

THE EFFECT OF URBANIZATION ON
GOPHERUS POLYPHEMUS SUITABLE HABITAT
IN FLAGLER COUNTY, FLORIDA

by

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DEDICATION

To Planet Earth and the Nature found on it, which fills me with awe and inspiration daily.

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I would like to thank my friends and family, who have supported me during this chapter of my life. I also would like to thank *Gopherus polyphemus* (gopher tortoise). From my first and my most recent sightings, as well as the memory of my Advanced Placement Environmental Science students' (Deltona High School, Florida) joy at their first sighting of a gopher tortoise; I have furthered my knowledge of your world and plight. A thank you to Nicole Savona and Nicole DeSha of Florida Fish and Wildlife Commission for their assistance with my tortoise questions, GIS, and other resources. I want to acknowledge all my professors in the Land Resources and Environmental Sciences Program. I want to say thank you to Dr. Bruce Maxwell and Dr. Lisa Rew for offering field classes, which I found invaluable. Also, a thank you to all my classmates. It was truly uplifting to work with such supportive people, especially during the field classes, as well as the professional paper. To The Quadrats – I can't thank you all enough for such wonderful memories. I need to thank the teachers from the dorm in the MSSE summer program. You were all welcoming and I don't think I will ever watch the Jurassic Park movies the same way. Kendia, I hope I remembered your name correctly, if not, I certainly remember your kindness in not only offering, but driving me to the airport. Thank you. I also would like to thank Dr. Tracy Sterling and Dr. Robert Peterson for their feedback. Dr. Scott Powell, thank you for your support and feedback. Lastly, I would be remiss if I did not acknowledge and express my gratitude to Marni Rolston. Thank you for always being available, answering all my questions, and being a wealth of knowledge.

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ABSTRACT

Globally habitats are being degraded, fragmented, and lost due to anthropogenic activities, such as land-use change. Land-use change is also one of the key drivers, and in some cases the chief driver, of biodiversity loss. Urbanization, a form of land-use change, results in the degradation, fragmentation, and loss of suitable habitat, which effects the plant communities, wildlife inhabitants, and the humans that rely on provided environmental services. While natural disturbances are needed for quality suitable habitat, it is the anthropogenic disturbance of urbanization in response to population growth that has primarily reduced *Gopherus polyphemus* suitable habitat and populations throughout its entire southeastern range. *Gopherus polyphemus* is the only North American tortoise found in the southeast and is considered a keystone species due to about 350 species relying on its burrows. The current population and urbanization in Flagler County, Florida and one of the county's municipalities, the City of Palm Coast, both of which have *G. polyphemus* suitable habitat areas, have increased and are projected to increase. Therefore, the aim of my study is to determine if the increase in urbanization in both Flagler County and Palm Coast has and/or will result in the fragmentation and/or loss of suitable habitat. Also, I aim to determine if the resultant change in habitat will be able to support a viable tortoise population. I used a 2018 index map for *G. polyphemus* suitable habitat and a projected Florida development map for 2020, 2040, and 2060 to evaluate *G. polyphemus* suitable habitat fragmentation and/or loss in Flagler County and Palm Coast. Additionally, using building permits for Palm Coast, the actual fragmentation and/or loss was evaluated from 2018 to 2022. Results of the evaluation indicated that there will be an initial increase in fragmentation and then a decrease for Flagler County (projected) and Palm Coast (actual only). Additionally, projected and actual loss of suitable habitat for both Flagler County and Palm Coast are likely. These findings support that urbanization in response to population growth will result in suitable habitat fragmentation and loss for *G. polyphemus* and possibly a reduction in viable populations.

CHAPTER ONE

INTRODUCTION

Habitat Change

Habitat is a basic need for all living organisms. Globally, habitats are being degraded, fragmented, and lost due to anthropogenic activities. In addition, land-use change is one of five key drivers of biodiversity loss (Sala et al. 2000). In some areas, it is the chief driver of biodiversity loss (Sala et al. 2000). Land-use change, in the form of urbanization, results in increased habitat degradation, fragmentation and loss (Liu et al. 2016, Zhu et al. 2020). This has an impact not only on the plant communities, but on the wildlife that relies on those communities for food, shelter, breeding, and for future generations, as well as the humans that rely on the provided ecosystem services (Ahrné et al. 2009, Guo et al. 2010, Haddad et al. 2015).

Habitat change, in the form of natural disturbances, is a necessary component for some ecosystems. Fire creates more suitable conditions for seedling survival, by opening the canopy for light or burning the understory vegetation to reduce competition, as well as resulting in an increase in habitat heterogeneity (Mushinsky & Gibson, 1991). Habitat heterogeneity, is also increased by elephant activity, both on the local and landscape scales, by opening up the tree canopies (Coverdale et al. 2016).

Habitat change due to land-use change, in the form of development, such as agriculture or urbanization, is one of the biggest threats to many habitats. Urbanization in response to population growth affects land-use through land cover change (Jolly 1993, Turner et al. 2020)

and alters the landscape which can result in the loss, degradation and/or fragmentation of habitat (Liu et al. 2016, Patel and Tripathi 2016).

Florida Population Growth

Currently, the state of Florida, which is the third most populated state, is leading the nation in population growth (US Census Bureau 2023). Florida's population increased 1.9% between 2021 and 2022 (US Census Bureau 2023) and continues to grow. Flagler County, Florida (Figure 1) is also experiencing growth. It's population increased 4.8% between 2021 to 2022 (US Census Bureau, n.d.) (Figure 2), which is leading to increased urbanization. Flagler County is predicted to be one of eight counties in Florida to experience the most change in urban development by the year 2060 due to a past projected increase in population, with a relative increase of 3.9 times in urban area (Zwick & Carr, 2006).

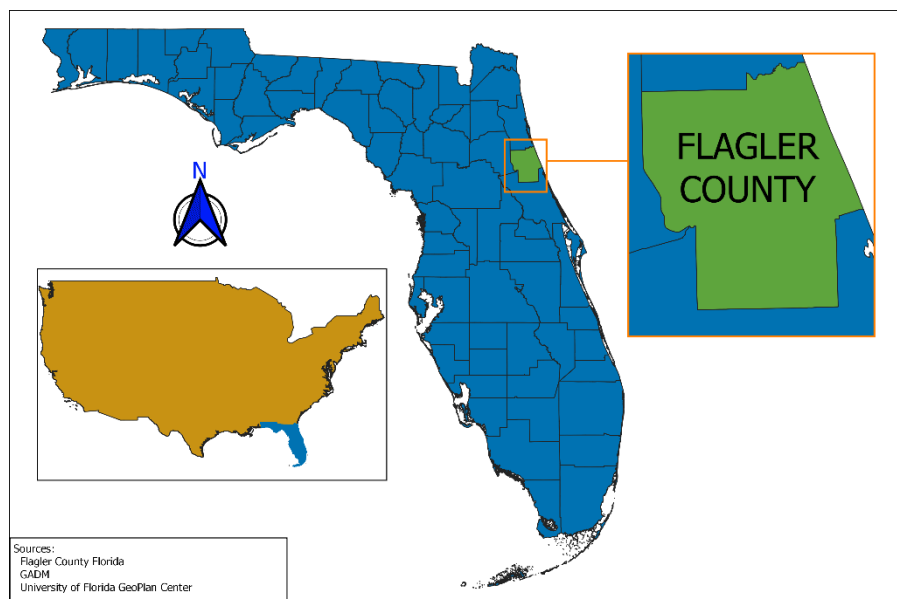


Figure 1. Flagler County, Florida - located on the east coast of Central Florida.

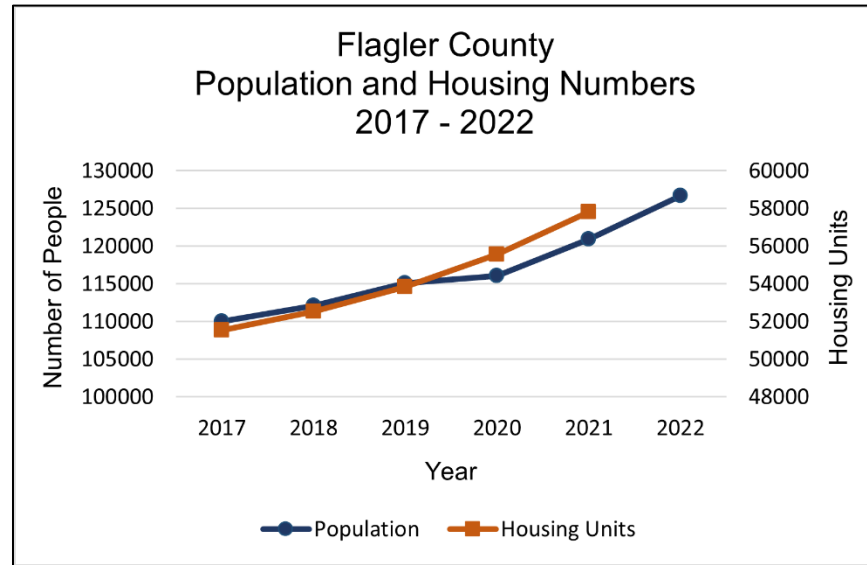


Figure 2. Flagler County has experienced a steady increase in both population and housing since 2017.

