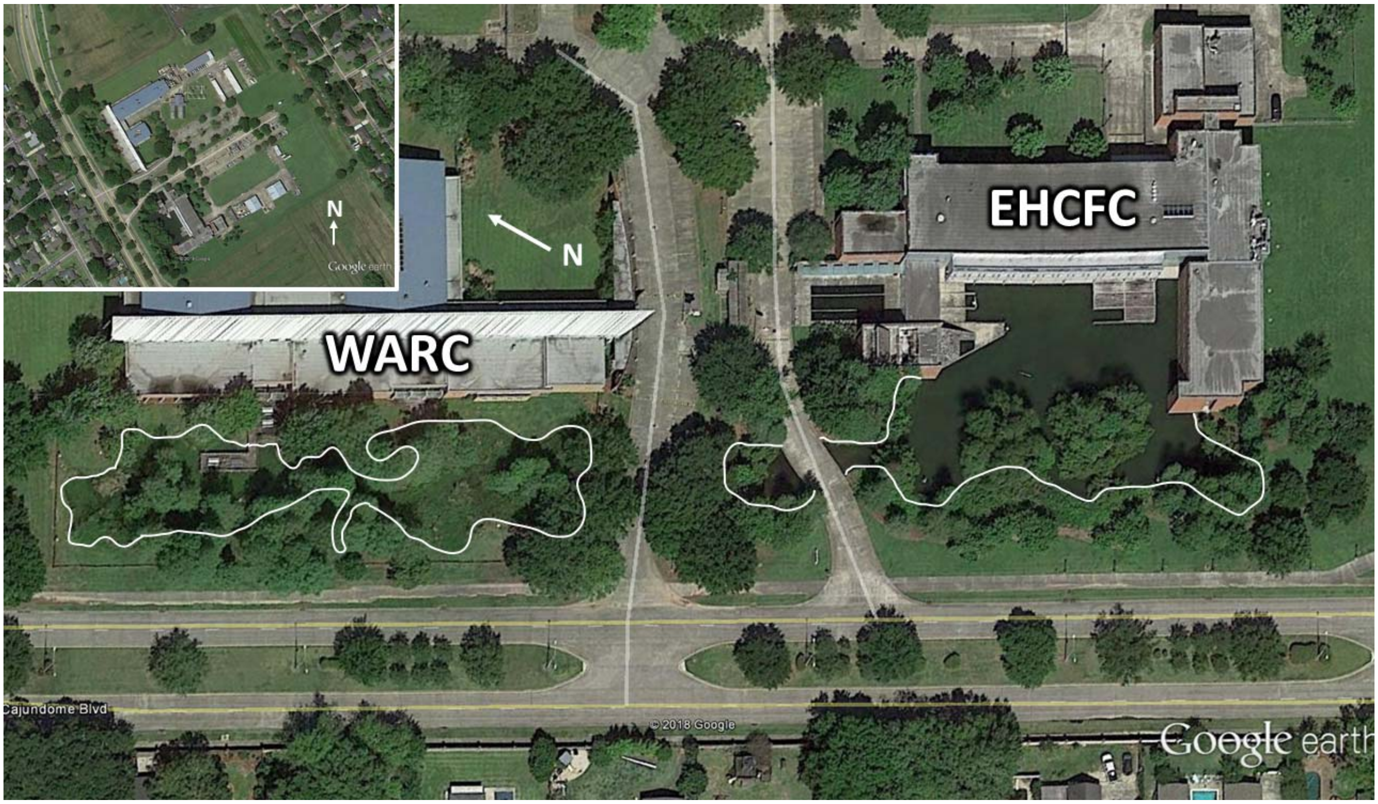

FIG. 1. Imagery of the Wetland and Aquatic Research Center (WARC) and Estuarine Habitats and Coastal Fisheries Center (EHCFC) ponds in Lafayette, Louisiana, USA. The inset image shows the roadway and adjacent land use including fields and neighborhoods. The WARC Pond has abundant emergent and floating vegetation somewhat obscuring the margins compared to the open water of the EHCFC pond, and thus an approximate outline is drawn of the vegetated edges of both ponds (Google Earth, 2018).

al., 2007). The two ponds are about 30 m from each other at their closest points, but do not share a water connection and are separated by two vehicle entranceways. The Lafayette region is on the eastern edge of historical coastal prairie habitat, but before the ponds and buildings were constructed the sites were open fields with shallow seasonal wetlands (Pham et al., 2007). A sidewalk, four-lane divided road, and a medium-density housing complex are located to the west of the ponds (Fig. 1).

