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Cover Photograph: Students checking hoop traps in Lake Hollingsworth with Florida Southern College in the background. Photograph © Gabriel Langford.

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Ecology of an Urban Turtle Assemblage in a Central Florida Lake

Bryan T. Snapp[1], Ashley L. Pelegrin[1], Jaleel O. Benjamin[1], and Gabriel J. Langford[1*]

Abstract - Urbanization is a primary cause of wetland destruction and habitat degradation. Human-dominated landscapes frequently experience a decrease in wildlife diversity and abundance. Our study aimed to establish the descriptive ecology of the freshwater turtle assemblage in a small, urban Central Florida lake that hosts an introduced population of invasive Red-eared Sliders (*Trachemys scripta elegans*). We captured turtles with hoop nets and by hand from Lake Hollingsworth in 2011–2013. All captured turtles were measured and marked with passive integrated transponder tags. We also conducted a nesting and road-kill survey from February–October of 2013 and 2014. We captured a total of 343 turtles comprised of 7 species during the mark-recapture study, with Red-eared Sliders representing 84% of all captures. Our nesting survey found 109 nesting females, with 78 of those nests dug by the Red-eared Slider. Twenty-two road-killed females were recorded during our study, with Florida Redbelly Turtles and Red-eared Sliders being the most common. Overall, our study found that Lake Hollingsworth's turtle assemblage was dominated by the invasive Red-eared Slider. We suggest several factors related to urbanization, e.g., vehicular threats to nesting females, and the invasive Red-eared Slider precipitated the decline of native turtles in Lake Hollingsworth. Additional studies on the impacts of invasive species on urban turtle assemblages are warranted, along with developing conservation strategies to restore native turtle assemblages to urban freshwater habitats.

Introduction

Waterbodies in human-dominated landscapes face a multitude of threats to their natural biodiversity and ecosystem functions, including the commonly recognized threats of habitat destruction, global climate change, environmental pollution, disease, unsuitable habitat, and invasive species (Gibbons et al. 2000). In particular, urbanization and suburban sprawl are a primary cause of wetland destruction and habitat degradation (Groom et al. 2005). Given these wide-ranging pressures, it is not surprising that most native vertebrates show a decrease in species richness with increasing urbanization (McKinney 2008), a phenomenon that occurs in fishes (Hermoso et al. 2011), amphibians and reptiles (Andrews et al. 2008), birds (Aronson et al. 2014), and mammals (Ordeñana et al. 2010). Reductions in biodiversity are harmful because diverse biological assemblages provide numerous ecosystem services (Mace et al. 2012), and biodiversity is difficult to restore once services are altered or removed (Groom et al. 2005, Mace et al. 2012). One assemblage that deserves more attention for the ecosystem services they provide are native turtles (Lovich et al. 2018). Turtles can maintain habitat heterogeneity, which can be critical to the maintenance of habitats and plant species (Froyd et al. 2014, Griffiths et al. 2011, Lal et al. 2010, Lovich et al. 2018). However, reductions in diversity among species providing key ecosystem services can lead to ecosystems that often become dominated by non-native, invasive species (Pejchar and Mooney 2009, Pickett et al. 2001). Invasive species can further exacerbate homogenization of species and loss of ecosystems services in urban habitats that ultimately may impact human well-being (McKinney 2008, Pejchar and Mooney 2009).

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In waterbodies worldwide, the introduction of non-native turtle species has become a threat to native turtle assemblages, through mechanisms such as within-guild competition, in which a superior competitor replaces a native species via competitive exclusion (Cadi and Joly 2003, Hardin 1960). *Trachemys scripta elegans* Wied-Neuwied (Red-eared Sliders, herein RES) are native to the central United States (Parham et al. 2020) but have become one of the most widely distributed and harmful invasive vertebrates in the world (Lowe et al. 2000). These invasive turtles adjust well to urban systems and can establish dense populations, leaving authors to speculate about their impacts on native turtle assemblages (da Silva and Blasco 1995, Holland 1994). Recently, authors have found RES able to replace or reduce native species with different mechanisms. For example, Parham et al. (2013) found that competition and introgression events between *Trachemys* spp., including RES, in the Caribbean may represent a threat to several endemic turtle species. An additional example includes evidence that RES directly compete for basking resources with endangered *Emys orbicularis* L. (European Pond Turtles; Cadi and Joly 2003). Cadi and Joly (2004) also found that European Pond Turtles kept under experimental conditions with RES lost weight and exhibited higher mortality rates, suggestive of interference competition. In California, Spinks et al. (2003) suggested that competition for basking sites between RES and *Actinemys marmorata* Baird and Girard (Western Pond Turtles) played a role in the decline of the native Western Pond Turtle. Lambert et al. (2013) found native Western Pond Turtles were more abundant than invasive RES in habitats with less human disturbance, steep banks, basking sites in shallow water, and in the presence of concrete substrates. Furthermore, RES are not only considered a threat to native turtles but to most native fauna and flora throughout its introduced range, e.g., Asia (Chen and Lue 1998, Ramsay et al. 2007), California (Thomson et al. 2010).