The planning of land management for an increasing population should make an attempt to meet public goals, including maintaining a quality of life (Theobald et al. 1997). However, this does not seem to be the case in Flagler County or some of the municipalities within the county, such as the City of Palm Coast (Palm Coast), which had an increase in population of 4.55% from 2020 to 2021 (US Census Bureau n.d.) (Figure 3). For the past few years, the local residents have been transparent about certain developments that they feel do not maintain their quality of life, as well as the wildlife that share the land (FlaglerLive 2019a, 2019b).

There has been a steady increase in urbanization over the past few years, with the exception of 2020, most likely due to COVID-19 (“Monthly new residential construction, December 2022” 2023, Community Development Department, US Census Bureau n.d.) (Figure 3). This increase can affect different human aspects, such as infrastructure, including plans for a new high school and an addition to one of the existing high schools (“School Planning - Flagler

Schools” 2023) and new roads for housing developments and possibly human health (Jolly 1993). Furthermore, it affects the plant communities and wildlife as well.

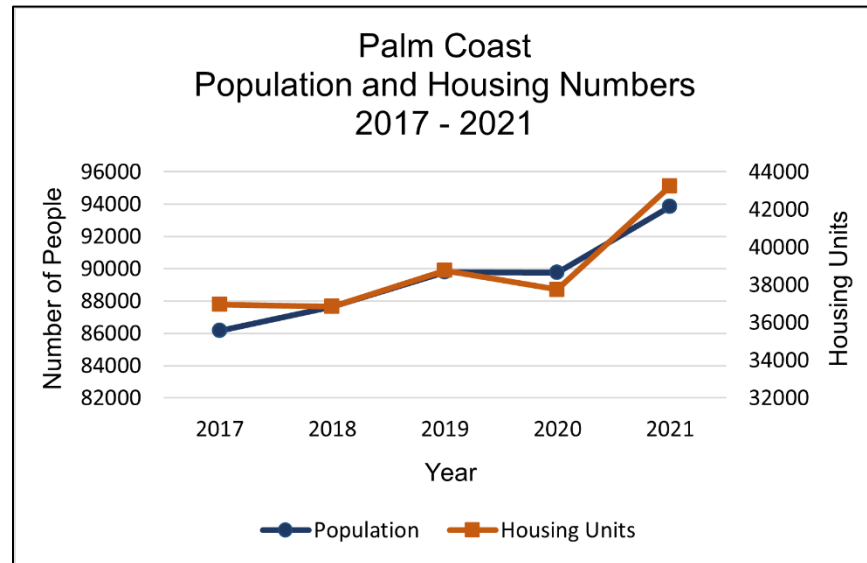


Figure 3. Palm Coast has experienced a steady increase in both population and housing since 2017, with the exception of 2020. This exception is most likely attributed to COVID-19.

Gopherus polyphemus

One species that is, and has been, losing suitable habitat due to urbanization, as well as a decrease in local and range populations, is *Gopherus polyphemus* (gopher tortoise) (Figure 4b) (Blonder et al., 2021; Enge et al., 2006; Folt et al., 2022). Additionally, suitable habitat is being lost due to hurricanes, and the subsequent dune repair, as well as sea level rise (Blonder et al. 2021, Florida Fish and Wildlife Conservation Commission 2022, 2022, Olsen Associates, Inc 2022, “SAJ-2017-01052 (SP-TMM)” n.d.).

Gopherus polyphemus, an obligate burrower, is solitary, long-lived (40 to 60 years), with a late sexual maturity (9 to 21 years) and a low fecundity. It is the only land tortoise in North

America found east of the Mississippi River with a southeastern range in Alabama, Florida, Georgia, Mississippi, and South Carolina (Figure 4a). Within this distribution, it has Federal threatened status (1987) in its western range (Western Distinct Population Segment), which is only in portions of Alabama, Louisiana, and Mississippi (*Endangered and Threatened Wildlife and Plants; Finding for the Gopher Tortoise Eastern and Western Distinct Population Segments* 2022).

In Florida and other states, the push to have the Eastern Distinct Population Segment (EDPS) status changed to threatened was recently denied by U.S. Fish and Wildlife and removed from the candidate list, stating that the EDPS population does not meet the criteria for endangered or threatened species (*Endangered and Threatened Wildlife and Plants; Finding for the Gopher Tortoise Eastern and Western Distinct Population Segments* 2022), but it remains threatened at the state level. Additionally, it is a keystone species, with approximately 350 wildlife species dependent on its burrows, including the Federal and Florida State threatened *Drymarchon couperi* (Eastern indigo snake) (Enge et al., 2013), which uses the *G. polyphemus* burrows in portions of its range for over-wintering (Bauder et al., 2017), the Florida State threatened *Pituophis melanoleucus mugitus* (Florida pine snake), and many other imperiled Florida native species, as well as other obligate commensals (“Gopher Tortoise Commensals” 2023) (Figure 5). Furthermore, *G. polyphemus* aids in native seed dispersal. Seeds of native *Paspalum setaceum* (thin paspalum) germinate very soon after passing through the tortoise’s digestive system. Additionally, the widespread invasive *Paspalum notatum* (bahia grass) seeds did not germinate shortly after passing through its digestive system, but it is undetermined if the seeds are no longer viable or just in a state of dormancy (Carlson 2003).

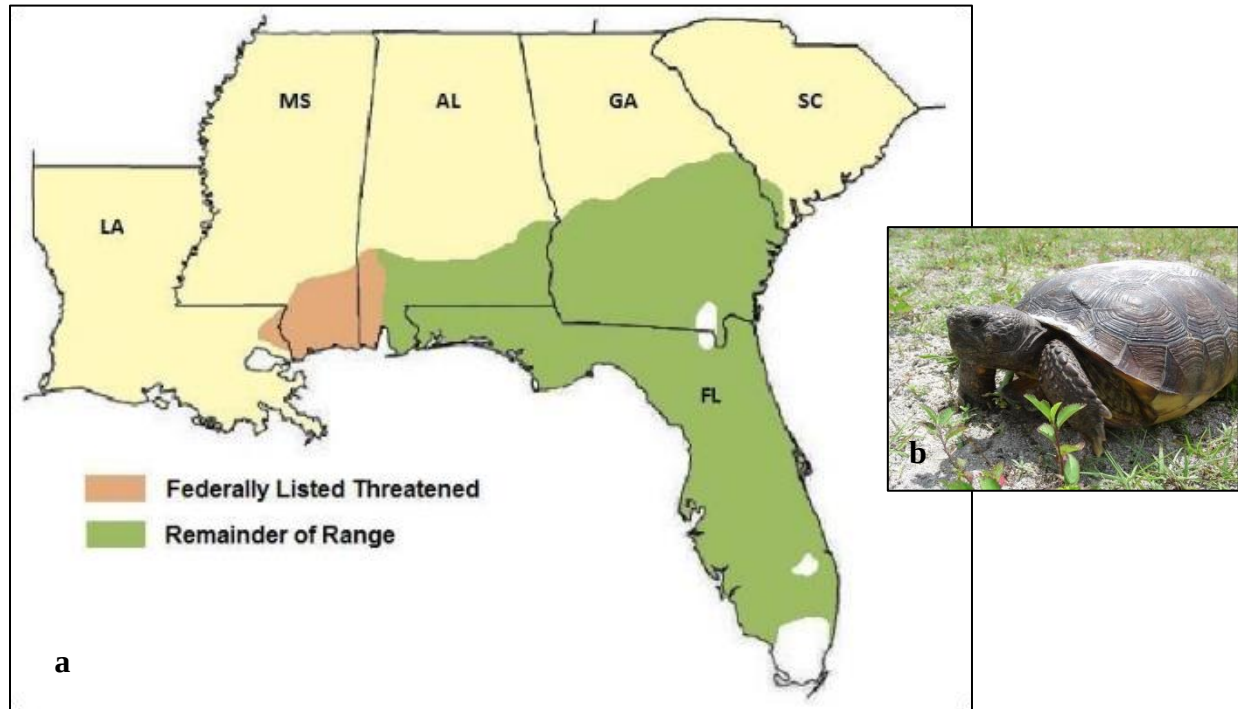


Figure 4. *Gopherus polyphemus* distribution map with Federal Conservation Status (“About the Gopher Tortoise - Gopher Tortoise Council” n.d.) (a). *Gopherus polyphemus* (Photo Credit: Florida Fish and Wildlife Research Institute) (b).

