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Population Demography, Spatial Ecology, and Habitat Use of the Florida Box Turtle (Terrapene bauri) on a Barrier Island

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Population Demography, Spatial Ecology, and Habitat Use of the Florida Box Turtle (*Terrapene bauri*) on a Barrier Island

by

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ABSTRACT

Turtles are one the most threatened vertebrate groups in the world due to anthropogenic threats such as habitat loss and overexploitation. In addition to occupying a range that has been vulnerable to major habitat loss, the Florida box turtle (*Terrapene bauri*) is particularly at risk of overexploitation due to its popularity in the pet trade. Sanibel Island is a barrier island in southwest Florida that has experienced major habitat loss and is the site of a recent poaching event. In response to these threats, studies of both the population demography and spatial ecology were conducted on Sanibel's Florida box turtle population, with the goal of informing management for the conservation of the population. Mark-recapture methods were used to estimate population size, sex ratios, growth rates and age and size distributions, while radio-telemetry was used to determine home range size, movement patterns, and habitat use and how they vary between sex and seasons. Total population size was estimated to be 3015 turtles for the island with an adult sex ratio of 1.2:1 male: female. Turtle body size was noticeably larger than that for other Florida barrier island box turtle populations. Turtles were also larger in the central and west end of the island when compared to the more developed east end. Mean home range size in the present study was larger than those reported for other populations of box turtles. Home range sizes did not differ significantly between the sexes and seasons though there was a difference in habitat utilization between males and females across the seasons. These data provide valuable information for developing a conservation management plan by providing a baseline for future monitoring. They also provide life history and other ecological data for comparison to box turtle studies in other habitats and in other parts of their range.

CHAPTER I: INTRODUCTION

Biodiversity, or the variety of life, offers numerous benefits to natural systems such as minimizing the impact of climate change on communities (Shin et al. 2022), providing health benefits through lowering the risk of exposure to zoonotic diseases (Keesing & Ostfeld 2021), and improving human psychological well-being (Fuller et al. 2007). Though the benefits are well established, biodiversity loss presently is happening at an alarming rate, with some researchers suggesting that we are witnessing the beginning of a mass extinction event (Barnosky et al. 2011; Palombo 2021). Human-driven anthropogenic threats are the leading factors for this decline and include habitat loss, introduction of invasive species, overexploitation of species, pollution, and rapid climate change (Singh et al. 2021).

Within the coming decades, hundreds of thousands of species will be threatened with extinction due to these factors (Davies 2019). For example, amphibian populations across the globe are being ravaged by infectious diseases such as chytrid fungi and ranaviruses that are increasingly common because of climate change (Pabijan et al. 2020). Primates are considered one of the most threatened clades in the world currently with 65% of its species at least threatened from habitat destruction by logging and agriculture (Fernández et al. 2022). Rising temperatures and ocean levels from climate change present challenges for sea turtle populations across the globe (Maurer et al. 2021), but it is the freshwater and terrestrial turtle species in this group that face the greatest challenge out of all the groups of vertebrates (Rhodin et al 2018).

Turtle's (Testudines) first appeared in the fossil records around 220 million years ago (Stanford et al 2020). There are 14 different turtle families consisting of 365 species that span every continent across the globe except Antarctica, living in terrestrial, freshwater, and marine habitats (Stanford et al. 2020). Of all the currently recognized turtle species, 56% are at least threatened, with 35% being endangered or critically endangered, making turtles the second most threatened vertebrate group (Rhodin et al. 2018). Although all turtles are some of the most threatened species in the world, they are often overshadowed in the public and scientific community by charismatic megafauna such as primates and marine turtle species (Shah and Parsons 2019).

Turtles play a vital role in the ecosystems they inhabit by acting as the top predator, prey, or anything in-between; moreover, they can be important seed dispersers (Lovich et al. 2018). Turtles not only play a key role biologically, but they also provide an intrinsic value to humans as well. Almost every culture has ancient ties to turtles, with Hindu, Chinese, and Native American cultures all having a "world turtle", a celestial turtle that carries the world on its back, in their mythology (Tylor 1878). If turtles are to continue playing their roles in our ecosystems and culture, then the threats facing turtles must be addressed, specifically the greatest threats, which are habitat loss and overexploitation (Rhodin et al. 2018). These two threats are the most cause of concern because of the exceptional pressure they place on turtle populations due to turtles' high levels of site fidelity, reliance on adults surviving for extended periods of time, and diverse microhabitat requirements (Mitchell et al. 2016).

Box turtles (*Terrapene* spp.) are long-lived, mostly terrestrial turtles that have high site fidelity or small home ranges that they utilize their entire lives (Dodd 2002). With such high site fidelity, longstanding destruction of box turtle habitat lowers survival rates by increasing the rate of predation and mortality due to increased exposure to environmental factors (Mitchell et al. 2016). Box turtle populations rely on adults living to old ages and laying small clutches of eggs every year (Dodd 2002). The negative effects of adult individuals being poached is amplified because of this reproductive trait, devastating populations to a point where they may never recover (Stanford et al 2020).

With an increase in poaching, all *Terrapene* species since 1995 are listed as Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II species, suggesting that they are all at risk of extinction if the illegal trade is not closely monitored. In particular, the Florida Box Turtle (*Terrapene bauri*) has been targeted because of its brilliant coloring and patterns (Franklin and Killpack 2009), its smaller size compared to other species (Dodd and Griffey 2005), and its long lifespan of up to many decades (Dodd 2002). Moreover, they are advertised as pets that are relatively easy to care for, although it is quite the opposite for wild-caught individuals (De Vosjoli and Klingenberg 2012).

The Florida box turtle occurs state-wide in Florida and inhabits a small part of Georgia (Iverson and Etchberger 1989). The carapace length is typically under 155 mm (Dodd and Griffey 2005), making them one of the smaller box turtle species. On southwest Florida barrier islands, they use a diversity of habitats including palm-pepper/Australian-pine forests, coastal sea oats meadows, open beach, shrub fields, and open grass lawns in developed areas (Dodd et al. 1994). Florida box turtles are dietary generalists (Dodd 2002; Eversole et al. 2013; Klimstra and Newsome 1960), consuming plants, animals, fungi, and even inedible materials such as plastics (Lipps 2021). Females are gravid with shelled eggs from late March to early August and lay 1-3 clutches of 1-5 eggs, although there is still a large knowledge gap in their reproductive biology (Dodd 1997). Adults are considered critical to population health due to apparent high mortality levels in juveniles, hatchlings, and eggs (Dodd 2002). Once considered a sub-species of the Eastern Box Turtle (*Terrapene carolina carolina*), *T. bauri* was elevated to its own species (Butler et al. 2011). Though there initially was a lack of consensus about whether the Florida box turtle represented a unique species or was a subspecies (Martin et al. 2013), recent literature accepts T. bauri as the scientific name for this taxon, and that name is used in this thesis (Dodd et al. 2012; Jones et al. 2021; Loredo et al. 2022).

Aside from having desirable traits sought out by the pet trade, the Florida box turtle is also at risk because of habitat destruction and fragmentation that has already occurred at an extremely high rate in Florida (Hefty & Koprowski 2021). Moreover, population growth in Florida has increased by 14.6% (2.7 million) from 2010 to 2020, nearly double the growth rate of the United States overall (7.4%) (U.S. Census Bureau 2021). Rising sea levels from climate change will decrease available habitat in coastal areas (Bloetscher 2009) such as Florida, which has 8,436 miles of coast and a mean elevation of 100 feet above sea level (Carpenter and Provorse 1996). With both threats applying uniquely to the Florida box turtle, the International Union for Conservation of Nature (IUCN) Red List of Threatened Species has listed *T. bauri* as vulnerable, with its population trend as decreasing (van Dijk 2011).

Thousands of barrier islands surround the mainland of Florida and are home to many species including the Florida box turtle. It is well documented that island wildlife populations are in more danger of disappearing than their mainland counterparts because they generally are smaller in population size, and they occupy areas with more limited resources (Simberloff 2000). Smaller island population sizes can result in greater rates of inbreeding which often lead to higher rates of extinction (Frankham 1998). Catastrophic events such as natural disasters, disease outbreaks, large poaching events among other factors also have greater impacts on island populations (Kohlman et al. 2005). For example, a population of Florida box turtles on Egmont Key was estimated to include 1500 individuals in 2002 prior to a July 2016 lightning strike that ignited a fire that burned 26.1 acres and approximately 34% of Florida box turtle habitat (Jones et al. 2021). Jones et al. (2021) estimated that only 66 turtles now populate the island, reflecting a 96% decline in the population.

Sanibel Island, approximately 230 km south of Egmont Key is another barrier island that Florida box turtles inhabit. Since its formation around 6,000 years ago, Sanibel has included habitats such as dunes and swales, beach ridges, marshland, and mangrove forests (LeBuff and Lechowicz 2014). In just 50 years, intense development has completely changed hydrology and habitat make-up that had persisted on the island for thousands of years, now making it mostly covered in thick hardwood forest patches that are fragmented by roads, canals, and human structures (LeBuff and Lechowicz 2014). Florida box turtles have a long history on Sanibel Island; for example, naturalist George R. Campbell coined them the "jewel of Sanibel." They were considered common until the late 1960s when sightings became rarer in areas that they were once abundant (LeBuff and Lechowicz 2014). In 2002, Chris Lechowicz of the Sanibel Captiva Conservation Foundation (SCCF), a local non-profit organization located on Sanibel, began a mark-recapture study of Florida box turtles to determine population status, population structure, and life-history characteristics.

On 9 August 2019, the Florida Fish and Wildlife Conservation Commission (FWC) confiscated hundreds of turtles from a Lee County, FL poaching ring, including 276 Florida box turtles. One of the Florida Box Turtles was confirmed to be from the SCCF mark-recapture study based on the notching number ID and photos. During interviews with FWC law enforcement, the detained poachers confirmed that the poaching of Florida box turtles had taken place on Sanibel and in other surrounding areas.