Invasive RES have a fecundity advantage over many of their potential competitors (Arvy and Servan 1998), producing as many as 5 clutches of eggs in a single year (Jackson 1988). Red-eared Sliders nest close to the shoreline in the United States (Steen et al. 2012) and appear to avoid roadways (Ryan et al. 2008), which may provide an advantage over turtle species that travel farther to nest and increase their exposure (and their offspring) to vehicular traffic and other threats common in terrestrial urban areas, e.g., dogs, cats, racoons, people. Roadways are known to negatively impact turtle populations, and they differentially result in the death of reproductive females and their offspring (Aresco 2005, deCatanzaro and Chow-Fraser 2010, Gibbs and Shriver 2002, Marchand and Litvaitis 2004, Wood and Herlands 1997). In some Florida wetlands, roadways may be the biggest threat to the long-term survival of turtle populations (Aresco 2005, Dodd et al. 2004). Mitigation devices, such as fencing and diversion culverts, show potential to reduce turtle road mortalities in road-kill hotspots, but may be impractical over an entire roadway (Langen et al. 2012).

Given the obvious threats to aquatic ecosystems and the potential for the turtles to carry *Salmonella* bacteria in the pet trade, the sale of juvenile RES was banned in 1975 in the United States (Title 21 CFR 1240.62). In Florida, all RES are listed as a banned, conditional species. Nevertheless, these turtles can still be found for sale in the southeastern states by commercial vendors (G. Langford, pers. obs.). Overall, whether through natural dispersal or future illegal introductions, RES will continue to invade urban waterbodies in Florida. Given the continued spread of RES, we emphasize the importance of understanding how these turtles impact native turtle assemblages.

Few published studies have investigated the composition and structure of freshwater turtle assemblages in Florida (Chapin and Meylan 2011, Johnston et al. 2011), especially in urban habitats that contain invasive species (Witzell 1999). In addition, most studies have been conducted in lotic systems, such as spring runs, which appear to maintain similar, but distinct assemblages when compared to Florida's more common eutrophic lakes (Chapin and Meylan 2011, Meylan 2006). Lake Hollingsworth is a small urban lake in peninsular Lakeland, Florida that hosts a turtle assemblage that includes invasive RES; however, it is not clear if the invasive turtle impacts the native turtle assemblage. Based on a previous collection of turtles from Lake Hollingsworth using hoop traps and hand captures (D. Lee, Florida Southern College, Lakeland, FL, 1964 unpub. data), the turtle assemblage contained (in order of relative abundance [high to low]): *Pseudemys nelsoni* Carr (Florida Redbelly Turtle), *Apalone ferox* Schneider (Florida Softshell Turtle), *Chelydra serpentina* L. (Common Snapping Turtle), *Sternotherus odoratus* Latreille (Common Musk Turtle), *Kinosternon subrubrum* Bonnaterre (Eastern Mud Turtle), *Pseudemys floridana* LeConte (Florida Cooter), and *Deirochelys reticularia* Latreille (Chicken Turtle). Lee's collection only provides a general (lacking exact species capture numbers) baseline of the turtle assemblage. Nevertheless, the absence of the RES in Lee's survey suggests that the invasive turtle was released into the lake after his survey. The introduction likely occurred in the 1970-80s, when releasing unwanted pet turtles was common across the United States. (D. Nelson, University of South Alabama, Mobile, AL, 2010 pers. comm.). It is important to consider that Lee's study occurred in an already urbanized landscape; most residential areas surrounding Lake Hollingsworth were built in 1890–1970. It is possible Lee's turtle assemblage had already been altered by urbanization. Given this background, the purpose of our study was to establish the descriptive ecology of the urban freshwater turtle assemblage living in Lake Hollingsworth, including whether it includes invasive RES. Our study also provides baseline data on turtles in an under-sampled region and ecosystem in the southeastern United States.