Gopherus polyphemus suitable habitat is one with well-drained, sandy soils, which is more of an indicator of habitat suitability than the vegetative community (Baskaran et al., 2006; Crawford et al., 2020). However, they tend to occupy communities such as scrub, sandhills, xeric hammock, coastal dunes, and others. Sandhill communities and areas with a 30 to 60% open canopy are preferred habitat for the tortoise, though smaller population densities are supported by closed canopies (Auffenberg and Franz 1982). Furthermore, some of the suitable habitat, such as loblolly pine forests and scrub, is fire dependent which keeps the canopy open, and the mid-story thinned out (Crawford et al., 2020; Mushinsky et al., 2006).

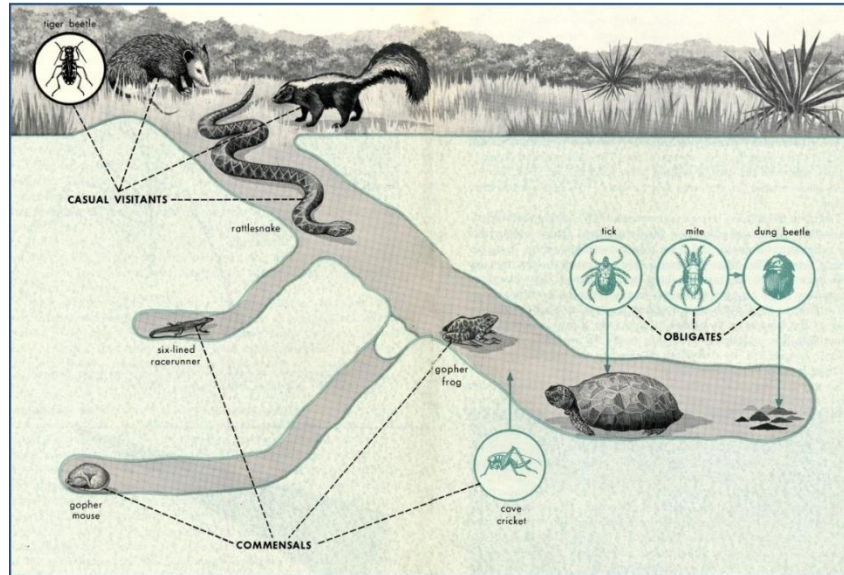


Figure 5. *Gopherus polyphemus* burrows are used by numerous species. Species, such as the *Lithobates capito* (gopher frog) are commensals, while *Chelyoxenus xerobatis* (gopher tortoise hister beetle) are obligate commensals. Image credit: Gopher Tortoise Counsel

The soil component is important as *G. polyphemus* excavates and maintains its own burrow using its shovel-like forelimbs. Burrows are usually 6 meters or less in length, with a depth of 1 to 2 meters, and may have more than one opening (Jones and Dorr 2004) (Figure 5). Burrows serve not only as a home, but as a refuge from extreme heat. Moreover, the burrows need to be adjacent to foraging areas, while *G. polyphemus* will stay within about 50 m of their burrows; they can journey greater than 100 m for forage (Enge et al., 2006). Their home range varies, with females having ranges from 0.10 to 0.6 ha, and males having larger ranges of 0.5 to 1.9 ha.

Gopherus polyphemus and Flagler County Urbanization

Demographics: *Gopherus polyphemus*

Gopherus polyphemus is found in Flagler County, Florida. The tortoise population in Flagler County was estimated to be 20,700 in 1973, with an estimated projected population of 300 in the year 2000 mostly due to urbanization in response to population growth (Auffenberg and Franz 1982). In Flagler County, as with many other areas, current population numbers are not well-known, since 80% of the population resides on private lands (*Endangered and Threatened Wildlife and Plants; Finding for the Gopher Tortoise Eastern and Western Distinct Population Segments* 2022). This fact, along with spending a majority of time in their burrows, makes surveying by presence of the tortoise difficult. In the past, density estimates used 63.2% of the number of observed active and inactive burrows using external characteristics, which was based on the average percentage of unoccupied burrows (based on as many as 15 years of data (Auffenberg and Franz 1982)). Today, *G. polyphemus* surveys, which are required in the state of Florida prior to activities related to urbanization, use estimates of 50% of the number of potentially occupied burrows observed to determine the number of tortoises in the project area (Florida Fish and Wildlife Conservation Commission 2022). However, classifying burrows by external characteristics is considered subjective and inaccurate and the use of a camera is suggested as an effective aid, but is not infallible (Chambers et al. 2005).

Urbanization is the primary cause of loss of habitat and population decline, but there are other factors, both natural and anthropogenic, that affect the populations through mortality. Natural factors that affect tortoise populations are the average hatchling survival rate of 10%,

with an estimated 89% of nest depredation (Landers et al. 1980) and pathogens that cause diseases, such as the upper-respiratory-tract disease (McGuire et al. 2014). For coastal populations, hurricanes can pose a threat to habitat and survival. After Hurricanes Matthew (2016) and Irma (2017), a 30% loss of suitable habitat was documented at Guana Tolomato Matanzas National Estuarine Research Reserve in St. Augustine, Florida, as well as changes in burrow densities (Blonder et al. 2021). More recently, Hurricane Ian not only caused the loss of burrows and suitable habitat, but also the loss of tortoises (Stetson 2022). Furthermore, dune repair from storm events also impact *G. polyphemus* (Florida Fish and Wildlife Conservation Commission 2022, Olsen Associates, Inc 2022).

But it is the impacts of urbanization that are far reaching. Continued human population increases and urbanization have been predicted to result in the loss of all tortoise populations that are not on protected land (Auffenberg and Franz 1982). As stated above, much of the preferred habitat is fire dependent, but fire regimes, with the exception of local government lands that still use prescribed burns, have been altered due to human habitation and changes in land-use (Landers et al. 1995, Costanza et al. 2013). Even though prescribed burns are used to maintain *G. polyphemus* habitat, mechanical means to open the overstory and reduce woody vegetation cover are also used and may pave the way for invasive species (McKinney 2002, Wetterer and Moore 2005).

The human need for food has caused *G. polyphemus* mortality. Before the 1980's, these tortoises, known as "Hoover chickens" or "scrub chickens", were categorized as game animals by the then Florida Game and Fresh Water Fish Commission and as such were captured and consumed (Taylor 2016). Despite their no longer being permitted to be harvested and their

protective status people still poach them, some with the intention of eating them (Owens 2004, Marino 2018).

Urbanization in the form of new subdivisions, which means new roads that fragment habitat and increase in motor vehicle traffic, can lead to an increase in *G. polyphemus* deaths (Enge et al., 2006). Moreover, the tortoises find the roadsides attractive due to the openness, presence of suitable forage, and have used roadsides as their homes (Baskaran et al., 2006; Enge et al., 2006; Rautsaw et al., 2018). Urbanization also brings invasive species (flora and fauna) that may also have an effect on *G. polyphemus*, such as the invasive *Imperata cylindrica* (cogongrass) which degrades habitat (Yager et al. 2010, “Cogon Grass” n.d.) and invasive *Solenopsis invicta* (red imported fire ants) that predate on hatchlings, have a negative effect on nestlings, and may affect adults as well (Epperson and Heise 2003, Wetterer and Moore 2005, Dziadzio et al. 2016).

Translocation, the moving of a tortoise from its “home” to another location, due to urbanization also affects the tortoise populations. Flagler County urbanization, including road and utility repairs, during 2018 to 2022, resulted in the translocation of 550 tortoises (477 off-site recipient areas; 73 on-site), which includes adults, sub-adults, and juveniles. Of those, 365 (337 off-site recipient area, 28 on-site), were relocated from the Palm Coast (Florida Fish and Wildlife Conservation Commission 2022). And although, translocation can be successful (Burke 1989) and does not tend to end in mortality, there have been mortalities and mortality events at Gopher Tortoise Recipient sites (Gates et al. 2002, Dziadzio et al. 2018, Cozad et al. 2020, Commernet, 2011 n.d.). Translocation from different populations to recipient sites that have high tortoise

densities, can cause stress and social disruption, and “appears to be strongly associated” in the mortality of tortoises, with the contributing factor of initial body condition (Cozad et al. 2020).

