Natural History Traits and Ecology of the Striped Mud Turtle in a Florida Wetland

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Abstract - The ecology of *Kinosternon baurii* (Striped Mud Turtle) has been studied in only a few locations within its range, which means we do not have baseline data to understand the ecology of this species. Further, no studies have been conducted on Striped Mud Turtles in restored wetlands, which are increasingly common in Florida landscapes and across the globe. Comparing populations in restored habitats to natural habitats could give insight into restoration success that focuses on supporting robust semi-aquatic turtle populations. We conducted a mark–recapture study at a restored wetland in Circle B Bar Reserve, in Polk County, FL, to assess the population size, sex ratios and morphometrics of the Striped Mud Turtle. We found a population estimate of 90 adults, from over 2849 checked trap nights over 2 years. Previous studies in natural habitats found larger populations of Striped Mud Turtles. Our morphometric data is similar to others in central and south Florida but adds to the conclusion that habitat variation can impact size variation of Striped Mud Turtles. In our population, we had more females than males (68.8% females), which appears to be consistent for Striped Mud Turtles in most other study sites. Overall, our study provides additional knowledge on the ecology, population size, and morphometrics of Striped Mud Turtles, which local reserve managers can use to better understand the turtles, especially in restored habitats.

Introduction

The goal of restoration ecology is to actively repair degraded habitats to allow organisms to thrive in human-impacted areas (Dudley et al. 2015, Marchand and Litvaitis 2004, Reid et al. 2016). Presumably, the recent increase in restored habitats and interest in restoration ecology has resulted in an increase in functional ecosystems; however, it is unclear how different types of organisms respond to restored areas (Dudley et al. 2015, Jähnig et al. 2011). Without knowledge of an organism's ecology, population sizes, movement, and habitat preferences, assessing their response to restoration efforts may be difficult (Dudley et al. 2015, Marchand and Litvaitis 2004). Yet, for many turtle species, we lack sufficient background data to formulate restoration plans for conservation (Ernst and Lovich 2009, Ernst et al. 1994). Because turtle populations are in decline (Christiansen et al. 2012, Gibbons et al. 2000, Lovich et al. 2018), we need to gather basic reference data, such as regarding population sizes, sexual dimorphism, movement, and morphometrics. This

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natural history information is critical for making conservation decisions including those involving habitat restoration (Dudley et al. 2015, Harden et al. 2009, Marchand and Litvaitis 2004).

Kinosternon (mud turtles) are charismatic small to medium-sized freshwater turtles whose ecology has not been extensively studied. The family Kinosternidae includes 26 species within 4 extant genera and is from Canada to Argentina (Meylan 2006, Rhodin et al. 2017). Mud turtles are semi-aquatic in nature and primarily consume invertebrates and small fishes (Ernst et al. 1994). Though species of *Kinosternon* in Florida are considered stable and of least conservation concern by the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, some populations are susceptible to the same threats that other turtle species face, primarily habitat loss (Turtle Taxonomy Working Group 2017). Florida is becoming increasingly urbanized, fragmenting or destroying entirely many turtle habitats (Wilson et al. 2006). These threats make it imperative to learn more about the natural history and population sizes of these turtles (Harden et al. 2009, Marchand and Litvaitis 2004) as well as their ability to reside in restored habitats (Harden et al. 2009, Wilson et al. 2006).

Kinosternon baurii (Garman) (Striped Mud Turtle) is a small turtle that ranges in the Eastern United States from Virginia to the Florida Keys (Ernst et al. 1994, Wilson et al. 2006). Even among *Kinosternon* spp., it is a relatively understudied species, especially in the southern part of its range (Ernst and Lovich 2009, Wilson et al. 2006). Wygoda (1979) found that Striped Mud Turtles in west-central Florida prefer still water and may estivate during the summer when their wetland dries up, agreeing with Carr's (1952) observations. Additionally, Wygoda found they spend a substantial amount of time on land when aquatic areas are limited. Ernst et al. (1972) in south Florida found that they inhabit flowing water with a depth greater than 24 inches and do not estivate. Habitat requirements are unknown for hatchlings/juveniles in any part of their range (Wilson et al. 2006). In southern latitudes, it is documented that Striped Mud Turtles may compensate for their relatively small clutches (average = 2.7 eggs) by extending their nesting seasons to have a peak season in the fall with a smaller peak in nesting in June, where females may lay multiple clutches a year (Mushinsky and Wilson 1992, Wilson et al. 1999). Wilson et al. (2006) stated that many studies focus on reproductive females and that more research must be done on other aspects of their biology to fully understand their natural history. Previous studies on Striped Mud Turtles in Florida have not focused on the center of the state, and none of the previous studies have been conducted on restored lands (Dunson 1981, Ernst et al. 1972, Johnston et al. 2019, Meshaka and Blind 2001, Mushinsky and Wilson 1992, Wilson et al. 1999, Wygoda 1979).