Surface water area of the two ponds is similar (WARC = 0.21 ha, EHCFC = 0.25 ha), and was calculated using Google Earth imagery in a geographic information system (ArcMap 10.8, ESRI). Both ponds receive their water from rainwater and separate well systems. Unlike the EHCFC pond, the WARC pond was built with a liner and has a greater variety of depths than the EHCFC pond. Whereas the EHCFC pond bottom is relatively flat, the WARC pond edges are generally sloped, with thinner, v-shaped passages. Since this study began in 2009, the EHCFC pond has remained open water, whereas the WARC pond is often largely or completely choked with vegetation. In March 2011, much of the vegetation in and around the WARC pond was removed, but the vegetation-choked state soon returned and continues to present day. Whereas the WARC pond bottom has always been very soft, likely because of the amount of decaying vegetation sitting on top of the liner, the EHCFC pond was relatively firm in early years of this study, but recently has become softer and filled with sediment. The deepest part of the WARC pond is approximately 2 m, but most of the pond is much shallower, with many areas less than 1.0 m. The majority of the EHCFC pond ranges from 1.0–2.0 m in depth.

Capture Methods.—We captured turtles for 5 days each May from 2009 to 2021. We used two primary methods to capture turtles: hoop traps (Lagler, 1943) and deep-water crawfish nets (Glorioso and Niemiller, 2006). Hoop traps are a passive capture technique, and therefore each year we set hoop traps on Sunday afternoon, checked them each weekday afternoon, and picked them up on Friday afternoon, giving five consecutive trap nights. Deep-water crawfish nets are an active capture technique, and each year we set crawfish nets and checked them every 20 min between 1700 and 1900 h (i.e., six total checks of all nets) for five consecutive trapping sessions with rare exceptions, usually because of inclement weather. In 2020, inclement weather forced us to reschedule our Thursday crawfish net sampling for Saturday, the only instance of five nonconsecutive trapping days in the study. The number and type of hoop traps used each year varied, generally with more traps used in later years. Total crawfish nets typically varied from 10 to 14 nets, sometimes spread equally between the ponds, but often with more in the WARC pond. We baited hoop traps predominantly with fish, whereas we baited crawfish nets with either raw poultry or beef spleen on all but 1 day. For specific information on the number and type of traps and baits used each year, see Glorioso (2022).

In 2009, we set hoop nets on Sunday afternoon and active crawfish net sampling followed that evening. We checked hoop nets Monday–Friday, but sampled using crawfish nets from Sunday to Thursday. In 2009, we released captured turtles after processing all hoop net captures before beginning crawfish net sampling. Because of the 2009 protocol, it was possible that we could catch a turtle captured in a hoop net again in a crawfish net on the same day. We changed the protocol after 2009, and

TABLE 1. Total captures (TC) and new individuals (Ind) by year of five aquatic turtle species in an urban pond complex in Lafayette Parish, Louisiana, from 2009 to 2021. *Ts* = *Trachemys scripta*, *So* = *Sternotherus odoratus*, *Cs* = *Chelydra serpentina*, *Ks* = *Kinosternon subrubrum*, *Sc* = *Sternotherus carinatus*.

			Ts		*So*		*Cs*		*Ks*		*Sc*	
Year	Total captures	Individuals	TC	Ind	TC	Ind	TC	Ind	TC	Ind	TC	Ind
2009	65	49	56	41	7	6	2	2	0	0	0	0
2010	26	12	18	7	4	1	3	3	1	1	0	0
2011	23	10	15	6	7	3	1	1	0	0	0	0
2012	32	14	29	13	0	0	1	0	2	1	0	0
2013	39	10	34	9	5	1	0	0	0	0	0	0
2014	33	8	29	7	2	0	1	0	0	0	1	1
2015	37	17	31	15	5	1	1	1	0	0	0	0
2016	21	6	13	2	7	3	1	1	0	0	0	0
2017	34	18	21	12	12	6	0	0	1	0	0	0
2018	32	11	23	8	7	1	1	1	1	1	0	0
2019	53	21	41	15	6	0	3	3	3	3	0	0
2020	75	29	56	21	14	6	4	2	1	0	0	0
2021	104	46	63	14	39	30	0	0	2	2	0	0
Total	574	251	429	170	115	58	18	14	11	8	1	1

from 2010 to 2021 we set hoop nets on Sunday afternoon, and checked them on Monday afternoon, followed by the first crawfish net sampling. We held all turtles captured with hoop nets until after crawfish net sampling, releasing all turtles from both capture methods at the end of crawfish net sampling into their pond of capture so that the same turtle could never be captured twice on the same day.

