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Gopher Tortoises in Protected Natural Areas: Effects of Natural Area Characteristics on Populations

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GOPHER TORTOISES IN PROTECTED NATURAL AREAS: EFFECTS OF NATURAL AREA CHARCTERISTICS ON POPULATIONS

by

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Abstract

The gopher tortoise (*Gopherus polyphemus*) is native to the Southeast region of the United States. The burrows it digs supports the survival and wellbeing of over 350 other species, with over 60 of those being other vertebrates, making it a keystone species. It is ranked threated to rare by differing organizations with the main threat throughout its entire natural range being habitat loss. The Florida Scrub is the natural habitat of Florida gopher tortoise populations and is one of the fastest declining ecosystems in Florida, particularly in South Florida, due to rapid urban development. Many of the remaining Florida scrub habitats are classified as protected natural areas and are managed by an organization. These protected natural areas vary in size and other characteristics such as management used, wetland size, public access, and more.

This exploratory study endeavored to discover which site characteristics significantly influenced the gopher tortoise populations living within these fragmented habitats. Through the collection and aggregation of large amounts of existing data, principal component analyses were applied to first identify which site characteristics influenced gopher tortoise populations the most. T-tests were then applied to discover which of those identified characteristics were statistically significant influences. The results suggested that site size and the presence of site boundary were the only statistically significant characteristics that influenced gopher tortoise populations. The results also suggested that certain characteristics such as management type, site size, and depth to groundwater warrant further exploration through their own studies to better understand their influence on site's gopher tortoises. Additionally, this study's results suggest that the presence of humans do not have any significant impact on natural area site populations. Finally, the results also gave some insight into best places to dedicate management resources in the interest of conserving gopher tortoise populations in protected natural areas.

Acknowledgments

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I would also like to express my deepest thanks to Lee Lietzke with Palm Beach County Environmental Resources Management. Without his open-mindedness and unparalleled patience, communication, and expertise this project would never have developed, never mind been completed. I will forever be in his debt.

Lastly, words cannot express the appreciation I have for my husband and parents. Without the support they have provided in countless ways, I would have never made it this far. I absolutely could not have completed this undertaking without them.

Dedication

To my children. You motivate and inspire me in ways I never knew possible. I love you both as much as there are drops of water in the oceans, grains of sand in the deserts, and leaves on trees.

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List of Abbreviations & Keywords

ERM Environmental Resource Management

IUCN International Union for the Conservation of Nature

MVR Mechanical Vegetation Reduction

PCA Principal Component Analysis

PC Principal Component

Gopher Tortoises in Protected Natural Areas: Effects of Natural Area Characteristics on Populations

The gopher tortoise (*Gopherus polyphemus*) is native to the Southeast region (Appendix A) of the United States (Ashton & Ashton, 2008; Baskaran et al., 2006; Enge, et al., 2006). It is considered a keystone species and ecological engineer as the burrows it digs support the survival and wellbeing of over 350 other species (Enge et al., 2006), with over 60 of those species being other vertebrates (Dziadzio & Smith, 2016). The species is ranked rare with Florida Natural Areas Inventory and vulnerable by the International Union for the Conservation of Nature (IUCN), though it should be noted that this species has not been evaluated by the IUCN since 1996 (FWC, n.d.). In Florida it is a state-designated threatened species (Enge et al., 2006, FWC, n.d.).

The main threat to gopher tortoise populations throughout its entire natural range is habitat loss (Ashton & Ashton, 2008; Baskaran, et al., 2006; Dziadzio & Smith, 2016, Howell et al., 2020). The Florida Scrub is one of the natural habitats of the Florida gopher tortoise and is one of the fastest declining ecosystems in Florida, particularly in South Florida, due to rapid urban development (Roberts & Cox, 2000; Hall, et al., 2002; Richardson & Hedgepeth, 2020). Many of the remaining Florida scrub habitats are classified as protected natural areas and are managed by an organization. These protected natural areas are typically small, fragmented, and surrounded by commercial and residential buildings and roads (L. Lietzke, personal communication, November 30, 2022). They vary in size and other characteristics such as wetland presence and size, public access, length of paved walking trails, length of sand hiking and utility trails, and site boundary lengths (L. Lietzke, personal communication, November 30, 2022). Another characteristic of these Florida scrub natural areas that varies is management type. (L.