Striped Mud Turtles require wetlands and uplands (uplands are used for nesting and possibly estivation). Thus, they exemplify the need to conserve wetlands and their surrounding upland habitats for turtle conservation (Buhlmann and Gibbons 2001; E.D. McCoy and H.R. Mushinsky, University of South Florida, Tampa, FL, unpubl. report; Wilson et al 2006). Restoring upland and wetland habitats benefits many species (Bowne et al. 2006, Harden et al. 2009, Reid et al. 2016), and both habitats should be considered during restoration and assessment to support all turtle life stages (Bowne et al. 2006, Harden et al. 2009). However, once restorations are completed, assessments of how native species respond are not normally well-documented (Block et al. 2001, Dudley et al. 2015, Jähnig et al. 2011). Restored lands are inherently different from natural and urban areas; thus, turtles may respond to or use such lands differently (Dudley et al. 2015, Reid et al. 2016).

We completed a 2-year study to examine the ecology and natural history traits of Striped Mud Turtles to help advance our knowledge of their morphometrics, sexual dimorphism, nesting periods, and population size in a restored central Florida former cattle ranch. Our study provides a better understanding of the species' natural history and ecology in an ecologically restored Florida habitat and provides insight for future management plans of recovering turtle populations in restored areas.

Field-site Description

We conducted our study at Circle B Bar Reserve (CBR), a restored former cattle ranch adjacent to Lake Hancock in Polk County, FL. CBR consists of 512.7 ha of land that is comprised of permanent marsh, semi-permanent wetlands, and upland habitat (Figs. 1, 2). Initial restoration of the reserve began in 2004 (T.Biehl, CBR, FL, pers. comm.). It was flooded to restore semi-permanent and permanent wetlands by destroying some man-made levees and installing large culverts to facilitate and mimic former water flow. Restoration of the hydrology was completed in 2006.