The fire event that transpired on Egmont Key revealed how at risk an island population of Florida box turtles can be if proper management is not effective. With Sanibel Island having its habitat completely transformed and suffering from a major poaching event, its box turtle population is at risk.

This thesis seeks to quantify the status of Sanibel's Florida Box turtle populations by gathering data on population demography and spatial ecology. The present study will provide information that is needed to devise a comprehensive conservation-management plan for Florida box turtle populations on Sanibel Island and will contribute to our understanding of the biology of box turtles in general.

CHAPTER II: POPULATION DEMOGRAPHICS AND HABITAT USE

Introduction

Population demography studies have become a staple in conservation and serve to monitor the status of wildlife populations (Lettink and Armstrong 2003). Mark-recapture serves as the primary method for monitoring populations of motile animals; species are marked in many ways depending on their morphology such as punching holes in crayfish appendages (Nowicki et al. 2008), putting unique bands around the legs of birds (Sandercock 2003), or attaching metal ear clips or clipping the toes of small mammals (Wiewel et al. 2007). When the individual is then recaptured, it can easily be identified from these marks. Important data such as a population's size estimate, survival rate, and sex and age ratio can then be calculated and assist in its conservation management (Lettink and Armstrong 2003).

Long-lived species such as turtles have life history traits that make them more susceptible to rapid changes and because of living for such long periods, adequate long-term data are difficult to collect for individuals. (Congdon et al. 1994). Population demographics are critical to understanding turtle conservation. Following a 30-year-long mark-recapture study of a spotted turtle (*Clemmys guttata*) population in central Maryland, Howell et al. (2019) discovered that population size decreased ~ 49%, even though the population occurred on protected land.

Box turtles are some of the longest-lived species of turtles with the oldest one recorded to be at least 138 years old (Graham and Hutchison 1969). An alarming number of long-term population demography studies (Henry 2003; Kemp et al. 2022; Mitchell et al. 2016) have documented declines in their populations over the years. One of the major reasons for these declines is overexploitation for the illegal international pet trade (Luiselli et al. 2016). There is concern that poachers will exhaust areas of primarily adult box turtles, devastating populations, and impacting their growth for many years (Stanford et al 2020). In 2019, a confirmed poaching event of 276 Florida box turtles occurred on Sanibel, bringing these concerns to the island.

Habitat make-up and quality can greatly affect box turtle health and growth (Dodd 2002), and they determine how easily an individual can be sighted. Different areas of Sanibel Island are more developed than others and differ in terms of habitat composition, potentially affecting an individual box turtle's health and how easily they could be vulnerable to illegal harvest. Identifying these areas where box turtles are visible and vulnerable is critical for the conservation of this population.

The present study investigated the population demography and habitat use of *T. bauri* on Sanibel Island for twenty-one years (2002-2021). Specifically, I quantified an island population estimate, age and sex ratio, and body size and growth. I then identified three island zones across Sanibel with varying levels of development and different habitat composition and quantified age, sex ratio, body size and growth rates of *T. bauri* individuals to determine if these factors affected population characteristics and if they exhibited variation across the island zones. The final goals were to determine the current health of the population for conservation management and to create a baseline population demography data for use in future studies of this species.

Materials and Methods

Sanibel Island is made up of a diversity of habitat types identifiable by their vegetation composition. The dune habitat is found exclusively along the entire southern coastline and part of the eastern northern coastline of the island and is made up of plants such as sea oats (*Uniola panicaulata*), railroad vine (*Ipomoea pes-caprae*), dune sunflower (*Helianthus debilis*), and prickly pear cactus (*Opuntia humifusa*). The dune habitat is mainly terrestrial aside from the formation of the occasional shallow ephemeral pool. The tropical hardwood hammock habitat, which is found throughout the island, contains large ephemeral pools that form during the wet season and has a vegetation make-up of sea grape *(Coccoloba uvifera*), gumbo limbo (*Bursera simaruba*), cabbage palm (*Sabal palmetto*), and myrsine (*Myrsine cubana*). Swale habitats are flooded during the wet season with permanent water contained in some; these habitats are connected interspersed with hammocks throughout the central part of the island. Swale habitats are made up of cordgrass (*Spartina bakeri*), sawgrass (*Cladium jamaicense*), buttonwood (*Conocarpus erectus*), leather fern (*Acrostichum danaeifolium*), and cattail (*Typha latifolia*). Mangrove forest contains red mangrove (*Rhizophora mangle)*, black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemose*) and occupies the entire northern side of the island with patches in the interior. The shrubbery habitat is found on the outskirts of hammock and dune habitat and are primarily small patches of shrub-dominated habitat planted by humans. Shrub plants include wax myrtle (*Myrica cerifera*), coco plum (*Chrysobalanus icaco*), and wild coffee (*Psychotria nervosa*).

Sanibel Island has a diversity of natural habitats, but turtles are often captured in developed areas, perhaps because they are more conspicuous in these sites. There were three main anthropogenic habitats in the present study. The first were golf courses which comprised large, open areas with mowed grass, sand bunkers, and lakes, bordered by hardwood hammock or residential structures. The second was residential areas, which comprised a mixture of native and invasive plants with open mowed grass surrounding a home or business. Lastly, roads at the site were paved areas with no natural features but were bordered by various habitat types. Most turtles found at these sites were actively moving.

Sanibel was divided into three different zones based on their habitat types and development. Each zone was calculated in Google Earth Pro (Version: 7.3.4.8573) (Fig. 3.1).

Having a perimeter of 18.8 kilometers and an area of 894 hectares (ha), the east end is the most heavily developed part of the island with most of its area being covered with residential areas and two golf courses (Fig. 3.1). The causeway that connects the island to the mainland is located on the north side of the east end. Roads and canals bisect a majority of the zone with its northern, southern, and eastern sides bordered by dune coastline. Small patches of protected land dot the zone but are bordered by heavily used areas. Its division line with the central zone traces a major road and branches in and out to include neighborhoods bisected by canals (Fig. 3.1).

With a perimeter of 33.4 kilometers and an area of 2,499 ha, the central island zone is the largest and most protected zone on the island. The J.N. “Ding” Darling National Refuge covers its entire northern border with a mixture of hardwood hammock and mangrove forest, while dunes cover its entire southern side. Hardwood hammocks and swales make up most of its interior with residential areas developed along its southern coast and sporadically in the interior.

The largest bodies of freshwater are in the interior with the Sanibel River and large man-made lakes and ponds dividing the habitats. Two of the busiest roads parallel each other in the northern and southern parts with the northern road running east-west the entire length of the zone and the refuge bordering its northern side. Between these two roads and bordering the southern side of the north road are the largest protected hammock and swale areas owned by SCCF. No box turtles inhabited the northern mangrove forest islands separated from the mainland, and they were not included in the total area considered in this study.

The smallest of the three zones with a perimeter of 12.9 kilometers and an area of 690 ha, the west end is a mixture of developed and protected land. Its southern coastal beach line is a large public beach and the only coastline not developed except for a small area on its western part. North of this beach are large land keys segmented by bayous; a unique feature only found on the west end. The same major road that divides the mid-island zone also divides the west end, with its southern side bordering the bayous. On its north side are residential patches and a large bayou. On the other side of this bayou and dominating the northwest part of the zone is a large neighborhood with a golf course. Small to large sized patches of protected hardwood hammock are found in spaces between the golf course and neighborhood homes. Its division line with the mid-island zone traces major roads and branches slightly to include one end of a bayou.

The majority of box turtle sampling took place from 15 November 2002 to 16 December 2021. Turtles were collected beginning in 2002 by incidental captures until 2013 when residents began calling in box turtle sightings (partnerships were formed with the golf course located in the west end and various resorts on the southern coast of the island). The number of individuals looking for box turtles grew exponentially when SCCF started the Freshwater and Terrestrial Turtle Volunteer Group in the summer of 2020. A “turtle hotline” number was given to the public where anyone could call if a turtle was spotted and those who called were asked to stay with the turtle until someone from SCCF could respond. Also, organized SCCF surveys were conducted 2-3 times a year in varying areas with group sizes varying from 1 to 15.

When a turtle was captured, a GPS point was collected (Garmin eTrex 10 GPS receiver) and its dominant habitat within a 5-meter area was noted. GPS points were later uploaded into Google Earth Pro to determine the island zone. Individuals were then processed onsite or taken back to a field station in a plastic tub and returned and released at the site of capture within 24 hours. Straight carapace length (SCL: to 1 mm), minimum carapace length (CLmin: to 1 mm), plastron length (PL: to 1 mm), width (W: to 1 mm), height (H: to 1 mm), head width (HW: to 1 mm, all using calipers), and weight (WT: to 1 g, using an electronic scale) were recorded. Individuals were sexed based on plastron concavity in males. Age class was determined as adult (SCL $\geq$ 120 mm), or juvenile (SCL $<$ 120 mm) based on Dodd (2002). Notches were drilled into the marginal scutes (Cagle 1939) for marking using a specific numbering code. Notches are not always permanent due to growth or injury so Passive Integrative Transponders (PIT) tags (Biomark HPT8) were inserted along the right bridge of the shell (SCL $\geq$ 70 mm); tags contain a unique number that can be scanned using a reader. Each turtle's shell patterning is unique which allows for photo identification. Pictures of the top, front, back, and sides of the carapace along with the plastron and notches were taken and uploaded into a data base. This three-way identification provided a robust system for identifying recaptures. When a box turtle was recaptured, the same measurements were taken, and growth (SCL) was determined by the difference from the original capture.

I estimated population size using the Schnabel Method (1938), a technique that allows for more than 2 capture-recapture encounters and has no limit on the amount of recaptures, unlike other techniques such as the Peterson estimate (Alcoy 2013). The Schnabel Method is appropriate to use due to the random sampling intervals over a long period of time in my study. Sampling periods were separated into years starting in 2013 when active searching by individual observers around the island began.