Methods and Methods

Lake Hollingsworth is a 142 ha hypereutrophic lake in urban Lakeland, Florida that is actively managed, with frequent vegetation removal and mowed banks along most of its perimeter. Importantly, from a turtle's perspective, over 90% of overhanging tree branches are trimmed, which appears to limit terrestrial cover and archetypical basking behavior among emydid turtles in this lake. Aquatic and emergent vegetation is common and includes: *Nuphar luteum* L. (Spatterdock), *Juncus effesus* L. (Soft Rush), *Hydrilla verticillata* L. (Waterweed), *Pontederia cordata* L. (Pickerelweed), and *Panicum hemitomon* Schult (Maidencane). Phytoplankton concentration and turbidity levels are high year-round. A 2 m wide asphalt walking path surrounds the entire lake at a distance of 1.5–9 m from the shoreline, with a roadway 1–3 m beyond the path. The walking path and roadway are very popular for transportation and recreation, with use 24 hours a day. The surrounding watershed is urban to suburban, with most homes and buildings built in 1890–1970. A boat ramp and yacht club are located on the southern side of the lake, whereas Florida Southern College (FSC) dominates the northern shoreline.

To establish turtle diversity and abundance, we captured turtles from the small wetland adjacent to the lake, which appeared to provide good turtle habitat from January 2011–April 2013 (Fig. 1). Our sampling was limited from August–November 2011, when traps were frequently disturbed or stolen. In addition to collection around the wetland, we subdivided the lake into 3 areas and intensively sampled each area for approximately a month in the summer of 2012; Section A: May 13–June 10, Section B: June 11–July 8, and Section C: June 9–August 8. We subdivided the lake to determine if the turtle assemblage varied around the lake based on urban density and assess turtle movements. The watershed in Section A, along the northern and northeastern shore from Success Ave. to Crystal Lake Dr., contains a large church complex, shopping center, medium density housing, and the FSC campus; this area is the most densely populated, and the roadway and walking path are directly adjacent to the shoreline. Section A provides a narrow to moderate strip of grass and sandy soil for nesting, unless turtles cross the street and path to nest in lawns. An exception is the small wetland on the FSC campus that borders the lake, which provides numerous nesting sites and some native vegetation. Section B, along the southeastern and southern shoreline, from Crystal Lake Dr. to Beacon Rd., is composed of low-density single-family homes, a small synagogue, and a yacht club with a boat launch. This section is of medium human density, but provides the narrowest section of suitable nesting habitat, as the roadway and walking path are often <3m from the shoreline. Section C, along the western shore from Beacon Rd. to Success Ave., is the least developed and provides substantial nesting habitat along its shoreline. The area contains only single-family homes with large yards, and contains some native vegetation along its bank, including a few overhanging trees for turtles to bask and seek cover. In summary, we qualitatively ranked A as the most urban, C as the least urban, and B has an intermediate human density. Of note, our collection at the FSC wetland was continuous; however those turtles are only included in the FSC Wetland data, not in sections A, B, and C.