In the past, and currently, urbanization has been the main cause of loss of suitable habitat (Sinclair et al. 2010, *Endangered and Threatened Wildlife and Plants; Finding for the Gopher Tortoise Eastern and Western Distinct Population Segments* 2022). Past urbanization also resulted in population declines. Before 2007, to develop *G. polyphemus* habitat in Florida, developers would pay a mitigation fee and be issued an Incidental Take Permit, which was transferable, for *G. polyphemus* (Cozad et al. 2020). This approach resulted in the tortoises being buried alive, which, due to their slow metabolism, meant a long, slow death. From September 1991 to May 2006, 83,995 tortoises were taken under the Incidental Take Permits, as well as permission to develop 55750 ha of suitable habitat (Mrykalo et al. 2010). Due to public attention (Flescher 2005, King 2005, “Stop killing gopher tortoises” 2007, Deland-Deltona Beacon 2008) this policy changed and since 2007 it is illegal to disturb a tortoise or its burrow. However, Incidental Take Permits issued before the policy change are still valid and transferrable, but some land owners will choose to relocate the tortoises, rather than entomb them (Cozad et al. 2020). The permitting guidelines do not require a permit for relocation on-site or activities, such as agricultural lands, including tillage and planting, due to the conservation benefit they provide to fish and wildlife (Florida Fish and Wildlife Conservation Commission 2020).

Conservation Efforts

The current conservation practice is translocation of tortoises to recipient sites, with incentives to translocate on-site. However, recipient sites, which are a minimum of 10 ha of

public or private lands, may not be large enough to support a viable population (250 minimum) (Miller 2001), as 100 ha minimum maybe needed (McCoy and Mushinsky 2007, Nesbitt et al. 2010). Additionally, many timberland companies have gopher tortoise management practices (Rayonier.com 2021). Timberland companies that hold a Sustainable Forestry Initiative Certificate are required to protect wildlife habitat, biodiversity, and species at risk (Admin 2022). Citizen-oriented programs such as, Gopher Tortoise Day (Florida) (April 10th) (“Gopher Tortoise Day | April 10th” n.d.), the Gopher Tortoise Sightings web application (“Gopher Tortoise Sightings” n.d.), the Gopher Tortoise Friendly Yard Program (“Gopher Tortoise Friendly Yard Recognition Program” 2023), and a proposed license plate (242/3000 pre-sales) (“Gopher Tortoise License Plate | Wildlands Conservation” 2020, “Pre-Sale Data” 2023) all aid in *G. polyphemus* conservation and awareness. In addition to these current programs, my goal is to add burrow sightings, with a required photograph, to the existing gopher tortoise sightings app (<https://app.myfwc.com/HSC/GopherTortoise/>) as a way to better monitor possible tortoise presence. Despite the subjective nature of using external burrow observations (Chambers et al. 2005), this tool could give an indication of tortoise presence, which also aids in determining the presence of other species that use their burrows, such as *Lithobates capito* (gopher frog) (Smith et al. 2021). Furthermore, even though surveys have been done in the past; a creation of a brief, periodic voluntary burrow/tortoise survey (every 5 years) to all landowners, public and private, possibly with an incentive if needed, could add to a better understanding of less suitable habitats used and possible population demographics. Incentives to create wildlife buffers or wildlife easements (this is a current practice for utilities), to not clear entire lots for building, and require

new subdivisions and commercial development to include gopher tortoise friendly areas in their development plans.

Objectives

The objective of my research was to determine if a predicted increase in future urbanization (2020, 2040, and 2060) will result in loss and/or fragmentation of *G. polyphemus* suitable habitat in Flagler County and Palm Coast, and any change in vegetation in Palm Coast. Additionally, my research was to determine if past urbanization (2018 to 2022) in the City of Palm Coast resulted in loss and/or fragmentation of suitable habitat or vegetation changes. Furthermore, I wanted to determine if the resultant habitat changes would be able to support viable populations of *G. polyphemus*.

CHAPTER 2

METHODOLOGY

Study Area

The study area is located in Flagler County, Florida and the City of Palm Coast, which lies within Flagler County (Figure 6). Flagler County encompasses approximately 130,000 ha and consists of five municipalities: Beverly Beach, Bunnell, Flagler Beach, Marineland, and Palm Coast, as well as portions of Ormond Beach. Palm Coast covers approximately 25,000 ha.

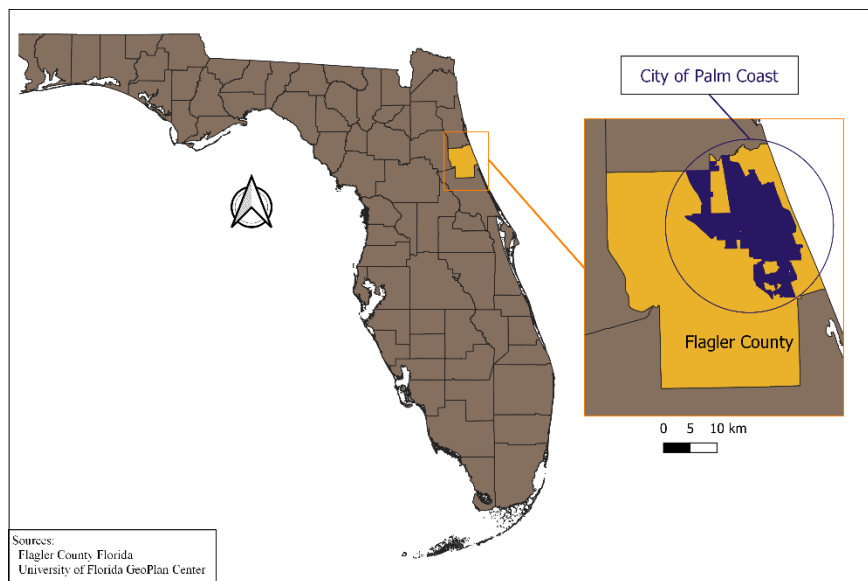


Figure 6. The Flagler County study area is located in the state of Florida. The City of Palm Coast study area (insert) is a municipality within Flagler County.

Data Sources and Baseline Map Creation

I acquired *Gopherus polyphemus* translocation data from the Florida Fish and Wildlife Commission Gopher Tortoise Permit Application site (Florida Fish and Wildlife Conservation

Commission 2022), entered in to a Microsoft® Access® database, and exported to Microsoft® Excel®. Additionally, I acquired building permits for residential, commercial and subdivision site development from the Palm Coast Building Permit website (City of Palm Coast Florida 2022) and used it to map out developed parcels. Due to the other four municipalities not having building permits digitized, I used the Florida 2060 Development Project raster layer for 2020, 2040, and 2060 (University of Florida GeoPlan Center 2006) to assess future Flagler County urbanization and loss of suitable habitat. The same raster layers were used to compare 2020 projections to actual Palm Coast urbanization for 2022 and to assess future urbanization for 2040 and 2060 (University of Florida GeoPlan Center 2006).

Gopherus polyphemus suitable habitat is based on soil, fire frequency, vegetative communities, and other environmental factors (Crawford et al., 2020). I used a 2018 at-risk species habitat suitability prediction map for the area longleaf pine system for *G. polyphemus* in southeastern United States (Crawford et al., 2020). This map was overlayed on the Florida Cooperative Land Cover vector layer (“Cooperative Land Cover, Version 3.6 - published November 2022” n.d.) and I clipped it using the Flagler County (Flagler County Florida 2021a) and Palm Coast (Flagler County Florida 2021b) boundaries. I then classified the habitat suitability map into low, medium, and high suitability. I used the low suitability for assessment as it encompasses the greatest area of possible suitable habitat.

I created all maps using QGIS 3.16.6 Hannover with GRASS (GRASS Development Team 2012, QGIS Development Team n.d.). I performed statistical analysis using R version 4.2.3 (R Core Team 2023) and RStudio (RStudio Team 2020). Figures 2 and 3, as well as Tables 2 and 3, were created using Microsoft® Excel®.