Welch's t-test was used to calculate the difference between male and female size measurements. Contingency analysis using a likelihood ratio test was used to determine age, sex, and habitat use differences between the three island zones. Analysis of variance (ANOVA) was used to calculate the difference in box turtle size (SCL) in the three island zones and Tukey's HSD test for multiple comparisons was used to compare the mean size values of each island zone.

A contingency analysis using a likelihood ratio test was used again to test the differences for sex, age, and season differences in habitat use.

All analyses were run in JMP® Pro, Version 16.0.0 (SAS Institute Inc., Cary, NC, 1989-2021) with a significance level set to $\alpha = 0.05$.

Results

A total of 1056 box turtles were captured including 158 recaptures which were all used in the population size estimate. However, due to some older box turtle data entries not having proper identification standards or measurements or not having a GPS location, only 1001 capture and 59 recapture logs were used for all other population characteristics. Most captures occurred in the last three years (2019-2021, N = 663, 66.2%) with only 59 captures from 2002 – 2012 and 0 captures in 2004-2007 and 2009 (Table 2.)

Total population size was estimated to be 3015 box turtles with a 95% confidence interval of 2546 – 3695. Adults (N = 775) made up most (77.4%) of the population with juveniles making up 22.6% (N = 226). The ratio of adults to juveniles was 3.42:1. Among adult box turtles, males (N = 425; 54.8%) outnumbered females (N = 350; 45.2%) for an overall sex ratio of 1.2:1 male: female.

Turtles were captured more frequently in the wet season (N = 646; 64.5%) with the most individuals caught in the month of June (N = 149; 14.9%), compared to the dry season (N = 355; 35.5%) with the least number of individuals caught in January (N = 20; 2%).

Adults had an average SCL length of 148.7 (± 0.53 SE). Males (155.3 mm ± 0.68 SE) were significantly ($t = 16.019$, $df = 773$, $p < 0.0001$) larger than females (140.8 mm ± 0.59 SE). Juveniles averaged at 94.5 mm (± 1.27 SE) (Table 2.2).

Totals of 437 (east end), 144 (central island), and 420 (west end) turtles were captured in each zone. The age ($\chi^2 = 78.92$, $df = 2, 1001$, $p < 0.0001$) and sex ($\chi^2 = 8.585$, $df = 2, 775$, $p = 0.014$) ratios between the three zones differed significantly with the east end having a higher proportion of juveniles (N = 155; 35.5%) and accounting for 68.6% of all juveniles on the island. Central island had a significantly lower proportion of females (N = 39, 33.1%) compared to the other zones (East end: N = 136, 48.2%, West end: N = 175, 46.7%).

Average adult sizes differed significantly ($F = 62.307$, $df = 2, 774$, $p < 0.0001$) among the three zones. Central island and west end ($p = 0.84$, 95% C.I. = [-2.57, 4.18]) were similar but the east end turtles were significantly smaller than turtles from central island ($p < 0.0001$, 95% C.I. = [8.45, 15.5]) and the west end ($p < 0.0001$, 95% C.I. = [8.62, 13.66]) (Figure 2.1).

Habitat use differed significantly among zones ($\chi^2 = 836.314$, df = 10, $p < 0.0001$). The most captures occurred within the dunes (N = 228, 22.8%) and the least on roads (N = 173, 17.3%). Although not included in the analysis, one individual was found by boat actively swimming across a bayou (Figure 2.2).

Habitat use differed significantly between adults and juveniles ($\chi^2 = 95.959$, df = 4, $p < 0.0001$); juveniles used dunes more frequently (N = 100, 44.3%) while adults (N = 138, 17.8%) used hammocks more often. Habitat use did no not differ between males and females ($\chi^2 = 8.82$, df = 4, $p = 0.0658$) but males (N = 100, 63.7%) were found almost twice as often (N = 57, 36.3%) on roads. Season significantly affected habitat use ($\chi^2 = 17.511$, df = 4, $p = 0.015$). The use of roads (N = 145, 22.4%) and residential areas (N = 149, 23%) increased in the wet season and the use of golf courses (N = 92, 26%) and hammocks (N = 74, 20.9%) increased in the dry season.

Discussion

Understanding long-term anthropogenic factors on *T. bauri* populations is necessary for the future survival of this species. The Sanibel population of Florida box turtles offered a unique opportunity to study the effects of a major poaching activity. The present study estimated that 3015 turtles inhabit Sanibel Island with an adult to juvenile ratio of 3.42:1 and a male to female ratio of 1.2:1. Adults of both sexes were larger than those reported in other studies of box turtles. East end turtles were significantly smaller than adults from the center and west end of the island but had a much higher proportion of juveniles. Juveniles used dune habitat more than adults, while adults preferred hammocks. During the wet season, activity increased on roads and in residential areas while the dry season showed an increase in use of golf courses and hammocks.

The Sanibel population estimate (N = 3015) was much larger than the population on Egmont Key in Pinellas County, Florida (N = 544) (Dodd 2001), Big Pine Key (BPK) (N = 61) (Verdon and Donnelly 2005), and Ten Thousand Isalnds (TTI) (N = 43.5 to 270) (Jones et al. 2016), however the Egmont Key estimate only considered the southern half of the island in the calculation. The Big Pine Key estimate only used a 6-ha land plot, and Ten Thousand Islands combined 4 different islands in their estimate. Moreover, different estimation models were used which can cause variation in the results (Pollock et al. 2002). Males were larger than females in the Sanibel population. Male-biased sexual dimorphism appears to be the norm on other island Florida box turtle populations such as Egmont Key (Dodd 2001), BPK (Verdon and Donnelly 2005), and TTI (Jones et al. 2016). Male-biased sexual dimorphism is also typical in other box turtle species populations such as the eastern box turtle (*Terrapene carolina)* (Weiss 2009; West & Klukowski 2016), however some ornate box turtle (*Terrapene ornata*) populations are female-biased or at a 1:1 ratio though the data is limited (Dodd 2002). Interestingly, the largest recorded turtle in my study was a female measuring 188 mm SCL (2016). However, the next 84 largest turtles from the study were all males measuring ≥ 168 mm, the size of the second largest female.

A high number of juvenile captures in the Sanibel population was similar to the results from the Egmont Key study (Dodd 2002) but differs from most other box turtle studies that have low juvenile capture rates (Hall et al. 1999; Verdon and Donnelly 2005; Demetrio 2019; Roe et al. 2021). The lack of juvenile captures in other studies can be attributed to their higher mortality rates and/or their more secretive habits relative to adults' nature that makes them harder to find (West & Klukowski 2016). My high capture rate could be explained by the fact that most juveniles were found in the dunes, a much more open habitat that has less cover to shelter in than forested areas. Juveniles showed the largest amount of growth when they were recaptured as adults compared to annual adult growth, a finding that is consistent with the literature on box turtles. *Terrapene spp*. experience their highest growth when approaching sexual maturity and slower growth once maturity is reached (Dodd 2002).

Age structures and sex ratios in Sanibel populations were similar to those from other southwest Florida barrier island populations. Body size, however, was much larger at Sanibel than the other islands as well as a mainland population (Pilgrim et al. 1997) (Table 3.4). An explanation for this may be island gigantism, a phenomenon whereby animals that occupy isolated islands grow to much larger sizes than animals found on the mainland (Cox and Burns 2017). This has been observed in turtles with giant tortoises on remote islands 1000 km away from mainland weighing over 250 kg (Powell and Caccone 2006). Jaffe et al. (2011) found that large sizes were optimal for these oceanic island tortoises, but also that larger sizes were optimal for any species of freshwater and terrestrial turtles with the proper environmental conditions.

High resource availability on Sanibel is a likely contributor to their larger sizes. Increased diversity and quantity of food items likely affects growth, clutch size, and frequency (Dodd 2002). Lower resource availability results in energy being used for other necessary functions rather than growth (Brown et al. 2017). This was hypothesized for Florida box turtles on Egmont Key (Dodd and Dreslik 2008) after seeing growth rates in males increase while females' growth decreased with a decrease in resource availability from intense storms and the removal of nonindigenous vegetation. Sanibel is a much larger island (~ 4850 ha) than Egmont (~180 ha), TTI (~ 2.00 to 27.93 ha), and BPK (~ 2400 ha), with ~70% of its land protected. This larger area and multiple habitat types reduce competitive pressures and allows for animals to grow to larger sizes (Dunlop & Morris 2018). High quality habitats result in greater resource availability (Pettorelli et al. 2005). With most of its remaining land protected, Sanibel has several high-quality habitats for turtles and other wildlife to inhabit. This might also explain the reasons why the central and west areas of the island (where most of the protected lands are located) are where the largest box turtles occur. The east end of the island, where most of the developed land is located, has the smallest average SCL.

Heavy development on Sanibel's east end began not long after a causeway was built connecting the island to the mainland in 1963. Most of the open canopy uplands and wetlands were lost, as well as the tropical hammocks along the Sanibel River, which have been documented to be the preferred habitat of Sanibel box turtles (see chapter 3). The Gulf Beach Ridge Zone, where all of the dunes are found, is a mostly open-canopied, vegetated area in between the open beach and any condominiums or homes. The city of Sanibel adheres to the Coastal Construction Control Line (CCCL) of 1978 that requires this vegetated buffer zone. Having nowhere else to go, box turtles congregate in this habitat on the east end; dunes were the most-used habitat on the east end (N = 217, 49.7%) and accounted for 95.2% of all dunes captures out of the three zones.

Mesic woodlands, like hardwood hammocks, provide a thick canopy that allows patchy sunlight through while maintaining high levels of relative humidity, providing better opportunities for thermoregulation than open habitats such as dunes (Dodd 2002). The substrate of hardwood hammocks also offers a higher amount of food with a higher diversity of invertebrates that are found under leaflitter (Roeder et al. 2022) compared to the sand dominated dunes without litter. East end box turtles may need to use more energy for thermoregulation and resource gathering instead of growth, resulting in smaller average sizes compared to the other island populations.