Turtle Processing.—We identified each captured turtle to species and individually marked them with a unique three-letter identification by filing the marginal scutes (Cagle, 1939; Dorcas, 2005). We modified the marking scheme for Eastern Musk Turtles (*Sternotherus odoratus*) and Eastern Mud Turtles (*Kinosternon subrubrum*) to compensate for the reduced number of marginal scutes in kinosternid turtles. In some of the smallest individuals we still made marks by using nail clippers, but we also injected an 8.2-mm passive integrated transponder tag (PIT, model HPT8; 134.2 kHz, FDX) under the left bridge of the turtle into the inguinal cavity out of concern the marks would be unreadable if not recaptured for multiple years (Buhlmann and Tuberville, 1998).

We determined the sex of turtles by examining secondary sexual characteristics such as elongated foreclaws and tails in males. We took standard measurements of all turtles, including straight-line carapace length (SCL) along the midline, straight-line plastron length along the midline, maximum width, and maximum height using tree calipers to the nearest millimeter. We measured body mass to the nearest gram using a digital scale. We attempted to age turtles by counting lines of arrested growth (annuli) on the plastron when possible. We typically used the abdominal scutes to count annuli, but sometimes used other plastral scutes if they were more apparent. We photographed the carapace and plastron of each individual captured each year to assist in identification discrepancies and aging turtles.

Statistical Modeling.—We summarized data on captures of uniquely marked turtles into capture history matrices for the 13 annual sampling occasions 2009–2021. For survival analysis, the matrix showed whether each individual was captured (1) or not (0) each year, whereas for growth analysis, the matrix showed the carapace length if the turtle was captured and NA (missing data) otherwise. We modeled overall survival for the two species with >50 individuals captured and modeled growth for the one species with >50 individuals measured on two or more occasions.

We used the live recaptures procedure in Program MARK (White and Burnham, 1999) to model survival using the Cormack–Jolly–Seber open population mark–recapture model. We fitted four alternative models that varied according to whether survival and recapture probabilities were either constant or fully time dependent. We conducted model selection based on Akaike's information criterion (AIC; Burnham and Anderson, 2002).

We modeled growth using a sex-specific hierarchical version of the von Bertalanffy growth model (Armstrong and Brooks, 2013) fitted using OpenBUGS 3.2.3 (Spiegelhalter et al. 2014). Under this model, the growth rate and asymptotic size parameters not only differ between sexes, but can also vary among individuals. We found that we needed to use mildly informative priors (Banner et al., 2020) for individual standard deviation in asymptotic size and mean asymptotic size of males and females to obtain sensible results. However, the use of informative priors only means that parameters were constrained to plausible ranges.

We used the growth model to generate posterior distributions for ages of individuals where age was not inferred from annuli. Therefore, we used Bayes' theorem to infer each turtle's most likely initial age based on its size when first measured, its subsequent growth rate, and the prior expectation based on the age distribution of the population (Armstrong and Brooks, 2014). For the prior age distribution, we used a negative binomial distribution based on the constant annual survival rate estimated from this study, that is, $NB(1, 1 - S)$ where S is the annual survival probability. We used the cut function in OpenBUGS to prevent this age estimation from affecting growth parameters, similar to Armstrong and Brooks (2014).

RESULTS

We had 574 total captures of 251 individuals of five species from 2009 to 2021 (Table 1). The most abundant species was *Trachemys scripta elegans* (Red-Eared Sliders), comprising 74.7% of all captures and 67.7% of all individuals, followed by *Sternotherus odoratus* (Eastern Musk Turtles) with 20.0% of all captures and 23.1% of all individuals. Interestingly, we captured only 28 individual *S. odoratus* in the first 12 yr combined, but

TABLE 2. Apparent annual survival and recapture probabilities for *Trachemys scripta* and *Sternotherus odoratus* captured in an urban pond complex in Lafayette Parish, Louisiana, from 2009 to 2021. A model with constant survival (phi) was supported for both species. For recapture probability (*P*), the time-varying model was best supported for *T. scripta*, hence a separate estimate is shown for each year, whereas constant detection probability was supported for *S. odoratus*.