Flagler County Urbanization and Suitable Habitat Loss

I vectorized the 2060 Florida Development Project raster layer for the years 2020, 2040, and 2060 (University of Florida GeoPlan Center 2006) and then clipped it with the Flagler County boundary vector file (Flagler County Florida 2021a). Next, I classified the vector file into the years, joined each clipped year layer with the boundary layer, and classified areas into suitable or unsuitable habitat. I then created a raster image for each year (2020, 2040, and 2060). I assessed the landscape metrics of the raster images utilizing the below scripts from the R package ‘landscapemetrics’ (Hesselbarth et al. 2019) in R version 4.2.3 (R Core Team 2023) (Table 1).

Table 1. Rscripts used for statistical analysis. Statistical analysis performed using below script in R package ‘landscapemetrics’ with queen’s case direction (8 directions) where applicable. (Hesselbarth et al. 2019)

Type of landscape metric	Script	Units
total landscape area	lsm_l_ta	hectares
total class area	lsm_c_ca	hectares
percent land cover (class)	lsm_c_pland	percent
greatest patch area (patch)	lsm_p_area	hectares
number of patches (class)	lsm_c_np	n/a
mean class area	lsm_c_area_mn	hectares
edge density (class)	lsm_c_ed	meters per hectare

Palm Coast Urbanization and Suitable Habitat Loss

The above vector files for the same years were clipped using the Palm Coast boundary layer (Flagler County Florida 2021b). Additionally, I used Palm Coast building permits (City of Palm Coast Florida 2022) to determine urbanization and loss of suitable habitat between 2018 and 2022, since the 2060 Florida Development Project was created in 2006 and could not account for the change in urbanization due to COVID-19. Using the *G. polyphemus* low suitable habitat vector file for 2018 (Crawford et al. 2020b) as a baseline, I was able to delete residential, subdivision, and commercial development, as well as some recreational projects, from 2018 through 2022 from the suitable habitat layer using the Flagler County Parcel vector file (Flagler County 2023), join it with the Palm Coast boundary vector file (Flagler County Florida 2021b), and lastly convert it to a raster image. I verified some larger development sites, recreational project sites, and permits that had incorrect data with Google Earth Pro (Google 2022) and the Flagler County Property Appraisers' website ("Flagler County Tax Appraisers Office" 2023) to check for land changes for the correct years and parcels that were actually subdivided but not reflected in the data. The resulting raster images were assessed using the same scripts as the Flagler County raster images (Table 1).

I assessed vegetation changes for Palm Coast using visual change detection and Normalized Difference Vegetation Index (NDVI). I downloaded Landsat 8/9 imagery (Landsat 2022) for January 4, 2018 and December 09, 2022 from the U.S.G.S. GLOvis website (U.S. Geological Survey 2001). Using MultispecW64 (Perdue Research Foundation 2022), I assessed visual change detection by "logically linking" the 2018 and 2022 images to create a composite image and adjusted the visible blue band. I then calculated the NDVI for both 2018 and 2022

images and then “logically-linked” the two images to form a composite images and adjusting the bands accordingly. I loaded both composite images into QGIS (QGIS Development Team n.d.) and I overlayed it with the low suitability habit map. The visual change detection and NDVI images were then clipped with the Palm Coast boundary layer (Flagler County Florida 2021b).

CHAPTER 3

RESULTS

Flagler County Urbanization – Predictions for 2020, 2040, and 2060

Future suitable habitat for *G. polyphemus* decreased in Flagler County from 2018 through 2020 to 2060 (Table 2) based on predicted urbanization due to projected population growth. Predicted suitable habitat in 2020 was 29007.63 ha, which was 22.06% of the total area of Flagler County (131,480.90 ha), compared to 35,031.33 ha in 2018 (26.64%), a decrease of 17.20%. Future percent land (PLAND) also decreased for 2040 and 2060 by 16.33% and 14.58% respectively. The projected loss of suitable habitat suggests an association with increased urbanization in response to population growth.

Analysis resulted in a future change in the number of patches, which can be used as an indicator of fragmentation. The change in the number of patches from 2018 (actual) to 2020 (predicted) resulted in a predicted increase from 1506 to 1895, which indicates increased fragmentation. Due to COVID-19, the actual 2020 number of patches may have been less than the predicted value, but as there was no predicted change between 2020 and 2040 in the number of patches; therefore, fragmentation was still predicted to increase by 2040. By 2060, the number of patches is predicted to decrease slightly to 1527, which would indicate less fragmentation. Additionally, the size of the patches is projected to change. Although there is no set minimum patch size recommended to support a viable population of 250 or greater individuals (Miller 2001); 100 ha or larger may be needed (McCoy and Mushinsky 2007, Nesbitt et al. 2010). Analysis of the number of patches with an area of greater than 100 ha resulted in a future decrease from 35 (2018) to 19 (2060) patches. Furthermore, there was a predicted greatest patch

size change from 2018 to 2020 of -47.62%, and a -40.96% change from 2020 to 2040, with no change from 2040 to 2060, suggesting less available habitat for supporting a larger tortoise population.

Table 2. Landscape metrics for *Gopherus polyphemus* suitable habitat loss for Flagler County, Florida which has a total area of 131,480.90 ha.

Year	Total area suitable habitat (ha)	Percent land (PLAND) (%)	Percent land change (%)	Greatest patch size (ha)	Greatest patch size change (%)	Number of patches - suitable habitat	Number of patches >100 ha	Percent of patches >100 ha	Suitable habitat - mean area (ha)	Edge density (m/ha)
2018	35031.33	26.64	-----	10089.36	-----	1506.00	35.00	2.32	18.87	28.92
2020	29007.63	22.06	-17.20	5284.35	-47.62	1895.00	33.00	1.74	15.31	31.31
2040	24271.56	18.46	-16.33	3120.12	-40.96	1895.00	26.00	1.37	12.81	27.71
2060	20733.30	15.77	-14.58	3120.12	0.00	1827.00	19.00	1.04	11.35	24.39

Edge density is another metric that can be used to determine habitat fragmentation. The analysis of edge densities showed an increase from 28.92 m/ha in 2018 to 31.31 m/ha in 2020, which is indicative of increased fragmentation. However, edge densities decreased over the predicted years with 27.71 m/ha for 2040, and 24.40 m/ha for 2060, which would suggest a decrease in fragmentation.

Palm Coast Urbanization – Predictions for 2020, 2040, and 2060; Actual 2022

Gopherus polyphemus suitable habitat in Palm Coast was predicted to decrease due to urbanization for the years 2020, 2040, and 2060, as well as from the 2018 suitability map used as a baseline (Table 3). Percent land of suitable habitat decreased 27.39% from 2018 to the predicted 2020 suitable habitat available after projected urbanization due to projected population growth. Analysis also resulted in projected decreases of 17.28% from 2020 to 2040 and 9.20% from 2040 to 2060, with a 40-year overall predicted 24.89% decrease of percent suitable habitat. However, actual loss due to urbanization was less than predicted. There was a decrease of 8.51% of suitable habitat from 2018 (8983.08 ha) to 2022 (8213.76 ha), based on building permits, compared to the predicted decrease of 27.39% from 2018 to 2020 (6522.48 ha). Despite the difference in the actual loss versus the predicted loss of suitable habitat, which most likely can be attributed to COVID-19, the results suggest a link between suitable habitat loss and urbanization.

Additionally, the number of patches was predicted to increase from 476 in 2018 to 704 in 2060, which is indicative of increased fragmentation. The actual number of patches from 2018 to 2022 did increase. But the increase was 476 to 561 and not the predicted 686 (2020), suggesting that fragmentation did occur between 2018 and 2022. Furthermore, the number of patches over 100 ha was projected to decrease over time from 11 (2018) to 5 (2060), even with the negligible actual increase in the number of patches (11 to 13) that occurred from 2018 to 2022. Along with the predicted loss in the number of patches, the greatest patch size area exhibited a decrease from 2018 (3378.15 ha) to 2020 (predicted) (1740.78 ha); a decrease of 44.59%, while the decrease from 2018 to 2022 (2364.75 ha) was 30%. These results suggest that even though the greatest patch size could support a viable population, the number of viable populations may decrease in

Palm Coast due to the decrease in the number of patches that are greater than 100 ha, as well as the decrease in the size of the patches.

Table 3. Landscape metrics for *Gopherus polyphemus* suitable habitat loss for Palm Coast Florida which has a total area of 24,958.71 ha.