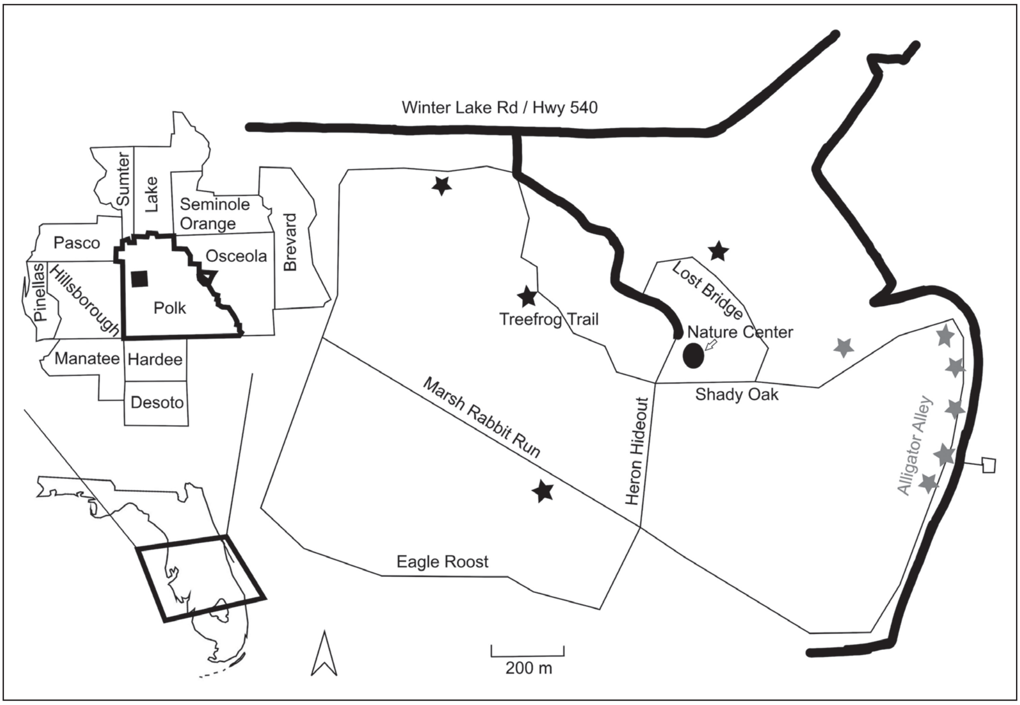

Figure 1. Map of Circle B Bar Reserve, its trails, our trapping locations, and the location of the Reserve in relation to Florida and Florida counties. The stars represent the trapping locations, with the main locations marked with in light gray.

Since this hydrologic restoration period, native plants have been added, invasive plants (Caesar Weed and Brazilian Pepper) have been continuously removed, and prescribed fire has been used as a management tool in the uplands (off of Eagle's Roost trail in Fig. 1). Our study site was a canal (Figs. 1, 2) that runs parallel to the lake. This canal is ~2 km from the nearest substantial upland habitat, through grassland and semi-permanent marsh (see Eagle's Roost trail in Figs. 1, 2). On the opposite side of the canal from the trail, there is semi-permanent wetland that extends around 400 m past the trail. Parts of the wetlands dry up occasionally in times of drought or the during the dry season (October–May), but often flood June–September. From October 2016 through mid-June 2017 a drought occurred, resulting in permanent water bodies becoming dry, except for Lake Hancock.

We sampled representative plant species to establish the composition of the habitat around and in the canal, which indicates the status of the restoration at CBR. Tree species in the study area included *Taxodium distichum* (L.) Rich. (Bald Cypress), *Sabal palmetto* (Walter) Lodd. ex Schult. & Schult. f. (Cabbage Palm), *Quercus virginiana* Mill. (Live Oak), *Taxodium ascendens* Brongn. (Pond Cypress), *Celtis laevigata* Willd. (Sugar Hackberry), *Morus rubra* L. (Red Mulberry), *Fraxius* spp.(ash), and *Ulmus rubra* Muhl. (Slippery Elm). We found the dominant ground cover to be *Bidens alba* (L.) DC. (Beggarticks), *Panicum repens* L. (Torpedo Grass), *Sambucus* spp. (elderberry), *Oplismenus* spp. (basket grass), *Toxicodendron radicans* (L.) Kuntze (Poison Ivy), *Phytolacca decondra* L'Her. (Poke Weed) and *Parthenocissus quinquefolia* (L.) Planch. (Virginia Creeper).