			95% Confidence interval	
Parameter	Estimate	SE	Lower	Higher
Trachemys scripta				
phi	0.7939	0.0214	0.7487	0.8327
P	0.3442	0.0316	0.2852	0.4085
P	0.3245	0.0876	0.1800	0.5125
P	0.2565	0.0807	0.1309	0.4415
P	0.2716	0.0852	0.1381	0.4645
P	0.4604	0.0863	0.3016	0.6276
P	0.3753	0.0835	0.2301	0.5469
P	0.3273	0.0863	0.1841	0.5121
P	0.2868	0.0768	0.1616	0.4563
P	0.2239	0.0775	0.1074	0.4089
P	0.3359	0.0876	0.1898	0.5220
P	0.5618	0.0973	0.3714	0.7357
P	0.5436	0.0923	0.3649	0.7118
P	0.7847	0.0950	0.5476	0.9165
Sternotherus odoratus				
phi	0.8920	0.0384	0.7909	0.9474
P	0.4043	0.0592	0.2955	0.5235

captured 30 new individuals in 2021. We captured *Chelydra serpentina* (Common Snapping Turtles) and *Kinosternon subrubrum hippocrepis* (Mississippi Mud Turtles) infrequently, along with a single *Sternotherus carinatus* (Razor-Backed Musk Turtle).

We had more recaptured individual *T. scripta* from previous years than new individuals in 8 of 12 yr. We captured individual *T. scripta* marked the first year of sampling in every subsequent year and likewise for *S. odoratus*, except for 2012, when we did not capture any *S. odoratus* (Tables S1 and S2). We captured more turtles using crawfish nets than hoop traps, especially considering we only trapped with crawfish nets for 2 h daily, whereas hoop traps were continuously set for 5 days (Table S3).

The constant survival and time-varying capture probability model was supported with >96.0% of the AIC weight for *T. scripta*, whereas the constant survival and constant capture probability model was supported with >99.9% of the AIC weight for *S. odoratus*. *Trachemys scripta* had an apparent annual survival of 0.79, whereas *S. odoratus* had an apparent annual survival of 0.89 (Table 2).

Mean asymptotic SCL for male and female *T. scripta* was 165.3 and 227.1 mm, respectively (Fig. 2). Growth rates were similar between the sexes until about 5 yr of age, when male growth rate slowed compared to females. Males were estimated to grow less than 1 cm per year after 15 yr, whereas this was after 24 yr in females. Most individuals of unknown age were larger individuals, and models suggested all but one of these females were over 10 yr old, with the largest (242 mm SCL) estimated to be over 29 yr old (Fig. 3). Age estimates ranged up to 21 yr old for our largest unknown-age male (190 mm SCL).

Of 429 *T. scripta* captures, we captured 226 in the WARC pond and 203 in the EHCFC pond, with a similar distribution of individuals and recaptured individuals (Table S4). We captured only 3 of 115 total captures of 58 individual *S. odoratus* in the EHCFC pond. The 14 individual *C. serpentina* were evenly split between the two ponds, with recaptures only in the EHCFC pond. We captured seven of eight individual *K. subrubrum* from

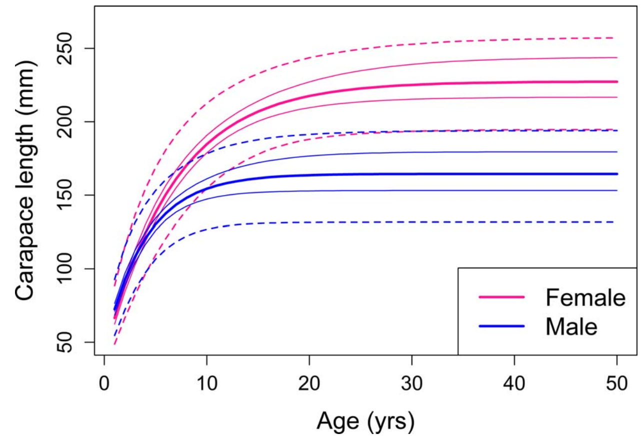

FIG. 2. Sex-specific hierarchical von Bertalanffy growth model fitted to data for *Trachemys scripta* in an urban pond complex in Lafayette Parish, Louisiana, from 2009 to 2021. Solid lines show means and 95% credible intervals for growth on an average male and female. Dotted lines show 95% credible intervals when individual variation is incorporated.

the WARC pond, and we captured the lone *S. carinatus* in the EHCFC pond.