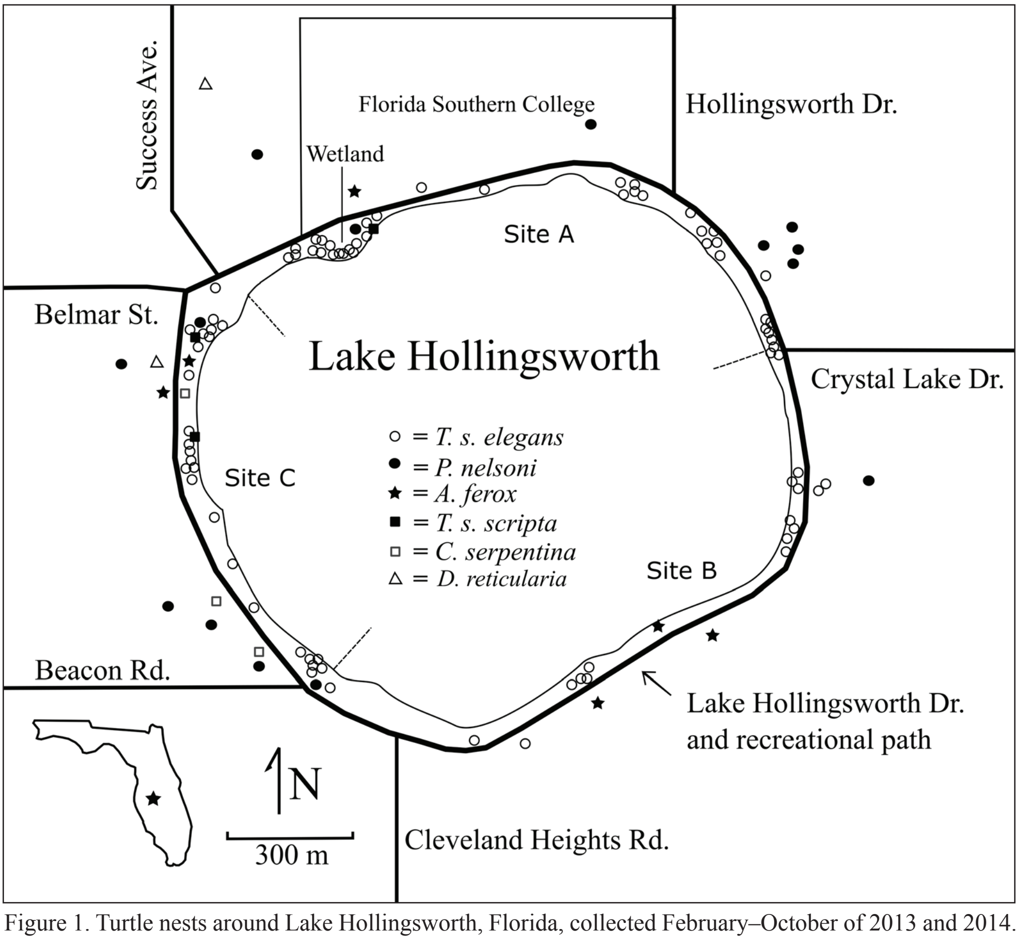

Figure 1. Turtle nests around Lake Hollingsworth, Florida, collected February–October of 2013 and 2014.

We sampled turtles using three ring hoop traps (120 cm diameter, 6 cm mesh) that were set unbaited to avoid attracting alligators. However, most traps were naturally baited by invasive *Oreochromis aureus* Steindachner (Blue Tilapia), which were common in the lake. We set 5 hoop traps within 20m of the shoreline, near vegetation, and we checked them every 1-3 days (less in winter), depending on turtle activity. We considered a trap day as 1 trap open for 24 hrs. We also deployed 4 basking traps (Heinsohn's Sundeck Turtle Trap), although they were ineffective at capturing turtles, and we did not use them in 2012-13. Finally, we opportunistically hand captured a limited number of turtles on land or in shallow waters. Our captured turtles were weighed with a handheld digital Pesola© scale, measured (straight line) for plastron length, carapace length, carapace width, shell depth recorded using calipers, sexed using secondary sexual characteristics (we could not sex Common Snapping Turtles and Florida Softshells), and tagged using Biomark© passive integrated transponder (PIT) tags to identify recaptures. We used PIT tags because they provide a permanent, non-subjective marking strategy for freshwater turtles, including those that are difficult to physically mark (Buhlman and Tuberville 1998). Next, we identified, photographed, and noted turtles for any unusual features, then we released them near their point of capture. We gave all turtles a full body scan for the presence of PIT tags. We measured movement when we recaptured turtles in different locations; the straight-line distance between traps was calculated. To assess diversity, we calculated the Shannon-Weiner index ($H' = -\Sigma p_i \ln(p_i)$) and Evenness ($E = H'/\log(S)$) for sections A-C.

During February–October of 2013 and 2014, we conducted a nesting (defined as a turtle digging a nest) and roadkill survey to determine whether gravid female turtles attempted to cross the road and where turtles nested. We documented activity by slowly driving (<30 kph), cycling, or walking at least 4 days a week to document turtle activity. Additionally, a few of our records were reported by citizen scientists using geo-referenced photographs. We documented all nesting and roadkill locations with GPS, and we calculated the straight-line distance from Lake Hollingsworth's shoreline for nesting sites using Google Maps. We identified turtles to species, sexed, measured, and marked (or recorded as recapture), when possible, after nesting. We were able to determine sex for all road-killed turtles. No attempts were made to document additional reproductive parameters. We calculated the proportion of nesting turtles killed through road mortality for each species (number of road-killed females/(number of nests + number of road-killed females)) to assess the relationship between the proportion of nesting turtles and average nesting distance.