Lietzke, personal communication, November 30, 2022). Historically the Florida scrub habitat would of self-regulated through wildfire, typically ignited by a lightning strike (Roberts & Cox, 2000; Hall, et al., 2002; Richardson & Hedgepeth, 2020). Now, due to the urbanization surrounding many of the protected natural area sites, not only are natural wildfires suppressed, but prescribed burning management is not permitted for many of them (Roberts & Cox, 2000; Hall, et al., 2002; Richardson & Hedgepeth, 2020). In these cases, mechanical vegetation reduction (MVR) management must be used in place of prescribed burns to prevent overgrowth of vegetation (Roberts & Cox, 2000).

In Palm Beach County the Environmental Resources Management (ERM) team is responsible for the restoration and management of many of the county's protected natural areas, including the decision to mow rather than burn. The goal of this study is to investigate the effects of 12 characteristics of 13 different protected natural area sites (Table 1) under ERM's care on their resident gopher tortoise populations. These site characteristics include the three management types (prescribed burn, MVR, wildfire), site size, length of sand hiking and utility trails, length of paved walking trails, size of ERM designated suitable habitat, size of wetland/open water presence, depth to ground water, visitor count, and length of site boundary present. Understanding which site characteristics affect gopher tortoises the most could prove to be enormously beneficial to ensuring populations thrive in these limited habitats. If gopher tortoises prosper, so will the over 350 other species that depend on their burrows for survival (Enge et al., 2006.). Following the "rivet popper" analogy proposed by Ehrlich & Ehrlich in 1981, the presence, or lack thereof, of so many different species will undoubtably affect the health and balance of their ecosystem as:

> Ecosystems, like well-made airplanes, tend to have redundant subsystems and other "design" features that permit them to continue functioning after absorbing a certain amount of abuse. A dozen rivets, or a dozen species, might never be missed. On the other hand, a thirteenth rivet popped from a wing flap, or the extinction of a key species involved in the cycling of nitrogen, could lead to a serious accident. (Bond, 1994)

Table 1

13 natural area site names and GPS locations.

Natural Area Site Name	Natural Area Site Location
Delaware Scrub	26°56'05.8"N 80°06'56.6"W
Delray Oaks	26°25'43.0"N 80°05'37.5"W
Frenchman's Forest	26°51'33.9"N 80°04'32.9"W
Highridge Scrub	26°34'03.3"N 80°04'20.9"W
Hypoluxo Scrub	26°33'57.7"N 80°03'22.4"W
Juno Dunes	26°52'51.6"N 80°03'43.1"W
Jupiter Inlet	26°57'10.5"N 80°04'54.6"W
Jupiter Ridge	26°54'50.0"N 80°04'31.0"W
Lake Park Scrub	26°47'45.1"N 80°04'37.8"W
Limestone Creek	26°56'17.4"N 80°08'12.5"W
Pondhawk	26°23'26.8"N, 80°07'06.9"W
Rosemary Scrub	26°33'30.4"N 80°04'05.7"W
Seacrest Scrub	26°29'46.1"N 80°04'04.5"W
Yamato Scrub	26°24'34.1"N, 80°05'40.5"W

Based on information gleaned from previous studies, it is hypothesized that nine of the twelve natural area site characteristics that influence gopher tortoise populations will be worth evaluating further for statistical significance. These characteristics will include the three management types (prescribed burn, MVR, wildfire), site size, length of sand hiking and utility trails, wetland size, size of suitable habitat, and depth to groundwater. The presence of wildfire, prescribed burn, and MVR management techniques should show a positive correlation with gopher tortoise populations along with larger natural area sizes, longer sand hiking trails and utility roads and larger designated suitable habitat areas. Negative correlations with tortoise populations are predicted to be seen with natural areas containing large wetland and/or open water size and short measurements to ground water depth. The three characteristics predicted to not be influential on gopher tortoise populations are visitor count, length of paved walking trail, and length of site boundary.