The SCL of *T. scripta* at first capture in the WARC pond was significantly smaller than the mean SCL in the EHCFC pond ($\chi^2_1 = 4.662$, $P = 0.031$; Table S5). We captured over 75% of *T. scripta* individuals <100 mm SCL in the WARC pond. In contrast, the EHCFC pond had not had a new individual <100 mm SCL since 2015 until a single capture in 2021. Over 96% of *S. odoratus* individuals, a small species, was captured in the WARC pond as well as the two smallest *C. serpentina*, and the only ones <150 mm SCL.

Of the 93 *T. scripta* we recaptured at least once, 78.5% remained in the same pond at each capture, with 45.2% and 33.3% remaining in the WARC and EHCFC ponds, respectively. We recaptured 15 (16.1%) *T. scripta* in a different pond than their original capture. Based on our captures, five individual *T. scripta* (5.4%) moved from their original pond to the other pond, and then back again to the original pond.

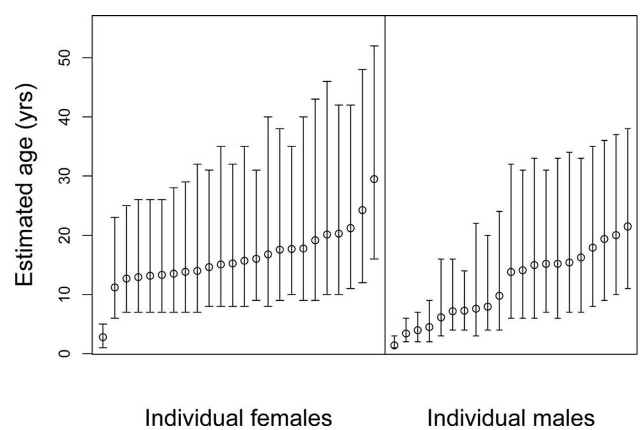

FIG. 3. Estimated ages at first capture for *Trachemys scripta* individuals not aged using annuli in an urban pond complex in Lafayette Parish, Louisiana, from 2009 to 2021. The posterior distribution for each turtle is based on its straight-line carapace length (SCL) when first captured, its subsequent growth rate, and the expected age distribution for the population based on the annual survival rate. Error bars show 95% credible intervals.

Discussion

The apparent annual survival of 0.79 for *T. scripta* in this study aligns closely with other studies of *T. scripta* from both natural and altered environments. In natural Carolina bays in South Carolina, Frazer et al. (1990) noted survival rates of 0.81 for females and 0.84 for males in 4+-yr-old turtles. At three locations in a Superfund site (i.e., contaminated with hazardous materials) in Oklahoma, Hays and McBee (2010) noted survival rates between 0.74 and 0.86. At five sites in metro Charlotte, North Carolina, Eskew et al. (2010) noted survival rates between 0.73 and 0.93. Lastly, in a northeast Mississippi farm pond, Parker (1996) found survival rates between 0.71 and 0.86.

The apparent annual survival of 0.89 for *S. odoratus* in this study is slightly higher than 0.84–0.86 reported by Mitchell (1988) in Virginia, and much higher than the 0.46 and 0.68 reported by Hrycyshyn (2007) for females and males, respectively, in Florida. High apparent annual survival at this site is likely because of the seemingly static and ideal habitat for the species within the WARC pond, where nearly all the population occurs. Also, the pond's isolation from other suitable areas likely limits or eliminates migration to and from the pond complex in this highly aquatic species. In addition, though there are avian and mammalian predators in the area, there are no large aquatic predators such as *Alligator mississippiensis* (American Alligators) in the pond complex. One female *S. odoratus* captured as an adult (94 mm SCL) in our first year in 2009 has been captured in every subsequent year in the 13-yr study except 2012, when zero *S. odoratus* were captured. This female was captured multiple times within the trapping week in 6 of 13 yr. The individual's SCL has been 99–100 mm since 2013, and her body mass has fluctuated between 160–180 g over the last 9 yr.