Results

Our mark-recapture study took place over 505 days (12,120 trap hrs) and captured 343 turtles total, with 35.34 hours per trapped turtle. The assemblage of turtles we captured were: RES (non-native), Florida Redbelly Turtles, Chicken Turtles, Yellow-bellied Turtles (non-native), Common Snapping Turtles, Eastern Mud Turtles, and Florida Softshell Turtles (Table 1). Our study found RES had the largest number of captures and recaptures with 288 captures and 104 recaptures and constituted 84% of all captures, whereas Florida Redbelly Turtles were the next most abundant turtle with 24 captured and 10 recaptured over the 2 years. Other species of turtles in our study were rarely captured and showed a minimal population in Lake Hollingsworth and the adjacent wetland. Of note, we occasionally saw, but were unable to hand capture, the Eastern Mud Turtle in Lake Hollingsworth. Our hoop nets collected only the largest individual Eastern Mud Turtles, making them under-collected in our study.

Table 1. Mark-recapture data of freshwater turtles collected from Lake Hollingsworth, Florida over varying time periods in 2011–2013 using primarily hoop traps and hand captures.

		FSC Wetland (2 years)		Site A (1 month)		Site B (1 month)		Site C (1 month)	
Species	Sex	Captures	Recaptures	Captures	Recaptures	Captures	Recaptures	Captures	Recaptures
Red-eared Slider		134	67	31	0	75	26	48	11
	male	80	52	22	0	41	17	35	9
	female	54	15	9	0	34	9	13	2
Florida Redbelly Turtle		21	10	0	0	1	0	2	1
	male	9	8	0	0	1	0	1	0
	female	12	2	0	0	0	0	1	1
Chicken Turtle		7	7	0	0	0	0	3	0
	male	6	6	0	0	0	0	1	0
	female	1	1	0	0	0	0	2	0
Yellow-bellied Turtle		2	2	0	0	0	0	1	0
	male	2	2	0	0	0	0	0	0
	female	0	0	0	0	0	0	1	0
Common Snapping Turtle		12	7	0	0	2	0	4	3
Florida Softshell Turtle		1	0	4	0	1	0	3	0
Eastern Mud Turtle	male	3	0	0	0	0	0	0	0

During the summer of 2012, wherein 3 areas were each sampled for 1 month, we captured 35 turtles comprised of RES (88.5%) and Florida Softshell Turtles (11.5%) from site A. Site A had a diversity index of H' = 0.35, E = 0.51. We collected 79 turtles at Site B, which consisted of RES (95%), Common Snapping Turtles (3.8%), Florida Redbelly Turtles (0.1%), and Florida Softshell Turtles (0.1%). Site B had the lowest diversity index, H' = 0.25, E = 0.18. At site C, we captured 61 turtles with 6 species being present: RES (78.6%), Common Snapping Turtles (6.5%), Florida Softshell Turtles (4.9%), Chicken Turtles (4.9%), Florida Redbelly Turtles (3.2%), and Yellow-bellied Sliders (1.6%). Site C had the highest diversity index, H' = 0.84, E = 0.47.

We recaptured 12 RES (9 males, 3 females) outside of their initial capture location, which moved an average straight-line distance of 825 m (range = 500–1400 m). A single recaptured male Florida Redbelly Turtle moved 500 m from its initial location. Surprisingly, no other turtles were recaptured outside of their initial capture area in our study.

We found that 6 species nested on the uplands surrounding Lake Hollingsworth (Fig. 1; Table 2): RES (n = 78), Florida Redbelly Turtles (n = 14), Florida Softshell Turtles (n = 6), Yellow-bellied Sliders (n = 3), Common Snapping Turtles (n = 3), and Chicken Turtles (n = 2). We found that RES nested the closest to the shoreline (=8.4 m, range 0.3–35 m; Table 2) and Florida Redbelly Turtles the furthest (=142.2 m, range 23–313 m). In combination, our study found all other species nested at an intermediate range (=30.4 m, range 3–118 m), but a single Chicken Turtle that nested 440 m away was excluded as an outlier in this calculation. We recorded 21 total road-killed turtles:10 Florida Redbelly Turtles, 7 RES, 3 Eastern Mud Turtles, 2 Florida Softshell Turtles, and 1 Common Snapping Turtle. We found Florida Redbelly Turtles were vulnerable to vehicular traffic when making nesting excursions, whereas RES and Yellow-bellied Turtles mitigated this risk by nesting near the shoreline (Fig. 2). We recorded an additional 6 turtles (3 Florida Redbelly Turtles, 2 Florida Softshell Turtles, 1 Common Snapping Turtle) struck by vehicles that survived with apparent minor injuries. All road-killed turtles that we found were female, except for 1 young male RES that we found after a heavy summer rain attempting to cross the road near the small creek that flows out of Lake Hollingsworth.