Background

Many investigations into the effects of habitat features and management techniques on gopher tortoise populations have been conducted throughout the southeast region of the United States (e.g., Ashton & Ashton, 2008; Howell, et al., 2020; Jones & Dorr, 2004; Tuberville, et al., 2014 & Yager, et al., 2007). Understanding the types of habitats gopher tortoises thrive in is paramount to the success of their conservation. To begin with, this information is invaluable for identifying potential protected areas as there is little use in preserving habitat that does not have the features necessary for the survival of the species. Large studies of terrain have identified areas in just this way. A study by Jones & Door (2004) in southern Mississippi and southwestern Alabama revealed that a gopher tortoises' preferred habitat is one of deep, sandy soils and open

over story canopy. Additionally, Baskaran et al. (2006) showed that land cover, soils, and distance to streams and roads affect gopher tortoise burrow location choice. Specifically, gopher tortoise burrows were more likely to be present in soils with low clay percentage, further from streams, and in areas of open canopy and sparse understory which often caused them to be closer to roads. The results of these studies support that a multitude of features should be considered when deciding upon the investment of land preservation in the interest of gopher tortoise conservation.

There are many occasions in wildlife conservation in which land can be secured for protection, but it has previously been altered from its natural state for human use. In situations like these it is paramount to consider the habitat needs of local wildlife during land restoration. As already discussed, when considering gopher tortoises in habitat restoration those needs can be quite complex. For example, Kowal et al. (2014) found that evaluating gopher tortoise habitat cannot be as simple as considering soil and vegetation type, but rather habitat evaluation must consist of multiple variables, such as landscape features, topography, soil, and vegetation to be effective. Additionally, a study in Miami-Dade County by Whitfield et al. (2022) discovered tortoise burrow features were associated with open canopy, sparse understory, grass cover, and deep soils. These studies both support that suitable gopher tortoise habitats are intricately composed of many different features, some of which (e.g., canopy cover and understory) must maintain a specific state to remain capable of sustaining a flourishing population. The overgrowth of canopy and understory become detrimental to gopher tortoise population numbers and therefore need to be maintained in order to support healthy populations, either by natural means such as wildfire or by human management such as prescribed burns or mechanical vegetation reduction (MVR).

Historical research has left no doubt that, due to the encroachment of human populations, many habitats containing gopher tortoise populations need to be managed to ensure long term success of those existing populations (Ashton & Ashton, 2008). Much like the aforementioned complexity of suitable tortoise habitat, management techniques such as prescribed burn may not be completely straight forward. The results of a 26-year study in southeast Georgia demonstrated "that gopher tortoise population responses to prescribed burning are complex, and primarily influenced by tortoise movements" (Hunter & Rostal, 2021, p. 1). Their results suggest that "prescribed burn plans may best accommodate spatially dynamic tortoise populations when they create spatial heterogeneity in burn ages within the range of typical tortoise movements" (Hunter & Rostal, 2021, p. 1). A 26-year study in Alabama found that management practices were inhibiting the tortoise's ability to maintain the social structure needed for long term survival, suggesting that improper management of habitats could lead to unsustainable populations and decline in gopher tortoise population numbers (Goessling, et al., 2021). The findings of a study in southwest Georgia and south-central Alabama by Tuberville et al., (2014) suggested that heavily managed habitats could be key to the regrowth of tortoise populations, while properly established habitats with appropriate maintenance management will support long term gopher tortoise population success. In south-central Florida, Howell et al., (2019) published a 6-year study that found population density to be higher, tortoises and their clutches to be larger, and survivorship to be higher in the open, ruderal field land use land cover types in comparison to the restored sandhill and fire-suppressed sandhill land use land cover types. In all of these cases land management techniques are shown to be vital to the growth, maintenance, or loss of the gopher tortoise.

The former research conducted on the gopher tortoise supports some basic fundamentals regarding positive habitat impacts on populations. It is quite well established that the species thrives in habitat with open canopy (Ashton & Ashton, 2008; Baskaran, et al., 2006; Jones & Dorr, 2004; Kowal, et al., 2014; Whitfield, et al., 2022; Yager, et al., 2007), sandy soils (Ashton & Ashton, 2008; Jones & Dorr, 2004; Kowal, et al., 2014; Whitfield, et al., 2022), in a xeric environment with low ground water table, (Ashton & Ashton, 2008; Baskaran, et al., 2006), in higher elevation relative to the area, and with lower slope (Kowal, et al., 2014). Gopher tortoises thrive in an appropriate climate temperature range, in open and sunny areas (Ashton & Ashton, 2008; Kowal, et al, 2014), with thinned trees, minimal midstories, (Howell, et al., 2020; Yager, et al., 2007) and sparse understories (Howell, et al., 2020; Whitfield, et al., 2022). These characteristics along with the proper forage species present in a diverse herbaceous ground cover (Ashton & Ashton, 2008; Howell, et al., 2020; Jones & Dorr, 2004; Tuberville, et al., 2014 Whitfield, et al., 2022; Yager, et al., 2007) provide the ideal habitat for gopher tortoise populations to flourish.