Year	Total area suitable habitat (ha)	Percent land (PLAND) (%)	Percent land change (%)	Greatest patch size (ha)	Greatest patch size change (%)	Number of patches - suitable habitat	Number of patches >100 ha	Percent of patches >100 ha	Suitable habitat - mean area (ha)	Edge density (m/ha)
2018	8983.080	35.992	-----	3378.150	-----	476.000	11.000	2.311	17.354	38.290
2020	6522.480	26.133	-27.391	1872.000	-44.585	686.000	8.000	1.166	5.543	29.683
2040	5395.140	21.616	-17.284	1740.780	-7.010	701.000	5.000	0.713	9.344	10.631
2060	4898.790	19.628	-9.200	1740.780	0.000	704.000	5.000	0.710	6.203	4.361
2018	8983.08	35.99	-----	3378.15	-----	476.00	11.00	2.31	17.35	38.29
2022*	8213.76	32.93	-8.51	2364.75	-30.00	561.00	13.00	2.32	14.64	45.13

* 2022 Palm Coast total area raster layer was 24943.95 ha; a 14.76 ha difference.

Edge densities for predicted urbanization for the years 2020 (29.68 m/ha), 2040 (10.63 m/ha) and 2060 (4.36 m/ha) decreased from the 38.29 m/ha of 2018 suitable habitat. A decrease in edge density is indicative of decreased fragmentation. Additionally, 2022 edge density increased with a value of 45.13 m/ha, which is about 1.5 times the projected 2020 edge density, signifying increased fragmentation and suggesting that fragmentation also increases with urbanization.

Visual Change Detection and NDVI

Areas of disturbance throughout Palm Coast are clearly observed with visual change detection, including areas that are considered suitable habitat. Shades of green are indicators of disturbed areas with brighter greens indicative of more disturbance (Figure 7a). This is exemplified with the Grand Landings subdivision, which has a characteristic “P” shape, in both the visual change detection (Figure 7b) and satellite imagery (Figure 7c). The analysis of visual change detection suggests that there is a correlation of disturbance due to urbanization resulting in bare ground and lack of vegetation.

Palm Coast vegetation decreases (orange and red) are observed within *G. polyphemus* suitable habitat in Palm Coast with Normalized Difference Vegetation Index (NDVI) (Figure 8). Vegetation increases (greens) have occurred within some of the suitable habitat areas, as well as areas that remained unchanged (yellows) (8a). The greatest decreases (orange and red) were found in areas that are subdivisions, as evidenced by the Sawmill Creek and Sawmill Branch developments (Figure 8b satellite image of subdivision and NDVI 8c). NDVI results indicate a correlation between vegetation loss and urbanization within *G. polyphemus* suitable habitat.

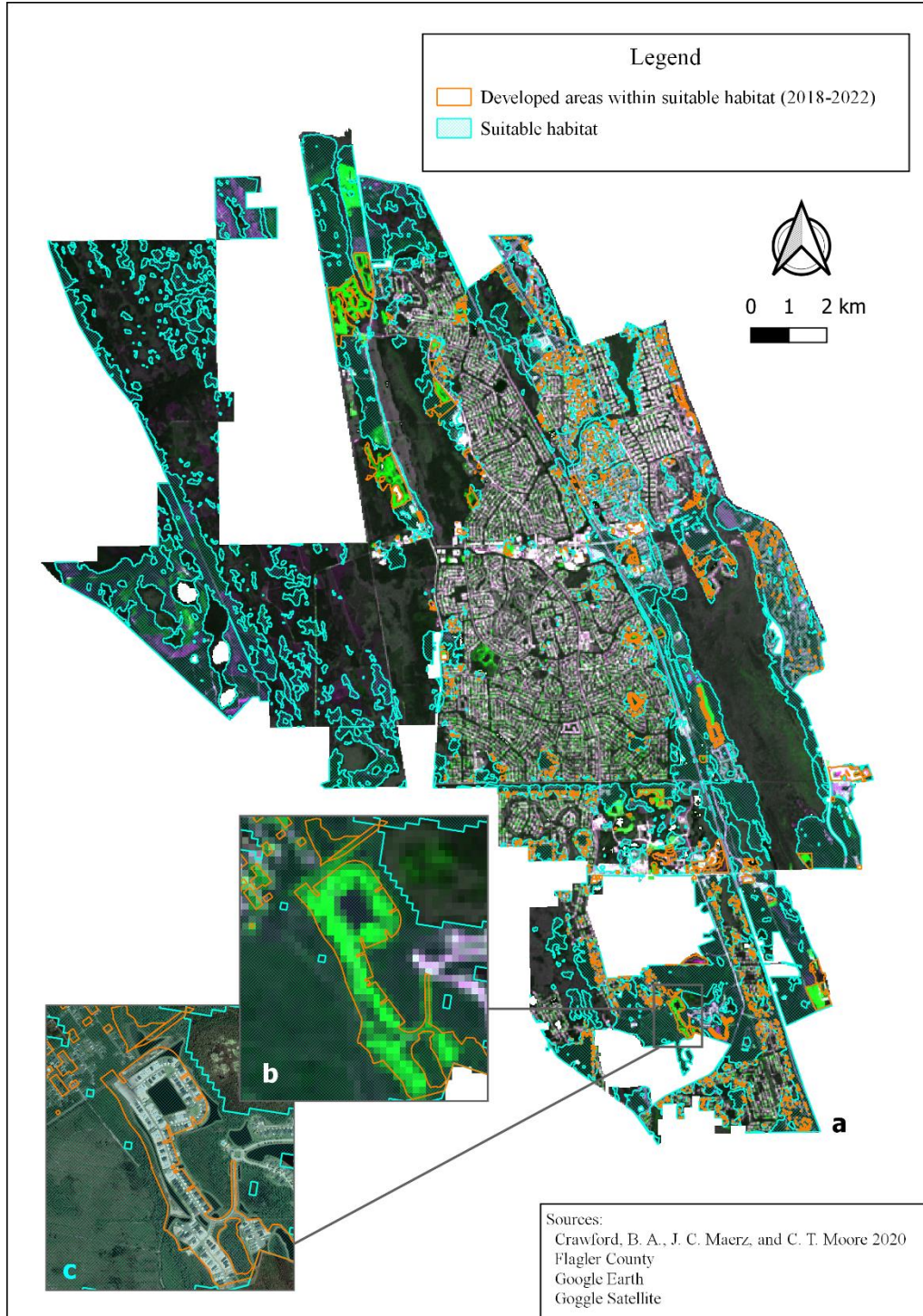


Figure 7. Areas of disturbance are clearly observed with visual change detection throughout Palm Coast (shades of green), including areas within suitable habitat areas (a). Shades of green are indicators disturbed areas with brighter greens indicative of more disturbance. Developments, such as Grand Landings (“P” shape), exemplifies disturbance with neon green shading (b) and satellite imagery showing the actual disturbed area (c).