Discussion

Our study provides the first survey of an urban turtle assemblage in a central Florida lake, a common habitat for turtles in rapidly urbanizing Florida. While we do not have capture numbers from D. Lee's baseline survey of turtles in Lake Hollingsworth from the 1960s,

Table 2. Parameters recorded from the nesting and roadkill survey of uplands directly adjacent to Lake Hollingsworth, Florida from February – October in 2013 and 2014.

Species	Number nests	Mean Nest distance (range) from shoreline (m)	Nesting Period	Number gravid females road-killed
Red-eared Slider	78	8.4 (0.5–18.5)	Feb–Oct.	6
Florida Redbelly Turtle	14	142.2 (15.5–313)	May–August	10
Florida Softshell Turtle	6	24.7 (3–83)	Feb.–August	2
Yellow-bellied Slider	3	8.6 (5–12)	Mar.–August	0
Common Snapping Turtle	3	56.3 (11.5–118)	April–May	1
Chicken Turtle	2	440 and 105	July	0
Eastern Mud Turtle	0	–	–	3

the rank abundance he recorded differed from our survey. Notable differences included the replacement of Florida Redbelly Turtles with RES as the most common turtle in the lake and the absence of the Florida Cooter and Common Musk Turtle, which we have not captured in the lake in 9 years (2010-2019) of trapping using a variety of methods (G. Langford, Florida Southern College, Lakeland, FL, 2019 unpubl. data.). In general, the Common Musk Turtle is considered a hardy turtle that is common to abundant in favorable habitat (Meylan 2006), such as the muddy-bottomed Lake Hollingsworth, whereas the Florida Cooter is known to inhabit slow moving rivers and larger lakes with muddy bottoms (Ernst et al. 1994). While neither turtle appeared to be common in Lee's survey, their absence in our study was unexpected. We suggest that a combination of factors precipitated the decline of native turtles in Lake Hollingsworth, specifically roadway traffic, habitat alteration, competition from RES, and over-collecting.

When compared to previous surveys of Florida waterbodies (Chapin and Meylan 2011, Johnston et al. 2011, Witzell 1999), the wetland along Lake Hollingsworth's north shore hosts a comparable number of native turtle species. Our 2-year sampling effort in the wetland found 5 native species of turtles and 2 non-native slider subspecies, yet the sliders represented 75.6% of all turtles captured in the wetland. When our collection revealed that the wetland was dominated by non-native slider turtles, we became curious if Lake Hollingsworth hosted a similar assemblage. The wetland does not reflect the shoreline habitat found around the lake; instead the wetland provides a small, managed habitat, e.g., native plant plantings, calmer waters, increased basking locations. Given the habitat and sampling differences, we have not included our wetland sampling in our discussion of Lake Hollingsworth's shoreline turtle assemblage. When the Lake Hollingsworth shoreline is divided into 3 sections, according to urban density, we found that the least developed section (site C) of the lake hosted the highest diversity, with RES representing a relatively low percentage (79.4%) of captures. In opposition, the shoreline with the most urbanization, site A, hosted the least diverse turtle assemblage when compared to sites B and C. The Florida Softshell