These types of habitats can be restored and maintained through certain management activities that have been shown to support gopher tortoise populations. The preservation of small dense thickets for hatchlings and juveniles to survive in provides a solid foundation for the most dangerous time in a tortoise's life (Ashton & Ashton, 2008). Other productive management techniques include providing mounds of appropriate burrowing soil, installing proper protective fencing from roads, controlling the presence of domestic and wild predators, and ensuring proper foraging is available and maintained (Ashton & Ashton, 2008). Creating and/or maintaining the proper vegetation habitat that has been described is best executed with prescribed burns however they should be executed at specific times as to not interfere with tortoise activity (Ashton &

Ashton, 2008; Howell, et al., 2020; Hunter & Rostal, 2021; Jones & Dorr, 2004; Kowal, et al., 2104; Tuberville, et al, 2014; Whitfield, et al., 2022). If fire is not a technique that can be executed due to urbanization, which is often the case, mechanical vegetation reduction is a suitable replacement. (Ashton & Ashton, 2008; Howell, et al., 2020; Jones & Dorr, 2004; Kowal, et al., 2014; Tuberville, et al., 2014).

If this pristine type of habitat is not available, the gopher tortoise prefers ruderal, grass dominated fields over restored sandhill & fire suppressed sandhill habitats or to poorly managed native habitat and will even make use of utility lanes/ roadsides (Howell, et al., 2020). Poorly managed habitat includes features such as lack of tree stand thinning (Gossling, et al., 2021; Jones & Dorr, 2004), total canopy closure (Jones & Dorr, 2004), and increased midstory canopy closure (Jones & Dorr, 2004) which are typically the result of lack of fire which allows increase in foliage growth restricting tortoise movements and results in decreased population densities (Gossling, et al., 2021; Jones & Dorr, 2004; Tuberville, et al., 2014; Yager, et al., 2007). Additional poor management practices include mowing for anthropogenic land use, such as roadsides, food plots, right of ways, pastures, and cleared military training areas (Yager, et al., 2007), and too much human interference which causes soils with too much disruption or limited sand content (Jones & Dorr, 2004; Tuberville, et al., 2014). These are not ideal habitats for gopher tortoise population conservation and represents a part of the challenges that gopher tortoises are sometimes forced to live within.

Observing the dichotomy of knowing the habitat features and management practices that support gopher tortoise conservation and the challenges that they continue to live with is initially what inspired this research. In addition, despite the research that has been done, there appears to be a gap in knowledge when it comes to the comprehensive evaluation of the varying

characteristics of protected natural areas and their effect on the gopher tortoise populations that are obligated to live within them. Of the aforementioned studies, five were not conducted in protected areas and of that five, one was not managed at all, two were managed for timber production, one was managed with prescribed burns and mowing for anthropogenic use (small military installation), and lastly only one was managed with prescribed burns and mowing with gopher tortoise benefits as a loose priority (large military installation with some managed natural areas). The remaining four studies took place on a variety of protected lands including national forests, ecological reserves, and varying nature preserves. These sites all used prescribed burning as a management technique with some including tree stand thinning, MVR, and herbicides. The locations of these studies included Alabama, Georgia, South-Central Florida, and Miami-Dade Florida. Specifically, information regarding the natural area sites of Palm Beach County information is sorely lacking. Considering the approximate 16.2% growth of the human population in this county from 2010 to 2023 (U.S. Census Bureau, n.d.) and that most areas with gopher tortoise populations are small, fragmented, and managed protected areas (FWC, n.d.) it seems necessary that these essential locations be evaluated for their effects on their resident gopher tortoise populations. Understanding what features and management techniques effect gopher tortoise populations the most in these protected natural areas may become essential for this species' survival in this ever-urbanizing county.