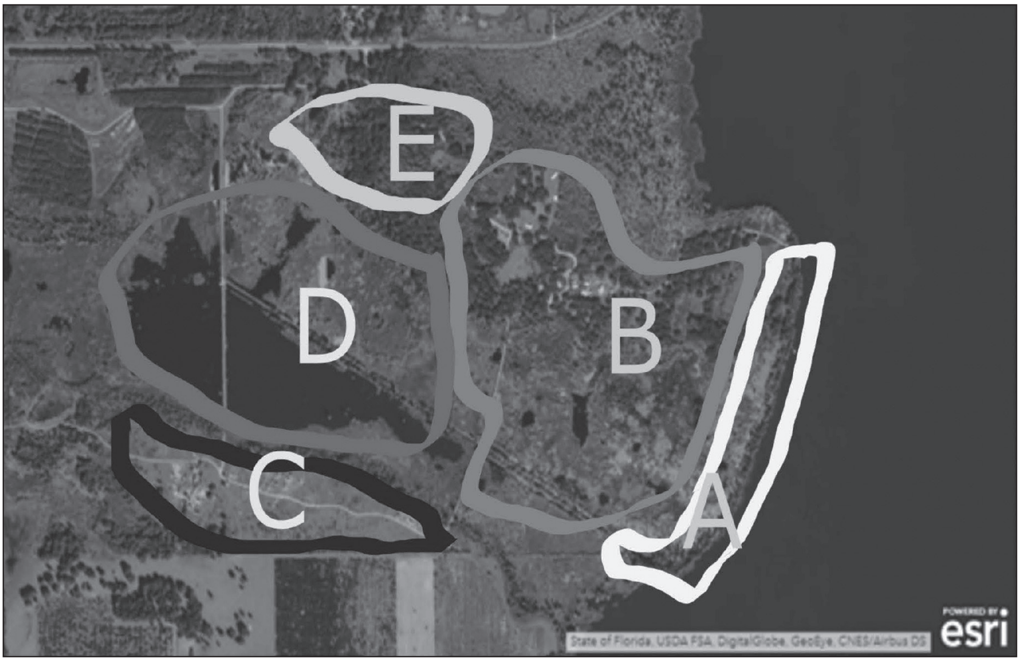

Figure 2. Habitat types of CBR. Area A is the main canal where we primarily sampled. Area B is semi-permanent wetlands where some trapping was done. Area C is upland habitat. Area D is an area of permanent wetlands. Area E is grassland area.

Dominant aquatic vegetation included *Thalia geniculata* L. (Fire-flag), *Lemna* spp. (duckweed), *Amaranthus* spp. (pigweed), *Pantederia cordata* L. (Pickerelweed), and *Colocasia esculenta* (L.) Schott (Wild Taro). These plants are all indicative of a well-restored Florida wetland (Nelson 1996, Petrides and Wehr 1998) and have been associated with Striped Mud Turtles in undisturbed habitats (Mushinsky and Wilson 1992, Wygoda 1979). The presence of native wetland plants and the absence of aggressively invasive plants suggests that this habitat is well-restored.

Methods

Mark–recapture

We began trapping Striped Mud Turtles in October 2015 and finished trapping in October 2017. We built modified box-like minnow traps (39 cm x 36 cm x 29 cm) with a ramp for turtles to walk up, similar to those used by Karl and Wilson (2001). In the preliminary part of the study, we tested a variety of commercially available traps, such as mesh minnow traps, but traps constructed by hand to fit mud turtle specifications maximized catch efficiency. We did not consider visual searches to be a viable option because no individuals were found during attempts while searching land and aquatic habitats. For similar studies, hoop traps have been used (Ceballos et al. 2016, Harden et al. 2009, Ligon and Stone 2003, Van Loben Sels et al. 1997); however, they are not a viable option at CBR due to the abundant alligator population that has destroyed previous hoop traps (G.J. Langford, pers. observ.). We began trapping across the entire aquatic portion of the reserve but had the highest trap success along a well-restored area in the reserve called Alligator Alley (Fig. 1), which is a shallow canal of still water. We set out 8–32 traps at a time. We removed traps only during flooding events (e.g., Hurricane Matthew, Hurricane Irma) and for most of December 2016. We baited traps with sardines and/or bologna 1 or 2 times per week and checked them 3 or 4 times per week. We marked all turtles, except 2 hatchlings, with unique notches on their marginal scutes by using a triangular file according to the numbering system standard for Florida Fish and Wildlife Conservation Commission protocol of notching Gopher Tortoises from 2013.

Natural history traits

We took morphometrics with a caliper (SPi 2000; Swiss Precision Instruments, Melville, NY) upon capture/recapture that included carapace length (CL), width, and height as well as plastron segments, to an accuracy of 0.002 cm. The measurements followed the process detailed by Hutchison and Bramble (1981) and used by Lamb and Lovich (1990). We obtained turtle mass, to the nearest gram, with Pesola scales (#40300 and #10100; Schindellegi, Switzerland) with a maximum capacity of either 100 g (accurate to 1 g) or 300 g (accurate to 2 g). If turtles were over or very close to 100 g, we used the larger scale. During the study, we recorded general notes on health, including presence of leeches, malformations, and physical injuries. We sexed adult turtles by assessing size and tail length (Ernst et al. 1994, Iverson 1978), and we palpated female turtles when they were caught to determine if they were gravid. Throughout the study, we took general notes on habitat disturbances, such as evidence of *Sus scrofa* L. (Pig) and *Procyon lotor* (L.) (Raccoon) digging through turtle nests.