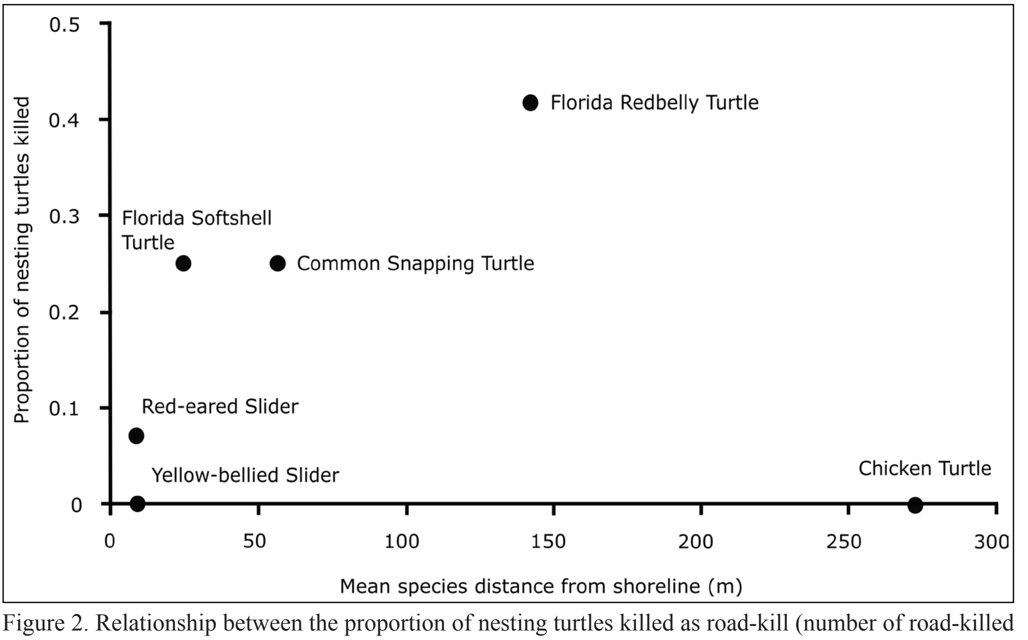

Figure 2. Relationship between the proportion of nesting turtles killed as road-kill (number of road-killed females/(number of nests + number of road-killed females)) and average female nesting distance around Lake Hollingsworth, Florida.

Turtle was the only native turtle we collected at site A, with RES accounting for 96.5% of captures in this area. Overall, the turtle diversity in Lake Hollingsworth was less than the adjacent wetland, and all 3 areas of the lake hosted a greater percentage of RES compared to the wetland. When compared to the wetland, we had expected Lake Hollingsworth to host a greater diversity and abundance of native turtles because of its greater size and Lee's previous sampling. Likewise, we had not anticipated the high proportion of RES captured in our study. Our finding isn't without precedent, as invasive RES are known to outcompete or otherwise dominate native turtles in many parts of the RES non-native range (e.g., Cadi and Joly 2004, Lambert et al. 2019, Witzell 1999).

Previous studies have found that roads negatively impact nearby turtle populations (de-Catanzaro and Chow-Fraser 2010, Gibbs and Shriver 2002, Marchand and Litvaitis 2004, Wood and Herlands, 1997). For example, in the Florida panhandle, Aresco (2005) found that few turtles could successfully cross a highway separating two lakes. While traffic on our roadway is not comparable to a busy highway, the road is well-travelled and it encircles Lake Hollingsworth at a close proximity, thus forcing turtles to interact with road traffic and pedestrians on a multi-use path. Excluding slider turtles, all turtle species in our study primarily nested after crossing Lake Hollingsworth Drive, in lieu of nesting in the narrow margin of grass between the shoreline and road. On average, Florida Redbelly Turtles and Chicken Turtles travelled the farthest from the lake and frequently crossed more than one road. For example, one female Florida Redbelly Turtle walked down the middle of a side street for ~150m and crossed 2 intersections. She avoided being struck by a car because a group of FSC students escorted her to nest 313m from the shoreline.

In our opinion, avoidance of the roadway by slider turtles during nesting ventures may be the single largest factor permitting RES to dominate Lake Hollingsworth's turtle assemblage. Turtle species in our study are known to produce up to 2-3 clutches in a single reproductive season (Ernst et al. 1994), thus each native female may cross a busy roadway up to 6 times a year, and hatchlings must cross the roadway within hours of emerging from the nest. Most turtles are characterized by slow growth and low levels of recruitment; therefore even small increases in mortality of reproductive females or the reduction of already naturally low recruitment rates can cause population declines in turtle populations (Brooks et al. 1991, Congdon et al. 1993). While further study is needed on nesting success at our site, we suggest that recruitment is low at Lake Hollingsworth for native emydid turtles. In support, during hoop traps surveys, we captured juvenile RES, Florida Softshell Turtles, and Common Snapping Turtles, but only large adult Florida Redbelly Turtles and Chicken Turtles. Overall, our data suggest that RES avoid roadways and thus are at reduced risk of becoming road-kill, which likely provides RES an advantage over native species, such as other emydid turtles that compete for resources in impaired waterbodies.

In Pennsylvania, Pearson et al. (2015) found that the endangered *Pseudemys rubriventris* LeConte (Northern Red-bellied Turtle) and invasive RES partitioned resources in natural waterbodies, whereas RES were a superior competitor in smaller, impaired wetlands. Pearson et al. (2015) suggested that niche overlap in small, less diverse wetlands would negatively impact native emydid turtles and lead to long-term population declines. In south Florida, populations of RES rivaled those of the Florida Redbelly Turtle in urban man-made ponds (Witzell 1999). Our results support these findings, as RES have replaced Florida Redbelly Turtles as the most common turtle in our impaired urban lake, although we did not study competition or resource partitioning.