Rain has been known to increase box turtle activity (Fredericksen 2014; Plummer 2003). When box turtles are captured on a road, they are almost always moving. This may explain my finding of more road captures with the onset of the wet season (month(s)) when rain and relative humidity averages increase. Male box turtles have been reported to have higher movement rates than females (Iglay et al. 2007; see also chapter 3) with transient males moving long distances to establish new home ranges (Kiester et al. 1982).

To my knowledge, the present study is the first of its kind to have a known poaching event occur while population monitoring was occurring, allowing for a baseline to be established to determine the effects a major poaching event can have on a box turtle population. Box turtles are long-lived animals with populations that require adults to reproduce over several years (Dodd 2002) and because of this, the negative effects a poaching event like this can have on a population may not be seen within the first two, five, or even more than ten years. Long-term monitoring to quantify any population declines is needed for box turtles (Kemp et al. 2022), making the continued monitoring of the Sanibel population vital for how this population was affected and for its future conservation and sustainability.

Dunes are a more open habitat type, with less cover, that turtles will congregate in if that is the only habitat available, making them easier targets for exploitation. Active monitoring needs to be increased in these areas to deter poaching. Signs can be placed on busy roads cautioning turtle crossings to decrease vehicle mortalities, especially during the wet season when turtles cross more often. One effort that has already met with success in turtle conservation is educational outreach. Whenever the turtle trafficking/poaching situation is explained to a Sanibel citizen, the usual response is offered to help in any way they can. This has led to the massive influx of turtle captures in the last few years from both residents and visitors reporting marked and unmarked turtles. The more people that are aware of the threat of overexploitation, the more individuals there are to monitor for illegal activity. Though high-quality population demographic data must continue to be collected, it will require efforts of all types of people including scientists, business owners, residents, and visitors alike to ensure the future survival of this population.

Year	(N)	Male	Female	Juvenile	Wet Season	Dry Season
2002	1	1	0	0	0	1
2003	4	3	1	0	4	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	0	0	0	0	0	0
2007	0	0	0	0	0	0
2008	1	0	1	0	1	0
2009	0	0	0	0	0	0
2010	6	4	2	0	3	3
2011	9	1	5	3	5	4
2012	38	18	16	4	30	8
2013	57	28	22	7	42	15
2014	27	7	18	2	13	14
2015	56	25	26	5	23	33
2016	49	16	24	9	31	18
2017	48	25	16	7	27	21
2018	42	25	16	1	28	14
2019	104	41	26	37	45	59
2020	168	76	53	39	118	50
2021	391	155	124	112	276	115
Total	1001	425	350	226	646	355

Table 2.1. Number of turtles (N) captured in each year from 2002-2021 on Sanibel Island, Florida, USA. Active volunteer captures began in 2013 with the Freshwater and Terrestrial Turtle Volunteer Group started in 2020.

Sex	**SCL**	**CLmin**	**PL**	**W**	**H**	**HW**	**WT**
Male	155.3	151.2	141.0	116.7	70.5	22.8	567.8
Female	140.8	137.6	132.0	106.4	70.3	20.5	506.8
Juvenile	94.5	92.4	88.0	72.5	46.6	15.6	157.0

Table 2.2. Average measurements of male, female, and juvenile Florida box turtle on Sanibel Island, Florida, USA. Measurements were taken for straight carapace length (SCL) (mm), minimum carapace length (CLmin) (mm), plastron length (PL) (mm), width (W) (mm), height (H) (mm), and weight (WT) (g).

Location	**Mean Male SCL (m)**	**Mean Female SCL (m)**
Egmont Key	139.0	132.9
Big Pine Island	146.9	134.1
TTI	141.4	125.3
Volusia County*	151.0	132.9
Sanibel Island	155.4	140.7
East End	147.6	135.0
Central Island	160.0	140.2
West End	159.0	145.5

Table 2.3. Mean SCL (m) lengths for Florida box turtle populations, * indicates a mainland population while all others are island populations. Italicized locations are different zones on Sanibel Island.

Figure 2.1. Map of Sanibel Island and its three zones (East End: Blue, Central Island: Yellow, West End: Red)

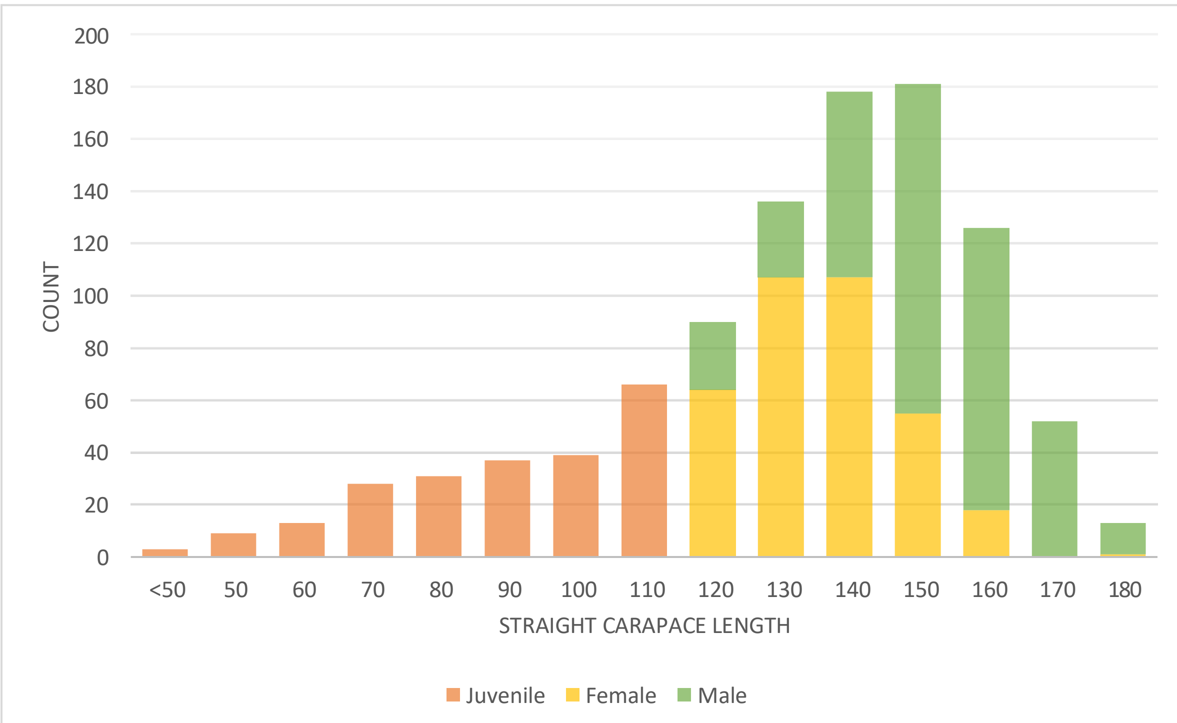

Figure 2.2. Straight carapace length (SCL) (mm) measurements for juveniles, females, and males (N = 1001) on Sanibel Island, USA.

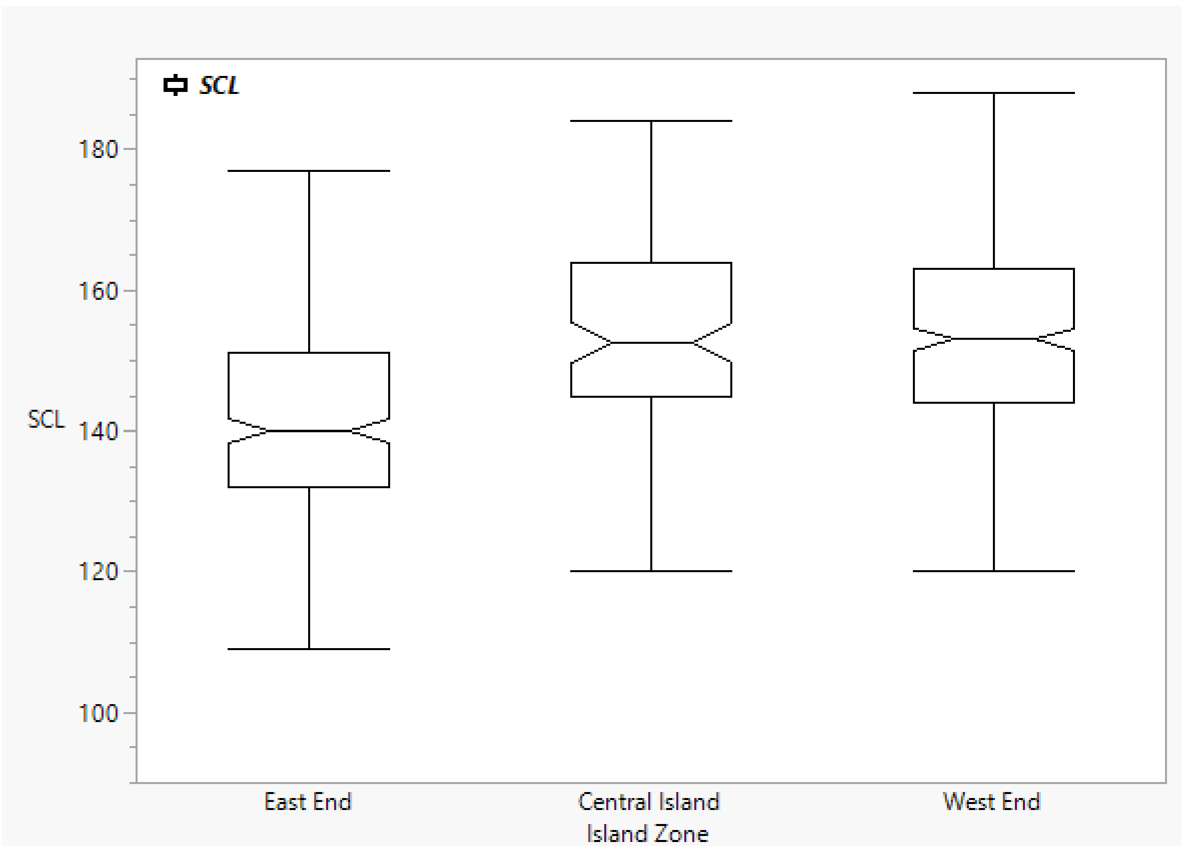

Figure 2.3. Box plot comparing average size (straight carapace length (SCL) (mm)) of adult Florida box turtles in different island zones on Sanibel Island, Florida, USA.