Statistical analysis

To determine if size differed by sex, we performed a Mann–Whitney U test on CL and weight of males vs. females. All values are reported as means ± standard deviation. We used a chi-square test to determine if the sex ratio differed from 1:1. We calculated the number of trap nights (1 trap open/night = 1 trap night) for the study and per each season to compare the number of turtles caught vs. trap effort. We used MiniTab 18 (Minitab LLC, State College, PA) and Microsoft Excel (2005; Redmond, WA) for statistical analyses ($\alpha = 0.05$). Lastly, we used the Program MARK (Version 9.0; http://www.phidot.org/software/mark/) with an open-population Jolly–Seber (JS) model and a sin function to find an estimated population size for the main study site, as an opened population. We used a POPAN option of the JS with sin as the link function. We used a JS model because it has increased chance for a smaller standard error and confidence interval for open populations and is often used for estimating turtle population sizes (Hensley et al. 2010, Howell et al. 2020, Lindeman 1990). For t (capture occasions), the model provides N (population size estimate). In addition to N, we used parameters φ (apparent survival), p (capture/recapture probability), and *pent* (probability of entry). Parameters were constrained with the parameter index matrix. We considered a candidate set of all 16 possible models for the POPAN formulation, but some models never converged. Other estimates are not developed under the Jolly–Seber model (White and Burnham 1999) using mark–capture framework because estimating survivorship parameters was not a central aim of the study. We used the likelihood-corrected form of the Akaike information criterion (AICc) to evaluate relative support for candidate models and provide model-averaged estimates of population size from the 4 models that converged (Burnham and Anderson 2002). Additionally, we used MARK with RELEASE TEST 2+3 as a goodness-of-fit test to examine the overall fit of the global model to the data. We used model averaging to combine the 4 most parsimonious models.

Results

Mark–recapture

Trapping effort in the main canal at Alligator Alley totaled 2849 checked trap nights over the 2-yr span. We caught 32 unique Striped Mud Turtles in the main study site, while the population size was estimated to be 89.74 individuals using the program MARK and a JS POPAN model (SE ± 25.50, 95% CI [39.74, 139.73]). We performed a goodness-of-fit test using MARK with RELEASE, which indicated that this model fit the data reasonably well with no model assumptions violated. A comparison of the numbers of turtles caught in our study versus other studies is presented in Table 1.

During the study, we captured 2 hatchlings and 4 juveniles in the traps. We had a total of 58 captures (when recaptures are considered). In addition to our species

Table 1. Comparision of number of mud turtles captured and morphometrics by sex in Florida. CL = carapace length, SD = standard. Sites abbreivations: SFR = Santa Fe River, FL; QHGC = Quail Heights Golf Course, FL; SFC = Santa Fe College, FL; SEV = Southeast Virginia; and VBCF = Virginia Beach County, FL. NA = not appllicable, NR = not reported

Location	Size (m^2)	Years	Turtles caught	Recaptures	Females caught	Female mean CL ± SD and/or (min–max) (mm)	Males caught	Male mean CL ± SD and/or (min–max) (mm)
CBR (this study)	11,100	2	32	58	22	93.8 ± 8.6	10	83.0 ± 7.1
West-central Florida (Wygoda 1979)	2500	1	67	157	44	93.5 (73.4–115)	22	83.4 (73.2– 98.1)
West-central Florida (Mushinsky and Wilson 1992)	120-m drift fentce	6	127	NA	127	98.2 ± 0.9	0	NA
West-central Florida (Wilson et al. 1999).	1490-m drift fence	4.5	515	1557	497	98.8 ± 6.2	NR	NR
SFR (Johnston et al. 2019)	NA	NA	97	NA	57	103.5 (86–125)	40	94.7 (81–110)
QGHC (Johsnton et al. 2019)	NA	NA	83	NA	58	93.0 (74–110)	25	88.5 (77–97)
SFC (Johnston et al. 2019)	NA	NA	51	NA	33	93.3 (75–116)	18	86.2 (74–102)
SEV (Johnson et al. 2019)	NA	NA	64	NA	17	109.6 (82.6–122)	46	90.6 (75.6–114.7)
VBCF (Johnson et al. 2019)	NA	NA	82	NA	31	95.7 (70.2–111.1)	51	87.1 (71.1–101.5)
Everglades (Meshaka and Blind 2001)	15-km road	2	35	NA	25	89.0 ± 7.0 (77–107)	10	77.2 ± 10.6 (50–90)

of interest, we also captured 1 juvenile *Apalone ferox* (Schneider) (Florida Softshell Turtle) as well as 3 *Sternotherus odoratus* (Latreille in Sonnini and Latreille) (Common Musk Turtle).