Additional threats from urbanization at Lake Hollingsworth include frequent lawn care that may impact nesting activities by limiting natural cover for nesting turtles and hatchlings. Likewise, removal of overhanging trees and branches from the lake reduces natural basking and shelter opportunities. Such intensive management practices may limit turtle abundances because they impact the terrestrial buffer zone and natural shoreline that presumably permits normal turtle behavior. Ryan et al. (2008) found a positive association between wooded buffer zones and turtle abundance. However, Elston et al. (2016) suggested that only the presence of a buffer was important, noting that the buffer's composition, e.g., woods vs. grasses, was not important. Elston et al. (2016) also found that turtles did not need to directly enter the buffer to benefit from its presence. Our results support the positive association between buffer zones and native turtles. We found the highest abundance of native turtles in Lake Hollingsworth while trapping along the area with the largest buffer, which contained the highest density of trees and bushes (least urban – site C). While riparian buffers are frequently associated with positive outcomes for native turtles, buffers may have negative impacts, such as an increase in predator densities (Hygnstrom et al. 1994, Madge and Burn 1994). Landscapes with increased predators may facilitate nest discovery and result in reduced nesting success (Hygnstrom et al. 1994, Nelson et al. 2009). All nests dug by native turtles during our study were discovered by a predator, e.g., Fishing Crows, Boat-tailed Grackles, Raccoons, Cats, before we left the nesting site, despite our efforts to avoid attracting attention to the nests.

Overharvesting is a major threat to turtle populations worldwide (Gibbons et al. 2000). In our study, the impact of poaching is difficult to separate from road casualties because both threats primarily eliminate large reproductive females from the population. At the least, collecting native turtles from Lake Hollingsworth likely has exacerbated turtle declines, as has been seen in other Florida lakes and streams (Heinrich et al. 2010). Indeed, despite the Florida-wide ban on collecting *Pseudemys* turtles, we witnessed a fisherman poaching 2 large Florida Redbelly Turtles during this study. We suggest that even minimal poaching may accelerate the extirpation of Florida Redbelly Turtles given their current low numbers in the lake.

During our survey, we noted 14 RES with shared characteristics between RES and Yellow-bellied Sliders that strongly suggested introgression between these subspecies. It is not clear whether introgression in *Trachemys* subspecies confers a fitness benefit, such as hybrid vigor, but it may be a factor in RES success in Lake Hollingsworth. Historically, 3 subspecies have been recognized in *Trachemys scripta*: *T. s. elegans*, *T. s. scripta*, and *T. s. troostii*. Recent molecular evidence suggests that *T. s. troostii* is a result of natural admixture between the former two subspecies and should not be recognized as a subspecies (Parham et al. 2020). Parham et al. (2020) also found evidence of anthropogenically created, e.g., turtle farms, hybrids between RES and Yellow-bellied Sliders. Thus, it is possible that the original slider turtles released into Lake Hollingsworth were hybrids of the two subspecies. Nevertheless, the vast majority of slider turtles captured easily conformed to the phenotype of RES. Without the use of genetic markers it is impossible to determine the degree of introgression that has occurred in this non-native population.

When properly monitored and managed, some turtle species can rebound and persist in urban or otherwise inhospitable habitat (Ryan et al. 2008, Spinks et al. 2003), through mechanisms such as removing non-native species (Lambert et al. 2019, Spinks et al. 2003), habitat improvements (Lambert et al. 2013, Somers 2000, Spinks et al. 2003), re-introductions (Mignet et al. 2014), reducing adult mortality (Congdon et al. 1993, Langen et al. 2012), and head-starting programs (Green 2015, Nelson et al. 2009, Spinks et al. 2003). Removal of RES would be a possible aspect of a mitigation plan at Lake Hollingsworth (see Lambert et al. 2019), but this would be a difficult and potentially costly endeavor (Ewel and Putz 2004).

Furthermore, removal of RES would not solve road mortality, lack of basking spots, and poaching issues that impact our native turtles. Turtle nesting locations are not concentrated enough to permit a single, focused wildlife crossing around Lake Hollingsworth (see Langen et al. 2012). Although a series of wildlife crossings with directional fencing, culverts, and turtle crossing signs in high crossing zones around the lake would likely direct many native turtles across the road to nest safely (Aresco 2005, Langen et al. 2012). Residents could be educated on turtle nesting and taught to use simple predator exclusion cages over turtle nests, such as those used in a campground lawn (Nelson et al. 2009). By reducing roadway deaths, educating residents, and protecting nests from predators, native turtle species may be able to naturally replenish their populations. We hope this study brings attention to Florida's numerous urban wetlands that host turtles, and we encourage basic and applied research on these turtle assemblages.

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