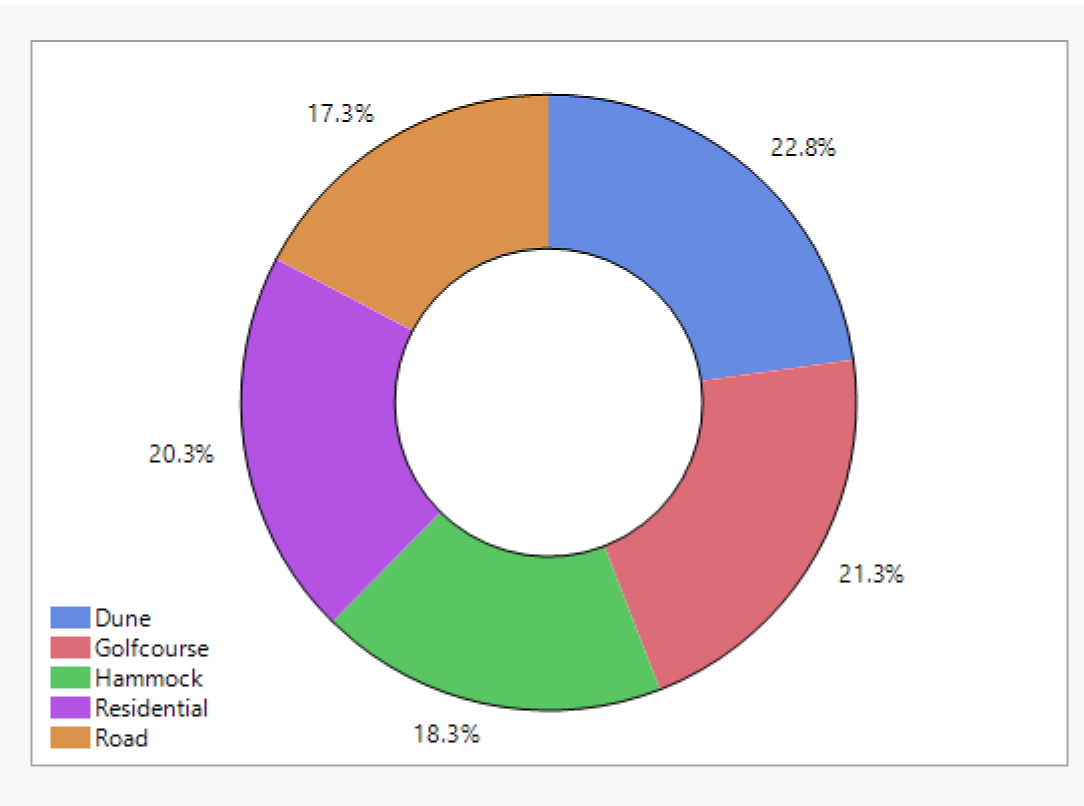

Figure 2.4. Percent dominant habitat types within 5m of Florida box turtle upon initial capture on Sanibel Island, Florida, USA.

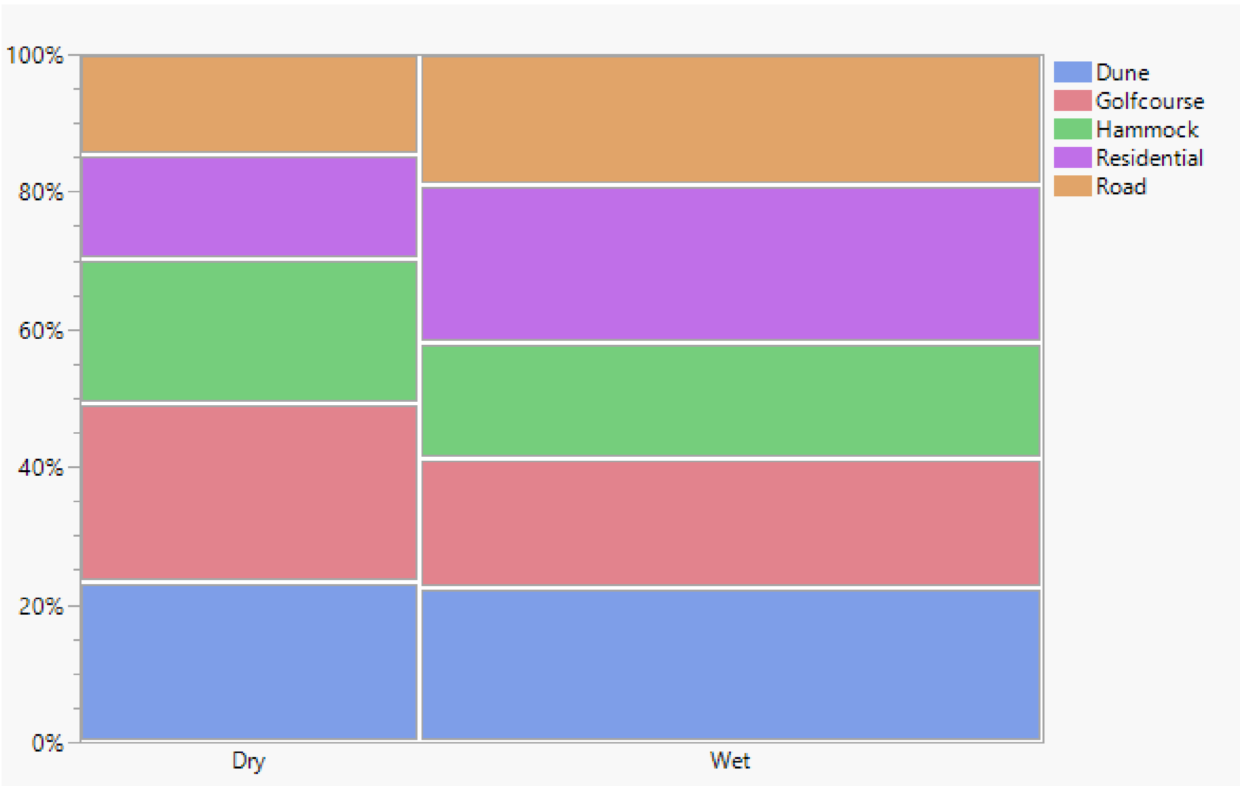

Figure 2.5. Mosaic plot comparing wet and dry season habitat use for captured Florida box turtles (N = 1001) on Sanibel Island, Florida, USA, 2019-2022. Habitat use differed significantly (χ^2 (4) = 17.511, p = 0.015) between seasons.

CHAPTER III: SPATIAL ECOLOGY AND HABITAT USE

Introduction

Habitat destruction and fragmentation can greatly affect a species' ability to persist by causing a reduction in quality living space and available resources (Robinson et al. 1992). Understanding how a species occupies and utilizes the space around it, or its spatial ecology, is thus necessary for a species' comprehensive conservation and management (Long and Nelson 2012). Quantifying the spatial ecology of an organism is complex (Neuhauser 2001) and requires knowledge of other aspects of the biology of a species such as habitat use/selection and how it varies with other factors such as body size, sex, and climate (Caro 1994; Guarino 2002; Grémillet and Boulinier 2009).

Box turtles are an appropriate and even ideal subject for spatial ecology studies due to their conservation status and the ease in tracking them due to relatively small home ranges (Habeck et al. 2019). Although the spatial ecology of other box turtle species has been reasonably well studied (Habeck et al. 2019), there is a dearth of information on the ecology of the Florida box turtle (*Terrapene bauri*). Only one unpublished master's thesis (Demetrio 2019) has used radio-telemetry to estimate home range size for the Florida box turtle. In that study, 10 turtles were tracked for two years in an area where mangrove forest was the dominant habitat. More data on the spatial ecology of Florida box turtles are needed, especially in habitats that have been fragmented and coincide with human development. These habitat types are becoming more common for box turtle populations (Harris et al. 2020).

The present study investigated the spatial ecology and habitat use of *T. bauri* on Sanibel Island for thirty-four months (May 2019- March 2022). I quantified home range size, movement patterns and the influence of demography on those attributes for 18 individual turtles inhabiting diverse island habitats. Specifically, I addressed the following questions: (1) What are the home range sizes in the population, how do they vary with season, and how do they differ between the sexes? (2) What are the movement patterns in the population and how do they vary with sex and season? (3) What habitats do the turtles use and how do these differ between sexes and season?

Materials and Methods

Sanibel Island is a 19.3 km-long barrier island located in southwest Florida and connected to the city of Fort Myers by a causeway in Lee County. Sanibel is an east-west orientated island, unlike most Florida barrier islands which run north-south. Surrounded by the Gulf of Mexico, it has subtropical to tropical climate year-round (Cooley 1955). The temperature (mean = 28 ˚C in August) and precipitation (mean = 145 mm in June) are at their highest during the wet season (May 15^{th} – October 14^{th}) and the lowest (mean temperature: 17.8 ˚C in January; mean precipitation: 32 mm in November) during the dry season (October 15^{th} – May 14^{th}) (Climate-Data.Org). Approximately 2/3 of the island's 4856 hectares are protected through federal, county, city, and Sanibel Captiva Conservation Foundation (SCCF) lands.