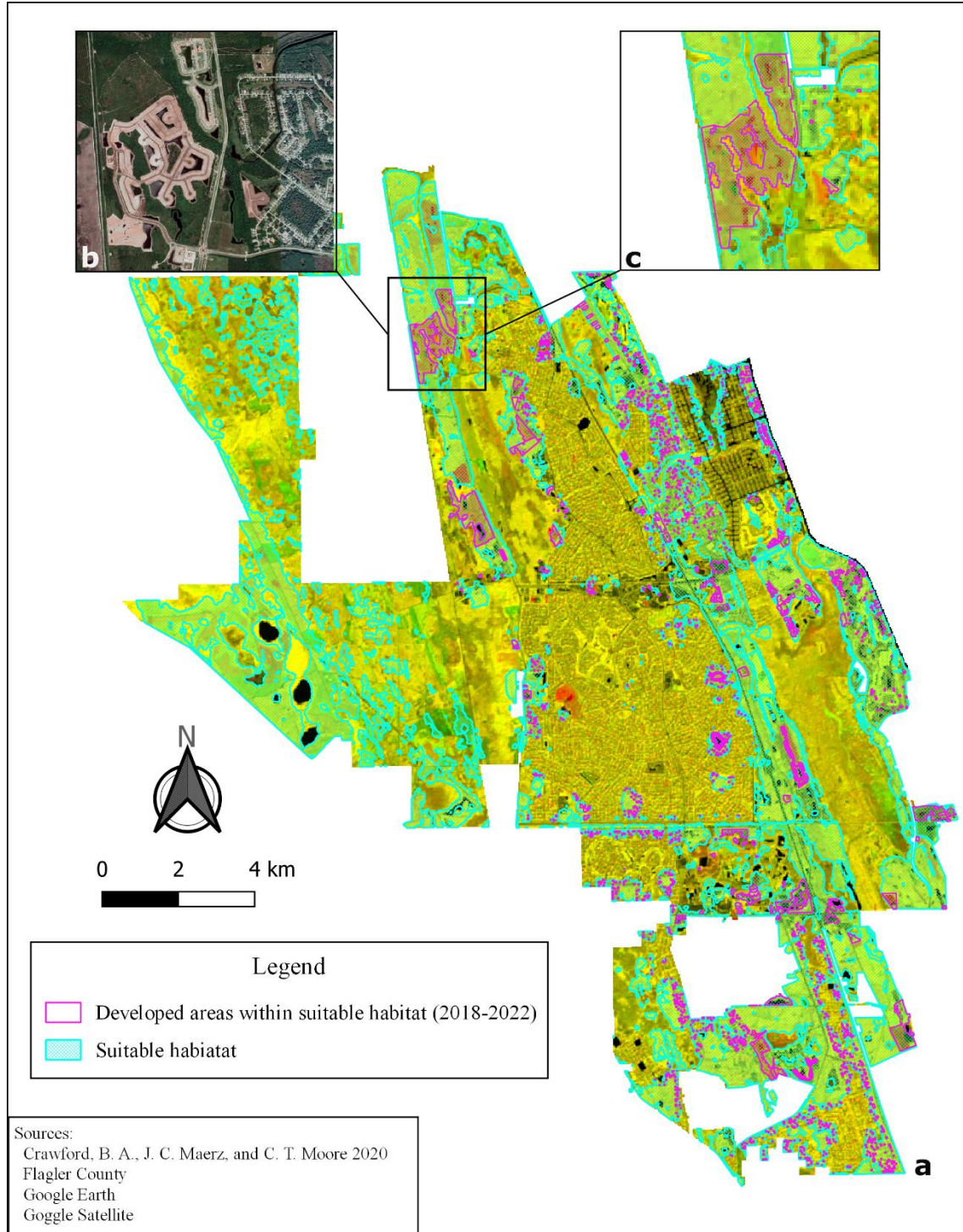


Figure 8. Palm Coast vegetation decreases (orange and red) are observed within *Gopherus polyphemus* suitable habitat in Palm Coast (a) with NDVI. Some areas within the suitable habitat increased (greens) in vegetation and some areas exhibited no changes (yellows) (a). Much of the decreased vegetative areas coincided with development, with the greatest loss in areas with subdivisions, such as the Sawmill Creek and Sawmill Branch (satellite (b) and NDVI (c)).

CHAPTER 4

DISCUSSION

My assessment found that projected urbanization in response to projected population growth impacted and will continue to impact *G. polyphemus* suitable habitat and local populations. Predicted loss of suitable habitat in Flagler County was found to be less than that of Palm Coast (predicted and actual), which as of 2018 had 31% of the county's total suitable habitat within its city limits. This may be attributed to Flagler County having 61,015.44 ha of timberland and most of it in the western part of the county and a portion of that area is unincorporated. While many pine plantations offer suitable habitat, especially *Pinus palustris* (longleaf pine), the suitability depends on a number of factors, including soil substrate, tree type, and the maturity of the forest. As the forest matures, the canopy closes making it unsuitable for *G. polyphemus*, which prefer an open canopy of 30 to 60% (Auffenberg and Franz 1982). If the timber companies, such as Rayonier, which has timberland in Flagler County and manages the land for the gopher tortoise (Rayonier.com 2021), continue their, or incorporate, *G. polyphemus* friendly land management, it is possible that the loss of habitat may be reduced.

My evaluation of future projected urbanization and the effects on patch numbers resulted in an increase from 1506 patches (2018) to 1895 patches (2020) for Flagler County, indicating a projected increase in habitat fragmentation (Saunders et al. 1991). However, from 2020 to 2040 there was no predicted change in the number of patches and a decrease from 2040 to 2060, that would indicate that there will be less fragmentation. Future projected Flagler County urbanization also affects patch size as well. The greatest patch size for 2018 was 10089.36 ha, while 2020 projections resulted in a greatest patch size decrease (5284.35 ha). There is also a

decrease from 2020 to 2040 (3120.12 ha), but no decrease from 2040 to 2060. These decreases indicate habitat loss. Edge densities were found to increase from 28.92 m/ha in 2018 to 31.31 m/ha for the predicted 2020 year, which is indicative that habitat fragmentation increased. Conversely, edge density is predicted to decrease from 2020 to 2040 (27.71 m/ha) and 2040 to 2060 (29.35 m/ha), which suggests that habitat fragmentation has decreased. Interestingly, the tendency is for edge density to increase and patch size to decrease as an indication of fragmentation (Rosa et al. 2017). Even though the edge density is predicted to decrease with a decrease in patch size for the years 2020 to 2040 and may be an indication of less fragmentation, I believe that this will be due to development of small areas of suitable habitat that were “islands” within the county (Figure 8). Further examination of the loss of these islands, its effect on edge densities, and the relationship to habitat fragmentation is needed. And while the loss of these “islands” may reduce fragmentation; it will still result in habitat loss as evidenced by the decrease in the mean area of suitable habitat.

I found the opposite for Palm Coast. Recent and future development have affected and will affect the number of patches indicating fragmentation of *G. polyphemus* suitable habitat. The number of patches increased from 476 to 561 (2018 to 2022) and will increase in the future from 701 to 704 (2040 and 2060), resulting in a more fragmented habitat within the Palm Coast city limits. As with Flagler County, the edge density for Palm Coast suitable habitat is predicted to decrease from 2040 (10.63 m/ha) to 2060 (4.3606 m/ha). Edge density did increase from 38.29 m/ha in 2018 to 45.13 m/ha in 2022, indicating habitat fragmentation occurred due to urbanization of suitable habitat.