Natural history traits

Along Alligator Alley, we found more females than males (22:10); this ratio was statistically different from unity ($\chi^2 = 4.5$, df = 1, $P = 0.03$, $n = 32$) (Table 1). Female CL was significantly longer than male CL (U = 28.5, $P = 0.0008$; $n = 32$). Females had a mass 1.5 times that of males (U = 38, $P = 0.005$, $n = 32$; male mean weight ± SD: 101 ± 18.7 g, female mean weight ± SD: 153.5 ± 41.8 g). Our 2 hatchlings had a CL of 28.1 mm and 30.2 mm, respectively. In September 2016, we confirmed 2 gravid females (by palpation), as well as 1 individual each in November 2016 (confirmed by witnessing nesting on 30 of November 2016), March 2017, April 2017, and May 2017. We found predated nests and Raccoon prints near turtle activity mostly from September to January. We found turtle health to be generally good, as they had clear eyes, energetic movements, and undamaged bodies.

Discussion

Our study is the first to investigate the ecology and natural history traits of Striped Mud Turtles in a restored habitat as well as to the first study in central Florida to record the natural history traits of both males and females of the species. Overall, we found slightly smaller population numbers when compared to other studies (Mushinsky and Wilson 1992, Wilson et al. 1999, Wygoda 1979), but the morphology of our primary population conformed to previous studies (Ersnt et al. 1994, Iverson 1978, Wilson et al. 1999, Wygoda et al. 1979). Our study reinforced the idea of wetlands having female-biased sex ratios for Striped Mud Turtles in central Florida (Wygoda et al. 1979). In addition, our study provides unique notes on the nesting periods and habitat preferences of Striped Mud Turtles in a recently restored area. Comparing data from restored areas to natural areas can be important for future management plans (Dudley et al. 2015, Jähnig et al. 2011). As management strategies are modified, for turtles or other species of concern, our baseline data can be used to measure how Striped Mud Turtles respond to the restoration.

Our trapping was quite extensive and focused on an 11,100-m^2 area of canal and restored semi-permanent wetland (Alligator Alley; Fig. 1). Using the program MARK, we found an estimated population size of 89.7 individuals. The previous Florida studies showed a slightly larger number of captures of Striped Mud Turtles (Table 1), when the time frame and area of the sites are considered. Additionally, these studies did not calculate mark–recapture estimates from their data, which would presumably predict an even larger population. Similarly, we were unable to compare to populations recently sampled in Northern Florida because that study did not report recapture numbers or area sampled (Johnston et al. 2019). Further studies should be done, such as comparing historical data from undisturbed habitats to current restored habitats, to determine if restored habitats are able to support robust populations of Striped Mud Turtles in central Florida. The population sizes of Striped Mud Turtles might be relatable to other species of turtles also residing in the reserve. It is possible, because of low amounts of suitable nesting habitat, that CBR is not able to support larger populations of small turtles. Larger turtles, however, often have a greater ability to move further (with less risk of being eaten or desiccating), so they probably have a higher nesting success rate at the reserve than small-bodied Striped Mud Turtles (Eubanks et al. 2003, Murphy et al. 2016, Steen et al. 2012, Stemle et al. 2019). Alternatively, surveys should be conducted to see if the wetlands within the numerous sandhills of central Florida, in general, support smaller populations when compared to low-elevation sites along coastal central Florida. It is promising that varying age ranges were found during the study; we assume that the population has regular, but low recruitment, which is not unexpected for a reestablished population (Reid et al. 2016). Also of note, we did not capture *Kinosternon subrubrum* (Bonnaterre) (Eastern Mud Turtle) during this study, despite being within the expected range of the Eastern Mud Turtle (Ernst et al. 1994). We attribute this to the difference in habitat preferences of the 2 species (Ernst et al. 1972), although it is possible Eastern Mud Turtles used to occur at our sampling site.