Sanibel Island is made up of a diversity of habitat types identifiable by their vegetation composition. The dune habitat is found exclusively along the entire southern coastline and part of the eastern northern coastline of the island and is made up of plants such as sea oats (*Uniola panicaulata*), railroad vine (*Ipomoea pes-caprae*), dune sunflower (*Helianthus debilis*), and prickly pear cactus (*Opuntia humifusa*). The dune habitat is mainly terrestrial aside from the formation of the occasional shallow ephemeral pool. The tropical hardwood hammock habitat, which is found throughout the island, contains large ephemeral pools that form during the wet season and has a vegetation make-up of sea grape *(Coccoloba uvifera*), gumbo limbo (*Bursera simaruba*), cabbage palm (*Sabal palmetto*), and myrsine (*Myrsine cubana*). Swale habitats are flooded during the wet season with permanent water contained in some; these habitats are connected interspersed with hammocks throughout the central part of the island. Swale habitats are made up of cordgrass (*Spartina bakeri*), sawgrass (*Cladium jamaicense*), buttonwood (*Conocarpus erectus*), leather fern (*Acrostichum danaeifolium*), and cattail (*Typha latifolia*). Mangrove forest contains red mangrove (*Rhizophora mangle)*, black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemose*) and occupies the entire northern side of the island with patches in the interior. The shrubbery habitat is found on the outskirts of hammock and dune habitat and are primarily small patches of shrub-dominated habitat planted by humans. Shrub plants include wax myrtle (*Morella cerifera*), coco plum (*Chrysobalanus icaco*), and wild coffee (*Psychotria nervosa*).

Radio tracked box turtles were selected based on their sex and what area of the island they occupied and were hand-captured opportunistically. I radio tracked 18 adult box turtles (10 females, 8 males) 1 to 6 times every two weeks between 25 May 2019 and 14 March 2022, except between the dates of 16 March 2020 and 20 April 2020 (when I was forced to leave the island due to COVID-19). Partial data were collected for 7 out of the 18 turtles. Two turtles were lost from the survey because animals chewed off the transmitter, probably a coyote (*Canis latrans*). I removed transmitters from two other individuals because they were inhabiting an area that was about to be developed and thus, had to be relocated. Data for three other individuals ceased when their transmitter signals were lost. Turtles were fitted with VHF radio transmitters

(SOPR 2380 transmitters – Wildlife Materials Inc.) attached onto the 3rd pleural scute for males and the 1st pleural scute for females with Devcon 5 Minute® epoxy. Tracking was performed with TRX-3S (Wildlife Materials Inc.) and R410 (Advanced Telemetry Systems) radio telemetry receivers.

Each tracking session involved a visual confirmation. For each location of a turtle, I recorded the date, time, and the habitat that was used. Habitat type (see above descriptions) was determined based on the dominant type of vegetation within 5 m of the turtle's location. Ambient temperature (˚C) and relative humidity (%) were taken between 1 and 1.5 m above the turtle and ground temperature (˚C) and relative humidity (%) were taken on the ground within 5 cm of the turtle using a Kestrel 3000. A GPS point was collected using a Garmin eTrex 10 GPS receiver.

I calculated two different home range estimates: 95% minimum convex polygon (MCP; Mohr 1947) for total area size and 50% kernel density estimate (KDE; Worton 1989) for core area size to determine the total home range sizes of each box turtle, as well as their home range during the wet season and the dry season in hectares (ha). KDE Smoothing factors (h) for 95% KDE were selected when they gave similar area values to 95% MCP and then 50% KDE was calculated with these h values. Linear regression was used to determine if the length of an individual's tracking period (days), the number of tracks, or the body size (straight carapace length, SCL) had an effect on home range size. Home range size was compared between the sexes using Welch's t-test with unequal variances. The Wilcoxon signed rank test was used to compare home range sizes between the wet season (May 15th – October 14th) and the dry season (October 15th – May 14th). The total, wet season, and dry season MCP and KDE home range sizes were all calculated on the Zoa Track platform (Dwyer et al. 2015) that uses the adehabitatHR package (Calenge 2006) within R.

A Contingency analysis of likelihood ratio was used to compare habitat and use as well as activity for male and female, including during the wet and dry seasons. Welch's t-test with unequal variances was performed to calculate the difference of ambient and ground temperature and relative humidity readings in the dry vs. wet seasons.

The minimum straight distance from each consecutive tracking GPS point was calculated in Zoa Track, in meters. The amount of time (DD:HH:MM:SS) passed between each tracking point was calculated and converted in decimal format. Each distance was then divided by the amount of time to calculate daily movement between tracks. Welch's t-tests were used to compare the differences in daily movements between the sexes and between the seasons. A linear fit line was run to test the correlation between the number of times tracked and average daily movement.

All analyses besides home range estimates were run in JMP® Pro, Version 16.0.0 (SAS Institute Inc., Cary, NC, 1989-2021) with a significance level set to $\alpha = 0.05$.

Results

Turtles were tracked for a mean total of 420 ± 58.5 SE days (range = 1031-238 days) with a mean number of 76.1 ± 13.0 SE tracks (range = 210-29 tracks). The mean minimum convex polygon (MCP) home range size was 14 ha ± 3.7 SE (range = 2.5-71.8 ha), and the mean 50% kernel density estimate (KDE) home range size was 2.9 ha ± 0.8 SE (range = 0.4-14.2 ha) (Table 3.1).

Home range size averages were larger for females (MCP: 16.5 ha ± 6.5 SE; KDE: 3.2 ha ± 1.3 SE) than for males (MCP: 10.8 ha ± 2.2 SE; KDE: 2.4 ha ± 0.6 SE). However, home-range size did not differ significantly between males and females (MCP: t = -0.825, df = 17, p = 0.427; KDE: t = -0.605, df = 17, p = 0.556).

There was no significant correlation (MCP: r^2 = 0.006, F = 0.101, df = 17, p = 0.755; KDE: r^2 = 0.005, F = 0.088, df = 17, p = 0.771) between body size (SCL) and home range size.

Home range size averages were larger in the wet season (MCP: 8.1 ha ± 1.1 SE; KDE 1.6 ha ± 1.6 SE) than in the dry season (MCP: 7.7 ha ± 1.6 SE; KDE: 1.5 ha ± 1.1 SE). However, home range size did not differ significantly between the wet and dry seasons (MCP: S = -10.0, df = 17, p = 0.678; KDE: S = -2.5, df = 17, p = 0.923).

Linear regression analysis revealed that home range size was not significantly related to the length of the tracking period (MCP: r^2 = 0.006, F = 0.09, df = 17, p = 0.7678; KDE: r^2 = 0.002, F = 0.026, df = 17, p = 0.875) or the number of times a box turtle was tracked (MCP: r^2 = 0.032, F = 0.525, df = 17, p = 0.479; KDE: r^2 = 0.025, F = 0.415, df = 17, p = 0.528).

The average minimum straight distance between tracking points was 35.5 m ± 1.0 SE with the average amount of time between tracks at 5.7 days ± 0.2 SE. Daily movement averaged 9.0 m ± 0.3 SE with males (11.4 m ± 0.4 SE) moving significantly more (t = 7.854, df = 1, p < 0.0001) than females (6.7 m ± 0.4 SE) and with no significant difference (t = 1.076, df = 1 p = 0.282) in movement between the wet (9.4 m ± 9.7 SE) and dry (8.7 m ± 11.6 SE) seasons. Mean daily movement distance was marginally significant with a negative association with the number of times an individual was tracked for all turtles (r^2 = 0.2224, F = 4.577, df = 17, p = 0.0482) but was not significant for just males (r^2 = 0.301, F = 2.584, df = 7, p = 0.1591) or just females (r^2 = 0.151, F = 1.424, df = 9, p = 0.267) (Table 2.1).

Out of all habitat types (N = 1351) hardwood hammock was used the most, by far (N = 679, 50.3%) with dune (N = 339, 25.1%) and shrubbery (N = 214, 15.8%) also heavily used. Swale (N = 67, 5%), mangrove forest (N = 26, 1.9%), and ephemeral pool (N = 26, 1.9%) were the least used (Figure 2.1).

Habitat use differed significantly ($\chi^2 = 235.338$, df = 5, 1351, $p < 0.0001$) between males and females, with males preferring hardwood hammock habitats and females preferring dune and shrubbery habitats (Figure 2.2). Season also significantly influenced habitat use, ($\chi^2 = 38.585$, df = 5, 1351, $p < 0.0001$) with dune use decreasing and hardwood hammock use increasing during the wet season (Figure 2.3). Temperature and humidity differed between the wet and dry season with ambient temperature ($t = 25.515$, df = 1, $p < 0.0001$; Wet: 30.4 ˚C ± 2.6 SE, Dry: 25.6 ˚C ± 4.2), ambient relative humidity ($t = 4.873$, df = 1, $p <0.0001$; Wet: 75.1 % ± 10.5 SE, Dry: 71.9 % ± 4.2 SE), ground temperature ($t = 20.996$, df = 1, $p < 0.0001$; Wet: 30.5 ˚C ± 2.8, Dry: 26.3 ˚C ± 4.3), and ground relative humidity ($t = 4.9$, df = 1, $p < 0.0001$; Wet: 80.5 % ± 11.2 SE, Dry: 77.1 % ± 12.8 SE) all significantly higher in the wet season.

Discussion

How and when Florida box turtles interact with their space and habitat is vital in understanding their natural history and providing better protection. Given the historical habitat loss and recent poaching activity on the Florida Box turtle on Sanibel Island, its persistence there may rely on a fuller understanding of its spatial ecology. My study revealed that although it was not significant, females had larger home ranges overall while males had significantly larger daily movements and seasonal effects were negligible. Home range size in the present study was considerably larger than those found in other studies in the southeastern U.S. Habitats used, in order of importance, were hardwood hammock, dune and shrubbery, with minor use of swale, mangrove and ephemeral pools. Males used predominately hardwood hammocks, while females mainly split their time between hammocks and dunes. Not surprisingly, hammock use increased during the (warmer) wet season, while dune use increased during the (cooler) dry season.