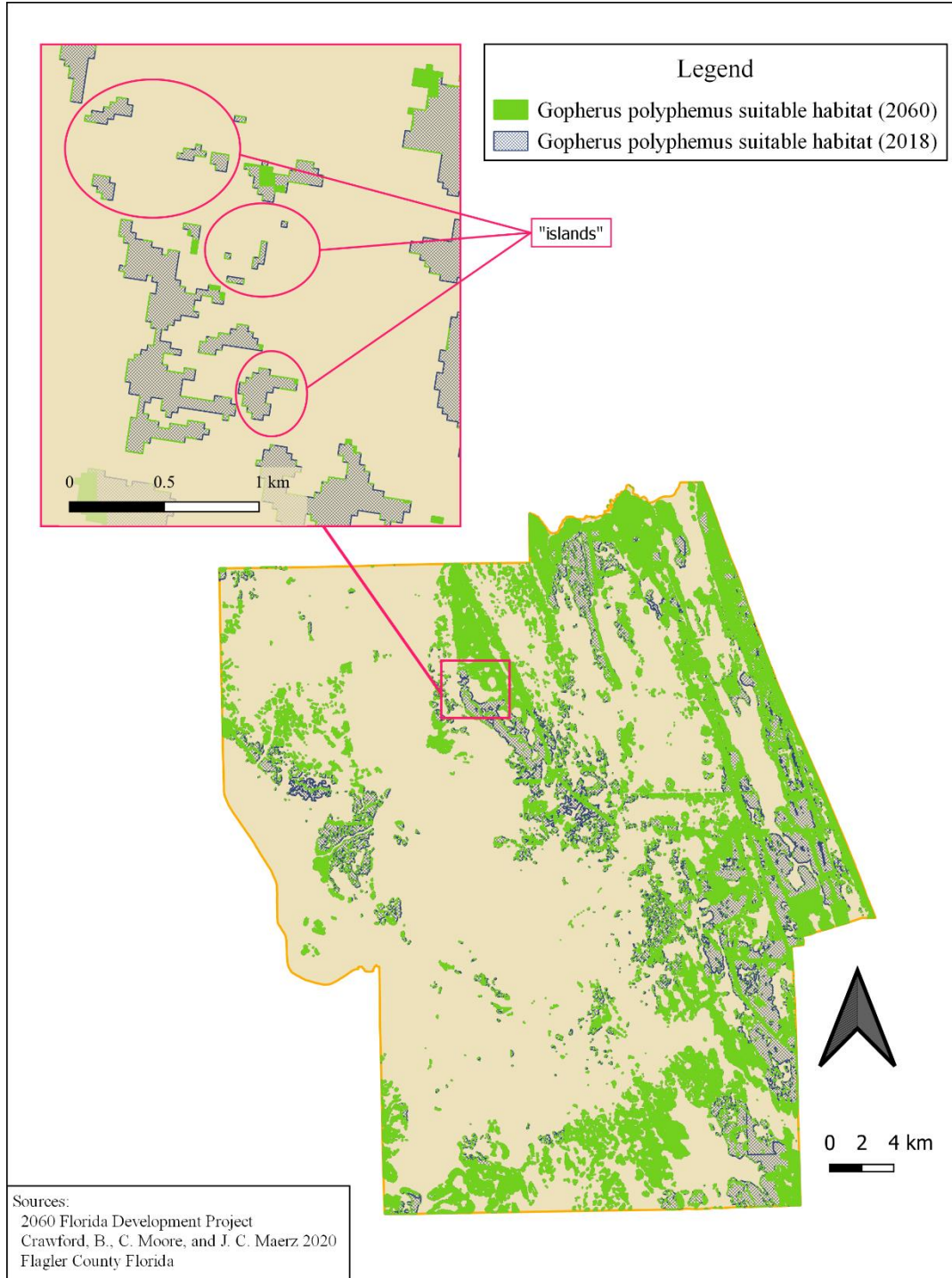


Figure 8. Loss of “islands” of suitable habitat patches may decrease edge densities indicating that there is less fragmentation. Urbanization by 2060 may result in the loss of small suitable patches that are isolated “islands” (pink ellipses within the inset) and decrease edge densities. Decreasing edge density tends to indicate a decrease in fragmentation, however, it will still result in the loss of suitable habitat.

I found that greatest patch size is projected to decrease with urbanization and a few patches would be large enough for a viable tortoise population. But, even with the large patch sizes, it was the number of larger patch sizes that stood out. Estimated minimum patch size for a viable population for gopher tortoises has varied over the years from 10 ha to 25 ha (Cox et al. 1987) to 81 ha (Ott et al. 2002) to 100 ha (McCoy and Mushinsky 2007). These estimates can change when they are calculated due to ever changing conditions (McCoy and Mushinsky 2007). Even with these past studies, the coming of extensive habitat loss will most likely be inadequate to recommend a minimum patch size (McCoy & Mushinsky, 2007). My assessment found that the predicted number of patches greater than 100 ha in Flagler County will be less than 2% of total patches for 2020 and 2040 and 1.04% for 2060. Palm Coast had 2.31% of total patches that were greater than 100 ha for 2022 and predicted patches were 1.17% for 2020 and 0.71% for 2040 and 2060. Despite the smaller patches in both Flagler County and Palm Coast, it may be possible to have viable populations on smaller areas, especially reserves, if they are managed with more determination (McCoy and Mushinsky 2007, Nesbitt et al. 2010).

Currently, Gopher Tortoise Recipient sites are only required to have a minimum of 10 ha (Short-Term Recipient Site) or 16 ha (Long-Term Recipient Site) of contiguous upland habitat, with most sites receiving two tortoises per 0.44 ha (“Gopher Tortoise Recipient Sites” 2023), which is quite a bit less than more recent estimates for viable populations. There are only two possible sites in Flagler County for translocated tortoises. Bulow Creek State Park Recipient Site has a suspended permit and Princess Place Preserve has a permit pending (Florida Fish and Wildlife Conservation Commission 2022). If indeed populations (~50 individuals) can exist on smaller reserves with quality habitat, then recipient sites, as well as a smaller nature preserve,

such as Betty Steflik Memorial Park in Flagler Beach, which does have a *G. polyphemus* presence, may have conservation value (Miller 2001). However, this small preserve is located near the Intracoastal Waterway and may be subject to sea level rise concerns.

There also have been cases where land management on the recipient sites were either poorly managed or incorrectly classified (Commernet, 2011 n.d.), which makes the habitat unsuitable for hosting the tortoises. Additionally, there are *G. polyphemus* populations on Princess Place Preserve (county), Washington Oaks and Gamble Rogers State Parks, all of which use prescribed burns as one means for maintenance, but also have relocated tortoises on-site (Florida Fish and Wildlife Conservation Commission 2022) due to road work or changes in recreational areas (Florida Fish and Wildlife Conservation Commission 2022).

In Flagler County and Palm Coast the majority of lots are cleared entirely of *G. polyphemus* burrows (Florida Fish and Wildlife Conservation Commission 2022) and vegetation (*personal observation*), leaving an open canopy, as well as changes to the edges of adjacent areas. After the lots are cleared of vegetation; sand is trucked in and eventually, spread and leveled (*personal observation*). It can take as many as three years, which is the time limit imposed by the city (Community Development Department), before building is completed. Visual change detection clearly showed large areas for subdivisions and commercial lots that were cleared to bare soil and/or had the sand layer already in place (Figure 6). Predictions for increased development based on population growth have suggested that there will be continued disturbance for Palm Coast and possibly Flagler County, especially if the timber companies ever decide to sell their properties. And to a greater extent, the possibility of losing more suitable

habitat than predicted is a concern because Flagler County is one of eight counties in Florida to show an almost four times growth in relative urban area (Zwick and Carr 2006).

My evaluation provided evidence of vegetation loss in the areas developed between 2018 and 2022. Parcels cleared for subdivisions clearly showed loss of vegetation in the NDVI image (Figure 7). As stated above, the clearing of all vegetation is a customary practice to ready the site for building. Additionally, new subdivisions include new roads and retention ponds (some ponds are located where there were once burrows) (Florida Fish and Wildlife Conservation Commission 2022), which reduce the possibility for revegetation that could be utilized by *G. polyphemus*. Even though most developed areas are not considered suitable areas, along with commercial parking lots, and agricultural lands (Mushinsky et al. 2006); *G. polyphemus* is found in residential areas (*Gopher Tortoise Sightings*, n.d., *personal observation*, 03/23/2023). Furthermore, *G. polyphemus* has been observed using roadways for foraging and nesting (Baskaran et al., 2006; Enge et al., 2006; Rautsaw et al., 2018).

My study yielded results that support that urbanization has had and will impact suitable habitat (Richardson and Hedgepeth 2020) for *G. polyphemus* in Flagler County, which is supported by another study that found urbanization will trend to a larger percentage of suitable habitat loss for certain species (Romañach et al. 2020). My assessment would have benefitted from more building permit data, as well as more accurate data. Flagler County parcel data, GIS layers, and the Gopher Permit Tortoise data had errors. This along with the author not being proficient in the building permit system, may have led to an underestimate of suitable habitat loss for the years 2018 through 2022 for Palm Coast. Furthermore, the predictions for future urbanization were based on predicted population growth from 2005, may have had an effect on

the estimates for future habitat loss. COVID-19 during 2020, may have also skewed the predictions. Regardless, *G. polyphemus* suitable habitat will continue to be fragmented and lost at the same time over the course of the predicted 40 years due to Palm Coast and Flagler County urbanization (Liu et al. 2016, Romañach et al. 2020). Additionally, due to the conservation practice of translocating the majority of *G. polyphemus* from building sites to recipient sites (currently outside of Flagler County); it is not just the loss of suitable habitat, but the loss of members of the local tortoise population and possibly its commensals.

CHAPTER 5

CONCLUSION

Urbanization is inevitable, especially as populations increase, and results in habitat degradation, fragmentation, and loss. The loss of suitable habitat affects plants, wildlife, and humans. *Gopherus polyphemus* suitable habitat and the population has been, continues to be, and will continue to be impacted by the loss of suitable habitat throughout its range. Its preferred habitats are the same ones preferred for urbanization. Conservation efforts have directly helped their populations by moving them from lands slated for development to protected areas, instead of continuing the past practice of entombing them. Incentives for landowners to be recipient sites help keep suitable habitat areas available, but there is little incentive not to build. More than just reducing the loss of suitable habitat for *G. polyphemus*, these efforts could assist with reducing the loss of suitable habitat for the 350 wildlife species that depend on their burrows.

Even with public awareness programs and public objection to subdivisions, there needs to be more efforts towards conserving existing suitable habitat. There should be incentives for landowners to not clear lots entirely and plan to keep as much suitable habitat intact. Additionally, addressing the lack of population and burrow data, which can be augmented through current citizen-oriented programs for reporting not just sightings, but by adding burrow presence observations. Agencies or organizations can send out brief, voluntary surveys to landowners every 3 to 5 years about *G. polyphemus* presence to aid in conservation efforts and policies.

The loss of suitable habitat due to urbanization may not be stopped, but with more effort, it can be reduced. And then, perhaps, the prediction that the only populations of *G. polyphemus* will be on protected lands may not come to fruition.

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