We found average CL for female and male Striped Mud Turtles to be consistent with the values reported in the study by Wygoda (1979)—93.5 mm for females and 83.4 mm for males. Our population's morphometrics were also similar to those of other studies of Striped Mud Turtles in Florida and Virginia (Johnston et al. 2019, Wilson et al. 1999; Table 1). Our finding of greater CL and mass for females corresponds with other Florida studies reporting on sexual size dimorphism for the species (Carr 1952, Ersnt et al. 1994, Iverson 1978). However, Johnston et al. (2019) reported generally larger sizes for males or females in some study locations but not others in Virginia and Florida, yet in general found sexual size dimorphism for the species, consistent with previous studies. Johnston et al. (2019) also pooled his findings with previously published data and found that there does not appear to be a geographic cline in size, but the authors suggested variation in local habitats results in morphometric discrepancies across sites. Moreover, the mean mass of females in our study (153.5 ± 41.8) was somewhat less than those found in west-central Florida (171.5 ± 31.2 g; Wilson et al. 1991). We found significantly more females than males, which aligns with Wygoda (1979), who found a female-biased (2:1) sex ratio in nearby Hillsborough County. Indeed, most studies, but not all, collected more females than males (Table 1).

In the fall of both years, we found 6 gravid females, whereas we found only 1 gravid female during any spring. Striped Mud Turtles usually avoid nesting during July and August, the hottest months in Florida (Wilson et al. 1999). The timing of nesting found during our study supports previous suggestions that Striped Mud Turtles have a peak nesting season in the fall in central Florida, with a smaller secondary nesting season in summer (Mushinsky and Wilson 1992, Wilson et al. 1999). Mud turtles in our study nested along the sandy levee trail that follows the length of the primary wetland, and we have observed many reptile nests on the levee, including Striped Mud Turtles. The trail along the main study sites was the primary elevated area other than upland habitat that was about 2 km away (see Figs. 1, 2). During our observations, we noted that ideal nesting habitat is sparse near our main study site, which may cause low recruitment. Although possible, it does not appear mud turtles were moving the 2 km to the other upland habitat to nest (Stemle et al. 2019); the levee trail is the only confirmed nesting area and appears to be the main nesting area for these turtles. The levee could serve as an ecological trap for these turtles (see Aresco 2005) because egg predators, such as Raccoons, seem to be drawn to the trail by human activity and a concentrated number of reptile nests. Nest predators in the area (observed in this study through depredated nests, tracks, or visual identification) should be studied to monitor nest depredation and hatchling survivorship in restored areas. As Florida's landscapes become increasingly urban and fragmented, predator populations are likely increasing (e.g., human-subsidized predators), and future research should be done to see if turtle populations are impacted (Harden et al. 2009). Indeed, increased vulnerability of nesting females and mate-searching males in urban and fragmented areas has been observed in other turtle species (Aresco 2005, Iglay et al. 2007). Even in protected habitats, increased predation could lead to a lower survivorship of Striped Mud Turtles, potentially hampering hatchling recruitment and juvenile survival to adulthood. Consequently, managers of restored areas may contemplate constructing supplementary nesting habitat to strengthen recruitment (Reid et al. 2016) and reflect upon the behavioral patterns and needs of the wildlife present (Bowne et al. 2006, Harden et al. 2009).

When compared to previous studies within more natural habitats in Florida, the population numbers at CBR are not as robust (Mushinsky and Wilson 1992, Wilson et al. 1999, Wygoda 1979). Turtles have slow population growth and are vulnerable to extirpation because of characteristics such as delayed sexual maturity (Congdon et al. 1993, Ernst et al. 1994). Thus, the Striped Mud Turtle population may take decades to reach higher population density after experiencing disturbances (Harden et al. 2009). In this study, we only found 4 juveniles and 2 hatchlings in 2 years of sampling, but some trapping methods are biased to catching younger age classes (Ream and Ream 1966). The possible bias of the trapping method we used has not been determined (Chandler et al. 2017, Karl and Wilson 2001). Population numbers, including recruitment, should be monitored to deduce if action should be taken. Fostering a better habitat, with continued restoration efforts, may suffice to bolster recruitment (Reid et al. 2016). With further attention to restoring habitats, such as adding supplementary nesting areas, a robust mud turtle population may be feasible. For example, Dudley et al. (2015) found that turtle abundance at restored sites was more than twice that of their reference/control sites. We are hopeful that the reestablished natural hydrology and resulting landscape is suitable for the turtles, although follow-up studies will be needed to confirm our assumption that the turtle population is currently rebounding.

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