Sanibel Island box turtles exhibited larger home ranges (14 ha) than other box turtle populations in the southeastern part of the United States. Most estimates are from eastern box turtle, who's mean MCPs were smaller in north Georgia (>10 ha), North Carolina (2.68 ha), Tennessee (3.77 ha), and Virginia (2.47 ha) (Rittgers et al. 2018; Kapfer et al. 2013; Dillard 2016; Bayless 1984). Home range size in the present study was also much larger than that of conspecifics (0.81 ha, N=7) on Ten Thousand Islands (TTI; 0.81 ha, N=7 individuals) (Demetrio 2019). However, Sanibel Island is (approx. 4856 ha) much larger than the TTI island (30 ha and may offer a much larger variety of quality habitats, whereas TTI is dominated by mangrove forest, which may be a lower quality habitat for Florida box turtles. Habitat quality and structure can influence box turtle home range size (Dodd 2002).

Consistent with past studies (Harris et al. 2020), there was no relationship between the size of the turtle and the size of their home range. Seasonal activity is well documented in most box turtle species but unlike the more northern populations whose activity totally stops during the winter months (Congdon et al. 1989), southern populations are active year-round due to the warmer climate (Meck et al. 2020) and are more influenced by a wet and dry season. Warm temperatures and high humidity are the most favorable conditions for box turtle activity (Reagan 1974), but home range size and daily movement did not differ when compared between wet and dry season.

Male and female home range sizes have been found to be similar in size (Stickel 1989; Nieuwolt 1996; Slavenko 2016). Though sex did not influence home range size, female home ranges were larger on average while males were found to have significantly larger daily movements. The differences in home ranges and movement patterns between sexes has been well documented (Dodd 2002). Males are known to "wander" in search of mates or to even establish new home ranges (Belzer and Seibert 2009), potentially explaining this higher movement. Females tend to find suitable nesting sites within their home range (Madden 1975) but have been known to travel large distances to nest (Stickel 1950; Legler 1958). Females covering a larger area in search of a proper nesting site could lead to larger home range sizes in general.

Another possible explanation for larger female home ranges could be due to one female individual being an outlier. Home range estimations can exhibit high variation among species and populations (Seaman and Powell 1996; Laver 2008; Habeck et al. 2019). In the present study, the female (MCP = 71.8 ha) with the largest home range had a much smaller home range when considering only her core area size (KDE = 14.2). This individual used multiple (suitable) hardwood hammock habitat patches in an unsuitable golf course matrix, causing its MCP to be inflated when considering the matrix. Similarly, Schwartz and Schwartz (1974) found inflated home ranges in three-toed box turtles (*Terrapene carolina triunguis*) that used (suitable) patches of woodlots in between unsuitable open ridges. If this individual's home range size is omitted from the sample size, then the average female home range size (10.3 ha) becomes lower than the male average.

Overall, turtles in the present study used hardwood hammocks most often (although females used dunes extensively). Mesic woodlands have been a favored habitat type for most box turtles ranging in the eastern United States, providing a thick canopy that allows patchy sunlight through and maintaining higher humidity levels than open area habitats, an ideal habitat for thermoregulation (Dodd 2002). The difference in sex use could be attributed to females using more open areas to help thermoregulate eggs while gravid and selecting nest sites (Fredericksen 2014). Dune use (Wet: N = 83, 16.5%; Dry: N = 256, 30.2%) was higher in the dry season and hardwood hammock (Wet: N = 271, 53.9%; Dry: N = 408. 48.2%) use was higher in the wet season. This can be explained by the wet season being significantly warmer and more humid than the dry season. Box turtle species in the southeast are often observed escaping the heat of summer in the shaded mesic woodlands and then using more open space to thermoregulate in the colder months (Dodd et al. 2002; Fredericksen 2014). Dodd et al. (1994) also reported the clustering of box turtles around sea grapes in the months of Autumn which may explain the increase in dune activity where most sea grape plants grow on Sanibel. The overall preference for hardwood hammock is consistent with the Egmont Key population, which mostly used palm-pepper forest (Dodd et al. 1994) and with the TTI population, which also mostly used hardwood hammock (Jones et al. 2016; Demetrio 2019). (Demetrio 2019) reported no difference in habitat use between the sexes and (Dodd et al. 1994) only reported a difference in Autumn when it was the only time males used palm-pepper forest less than females.

This is the first study of spatial ecology and habitat use for a Florida box turtle population in an area where protected habitat and human development coincide. Understanding how box turtles use these areas will become increasingly important as development continues in Florida at an unprecedented rate (Hefty & Koprowski 2021). Protection of hardwood hammock habitat should be a priority even if only small patches remain because of the ability for box turtles to utilize these spots within a habitat mosaic (Belzer and Seibert 2009). During the wet season box turtles may be more vulnerable to mortality due to expanded home ranges and weather parameters that promote movement, increasing the chances of road mortality. There is still much to learn about how Florida box turtles interact with their space and habitat. For example, a higher sample size of turtles in different areas of the island could reveal if there is any bias in habitat use based on the present study. Other spatial ecology studies should be conducted in other areas of Florida especially on the mainland to see if there are any similarities to island populations or if these are unique traits. Florida box turtles face increasing threats to their survival; comprehensive conservation management plans based on high-quality spatial ecology studies must be constructed to ensure the future of this species.

Turtle Number	**Sex**	**N**	**Time**	**Size (SCL)**	**MCP 95% (Total)**	**KDE 50% (Total)**	**MCP 95% (Wet)**	**KDE 50% (Wet)**	**MCP 95% (Dry)**	**KDE 50% (Dry)**	**Average Daily Movement**
374	M	169	1031	153	20.4	4.7	16.0	3.5	15.6	2.7	14.7
382	F	105	384	138	2.5	0.4	2.9	0.5	0.9	0.2	6.5
491	F	43	315	140	71.8	14.2	16	3.2	27.5	4.3	4.9
496	F	33	238	142	13.3	2.3	9.0	1.6	4.8	0.9	5.3
504	M	70	279	126	2.8	0.4	2.3	0.5	0.9	0.1	10.5
512	M	210	903	153	10.3	2.5	10.0	1.9	6.3	1.4	10.6
522	M	65	245	163	13.6	2.6	5.5	1.0	10.5	2.0	14.1
526	F	171	881	143	3.5	0.6	3.7	0.8	2.1	0.4	5.7
603	F	110	516	141	7.9	1.1	6.9	0.9	5.6	1.1	10.1
671	F	78	354	137	12.1	2.4	5.2	1.0	12.5	2.1	8.8
708	M	41	306	167	8.3	1.5	5.9	0.9	7.6	1.8	7.6
709	F	45	352	128	10.6	1.8	16.0	3.4	5.6	0.8	5.3
718	F	46	324	152	12.7	2.9	4.4	0.9	10.3	2.3	5.6
721	M	36	319	126	16.7	4.4	14.2	2.9	10.0	2.7	8.8
736	F	41	311	139	5.6	1.3	4.5	0.9	1.8	0.4	4.2
740	M	48	280	144	11.9	2.3	8.2	1.4	11.3	2.3	9.5
751	F	30	264	139	24.7	5.3	11.9	2.8	4.6	0.7	6.4
755	M	29	258	171	2.7	0.6	2.7	0.5	1.1	0.3	3.7
Mean											
Males					10.8	2.4	8.1	1.6	7.9	1.7	9.9
Females					16.5	3.2	8.1	1.6	7.6	1.3	6.3
Total					14.0	2.9	8.1	1.6	7.7	1.5	7.9

Table 3.1. Body size (mm), home range size (ha), and movement (m) for 18 radio-tracked Florida box turtles (*Terrapene bauri*) on Sanibel Island, Florida, USA, 2019-2022. N represents total number of tracks per box turtle. Time is the total number of days a turtle was tracked. Home range estimated using minimum convex polygons 95% (MCP) and kernel density 50% (KDE) for total, wet (May 15th – October 14th), and dry (October 15th – May 14th) seasons.

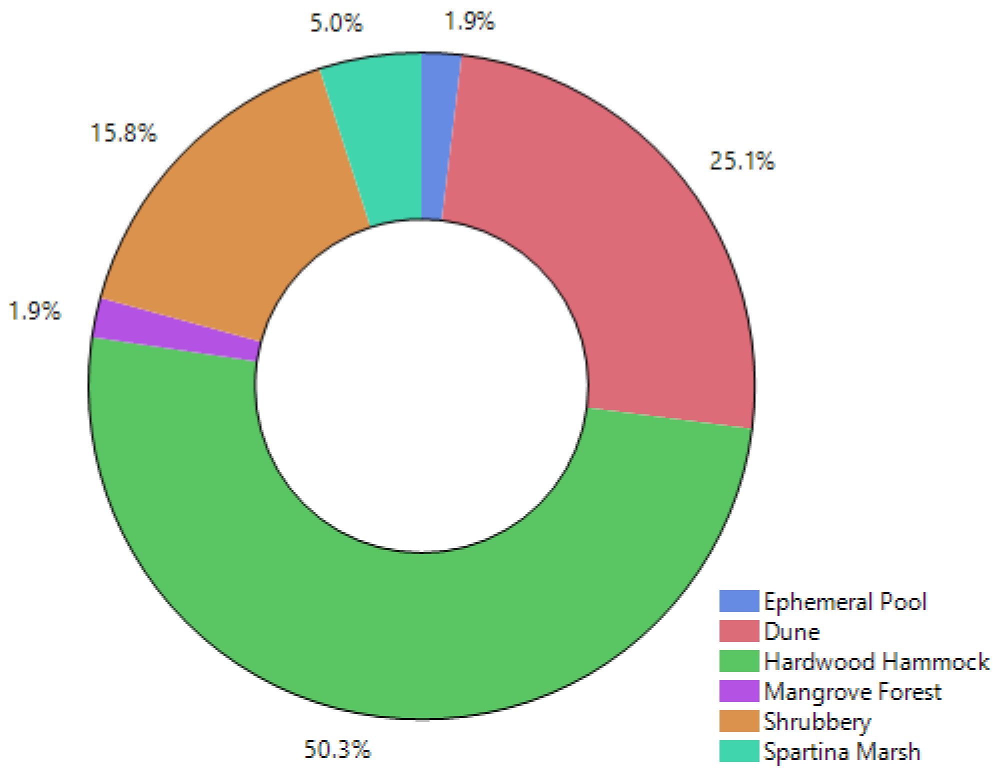

Figure 3.1. Percent dominant habitat types within 5m of Florida box turtle locations on Sanibel Island, Florida, USA, during 2019-2022.