Many studies have used annuli to estimate turtle ages, but the validity of this method has been questioned (Wilson et al., 2003). However, for *T. scripta* in the temperate zone, as in our study, both Cagle (1946) and Gibbons (1970) directly confirmed a one-to-one relationship between a major growth period and the deposition of one annulus per year. Stone and Babb (2005) tested the annual growth line hypothesis in *T. scripta* in Oklahoma and found that turtles were reliably aged to about 4 yr of age. In addition, Stone and Babb (2005) found that the annuli count of 100 of 106 (94%) *T. scripta* was consistent with their known age. In our study, 58 of 65 (89.2%) *T. scripta* assigned an age based on annuli had an estimated age of 4 yr or less. Our result aligns with those of Sexton (1959) and Gibbons (1983), who stated that there is a direct correlation between known age in years and major scute growth zones (i.e., annuli) in subadult and immature turtles, but growth slows or ceases at maturity, making it difficult to recognize annuli, particularly in turtle species that shed their scutes.

In addition to the five captured species, we observed two other turtle species in the ponds. On several occasions both during and outside of trapping weeks we and other co-workers spotted at least two different large female *Apalone spinifera* (Spiny Softshells) in the EHCFC pond. *Apalone spinifera* are often trapped in baited hoop nets, but they have eluded capture thus far in this study. In 2016 we confirmed a hatchling *Pseudemys concinna* (River Cooter) in the WARC pond, and have since seen at least one large adult female basking in the WARC pond. *Pseudemys concinna* is primarily herbivorous and not frequently trapped using baited hoop traps and crawfish nets (Dreslik, 1997).

Though we are uncertain whether turtles naturally colonized these wetlands over the years, we have anecdotal evidence of release of turtles into the ponds. We witnessed someone attempting to release a box turtle (*Terrapene* sp.) during our sampling, but we intervened by picking up the box turtle before it entered the pond. We suspect the lone *S. carinatus* we captured was a released turtle, as these ponds are not a typical habitat for this species. We were also made aware of an instance in 2013 where a person released an adult male *Chrysemys dorsalis* (Southern Painted Turtle) into the EHCFC pond.

It is apparent that the WARC pond is preferable to small size classes of turtles. Over 67% of *T. scripta* <100 mm SCL in the WARC pond were first captured in the last 5 yr, indicating either more successful reproduction in recent years or a better ability to capture younger size classes. For *T. scripta*, the young turtles likely prefer the WARC pond because of its abundant emergent and floating vegetation, which offers both a food source and protection from predators. For *S. odoratus* and *C. serpentina*, the thick layer of soft mud and detritus at the bottom of the WARC pond is likely preferable for these bottom dwellers compared to the firmer EHCFC pond with less organic matter.

Our recapture data indicate that most turtles prefer one pond or the other under the assumption turtles are not moving between ponds at other times of year outside the May capture period. The two ponds are only 30 m from each other, but are separated by two vehicle entranceways. The entranceways have high vertical curbs that may serve as barriers to some turtles. We have on occasion observed turtles struggling to get over the curb, and it is possible the curbs could direct them toward the four-lane road and put them in danger. That said, we opportunistically documented few instances of direct mortality at any time of year as we frequently come and go from our offices and observe the roads for live or dead turtles. It is clear, however, that at least some turtles successfully move between ponds.

The urban greenspace of our study site seems to be good habitat for the turtles that occur there, with survival estimates for our two most abundant species similar or higher than those reported by other studies. *Trachemys scripta* seems to be especially prolific, with successful annual nesting despite the human-altered landscape around the ponds. Despite capturing *S. odoratus* in all but 1 yr, we rarely captured juveniles and were concerned about their recruitment. Then, in 2021, we doubled the number of *S. odoratus* individuals captured, with most being juveniles. As our study is ongoing, more precision is expected with our *T. scripta* growth and survival estimates as we follow some of our known-age turtles into adulthood and larger sizes. In addition, we may be able to perform a growth model for *S. odoratus* provided we continue to catch juveniles like we did in 2021 and recapture them in subsequent years.

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Supplementary Data

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