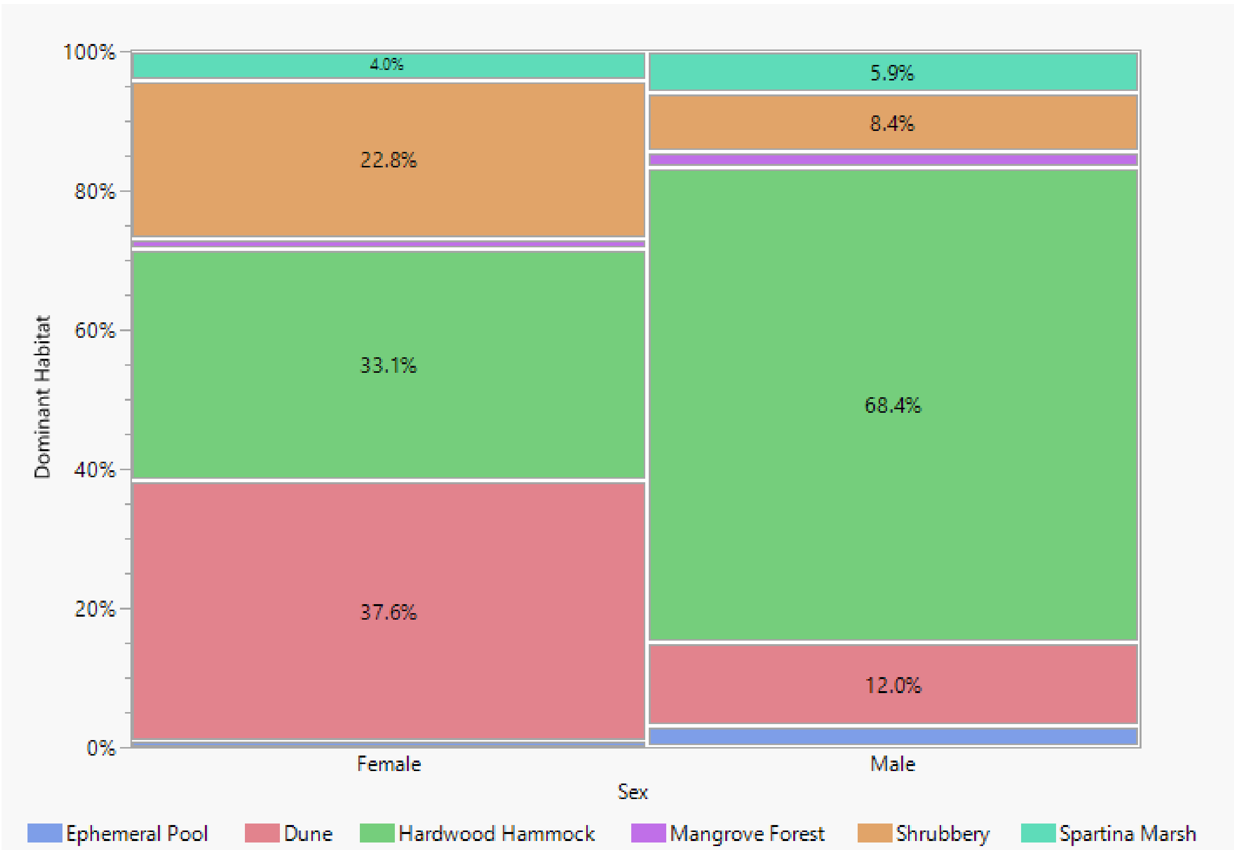

Figure 3.2. Mosaic plot comparing male and female habitat use for radio-tracked Florida box turtles (N = 18) on Sanibel Island, Florida, USA, 2019-2022.

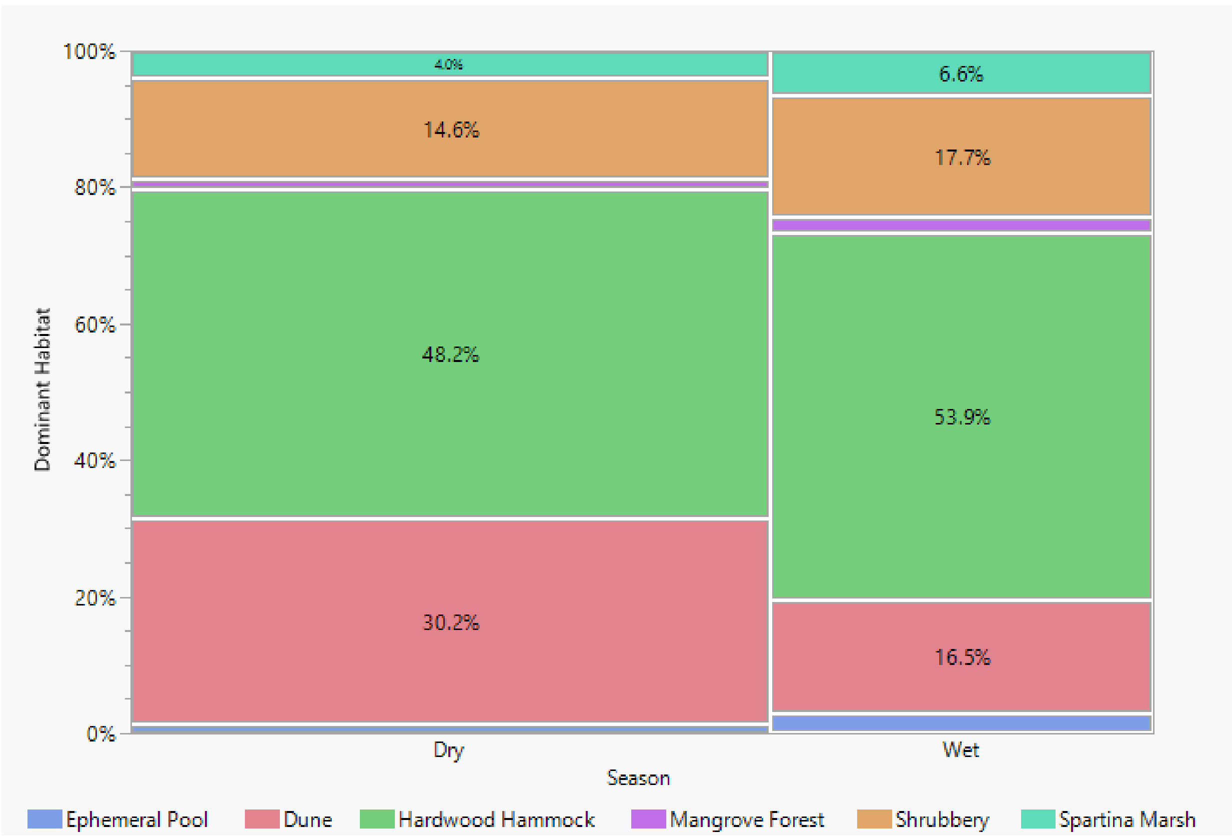

Figure 3.3. Mosaic plot comparing wet and dry season habitat use for radio-tracked Florida box turtles (N = 18) on Sanibel Island, Florida, USA, 2019-2022.

CHAPTER IV: CONCLUSION

. The population was estimated at 3015 individual turtles with a higher ratio of adults compared to juveniles and males compared to females. Average adult size (SCL) was 148.7 mm with an average growth of 6.2 mm with a difference in the size of adults between the east end of the island and the central and west end. The dunes were the habitat box turtles used the most when captured with almost all being in the east end and a majority of juveniles being found there as well. The average home range size for Sanibel Island Florida box turtles was higher than most reported southeastern box turtle populations and much higher than the reported average on Ten Thousand Island (TTI), the only other Florida box turtle spatial ecology study to take place. Hardwood hammock was the most used habitat type with a difference in habitat use occurring between sexes and seasons.

To more fully understand a box turtle population, both spatial ecology and population demographic studies should be conducted. Habitat use cannot be understood from mark-recapture or radio-telemetry alone. For example, in the demographic study not a single turtle was caught in a swale or mangrove forest habitat type, but both were utilized 67 and 26 times respectively by two radio-tracked individuals. On the other hand, hundreds of turtles were caught on open roads or golf courses, but not a single radio-tracked box turtle was located on either one. Both studies complement and rely on each other to provide a clearer picture of the ecology of the Florida box turtle.

This thesis provides insights into the complex biology of box turtles on a barrier island in southern Florida. Time is of the essence in protecting this vulnerable population. Two major threats have combined to create a potentially catastrophic result with habitat fragmentation pushing box turtles into areas where they are more easily visible and likely to get overexploited at a greater rate. Understanding the threat is just the first part though; comprehensive conservation management plans must be created from data collected in these population demographic and spatial ecology studies. The most vulnerable areas must be given protection and the public needs to be informed of what is happening in their own backyards. Only then will this population and others like it continue to survive for generations to come.

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