Materials and Methods

The ERM team conducts transect surveys of Gopher Tortoise populations every 2-3 years as part of their regular site management. Cooperative work between myself and the ERM team resulted in the collection and aggregation of large amounts of existing data regarding gopher tortoise population surveys dating from 1998 through to 2022, as well as numerical data for the

characteristics of all 13 natural area sites. The existing ERM data, Geographic Information Systems (GIS), and other web resources (ex: Unites States Geological Survey well measurements) were used to build a database identifying all the natural area sites and their corresponding gopher tortoise survey data and the site characteristics' data. This data consisted of the site names, the number of calculated gopher tortoises on the site, gopher tortoise population density values, prescribed burn, wildfire and/or, mechanical vegetation reduction management applied as well as the square footage of said management on the site, the size of the sites, the length of paved walking trails present on the sites, the length of sand hiking and utility trails present on the sites, the size of wetland and open water on the sites, the length of boundary present on the sites, the size of designated suitable habitat present on the sites, the depth to groundwater for the sites, and the amount of visitors to the sites.

R was used to run a principal component analyses (PCA) on the data. When evaluating environmental data using this technique the assumption of normality is not always possible. For this reason, non-normal statistical measures were used. This exploratory analysis informed which of the site's characteristics contribute the most to gopher tortoise population numbers and density, as well as whether the site's characteristic had a negative or positive influence on each site's gopher tortoise population. Essentially, this ranks the site's characteristics in terms of which characteristics correlate most with gopher tortoise population numbers and density in a negative or positive way. The initial PCA (PCA 1) that was run evaluated gopher tortoise population numbers and the raw data measurements of each characteristic category (Table 2).

Table 2

Data type used for PCA 1.

Characteristic	Unit of Measurement
Gopher tortoise population	# of individuals (ex:30.19)
Mechanical Vegetation Reduction Management	Square feet treated
Prescribed Burn Management	Square feet treated
Wildfire Management	Square feet treated
Visitor Count	# of Individuals (ex: 5374.65786)
Size of Natural Area Site	Square Feet
Length of Paved Walking Trails	Feet
Length of Sand Hiking Trails	Feet
Length of Sand Utility Roads	Feet
Size of Wetland/Open Water Present	Square Feet
Length of Site Boundary Present	Feet
Suitable Habitat Area	Square Feet
Depth to Groundwater	Feet

The second PCA (PCA 2) that was run evaluated gopher tortoise population density and site characteristic data normalized by site size (Table 3). This was done to remove the size effects of sites, as larger sites inherently can house larger gopher tortoise populations.

Table 3

Data type used for PCA 2.

Characteristic	Unit of Measurement
Gopher tortoise population density	# Of individuals per acre (ex: 5.33)
Mechanical Vegetation Reduction Management	% of site treated
Prescribed Burn Management	% of site treated
Wildfire Management	% of site treated
Visitor Count	# of individuals ÷ 1000 for scale (ex: 5.3746)
Size of Natural Area Site	Acre
Length of Paved Walking Trails	% of site
Length of Sand Hiking Trails	% of site
Length of Sand Utility Roads	% of site
Size of Wetland/Open Water Present	% of site
Length of Site Boundary Present	% of site
Suitable Habitat Area	% of site
Depth to Groundwater	Feet

Based on the results of PCA 2, two tailed t-tests assuming unequal variances were used to conduct statistical hypothesis testing. This analysis was used to identify which of the site's characteristics have a significant impact on gopher tortoise population density. This was done by calculating the median data point of each site characteristic's collective data values (ex: the median value of the percent of a natural area site that was managed with prescribed burn) and then splitting the corresponding gopher tortoise density data. This corresponding gopher tortoise density data was categorized into a high set and low set (ex: gopher tortoise density values corresponding to sites with a high percentage of paved walking trails vs gopher tortoise density values corresponding to sites with a low percentage of paved walking trails). These gopher tortoise population density data sets were then used as each tail of the t-tests with an alpha of 0.05. To summarize the statistical analysis methods, the PCA's suggested which site characteristics contribute most to gopher tortoise population numbers and densities and whether those characteristics corelate to populations in a negative or positive way, and the t-tests' confirmed beyond a reasonable doubt which of the characteristics make a significant impact on those populations.

Results

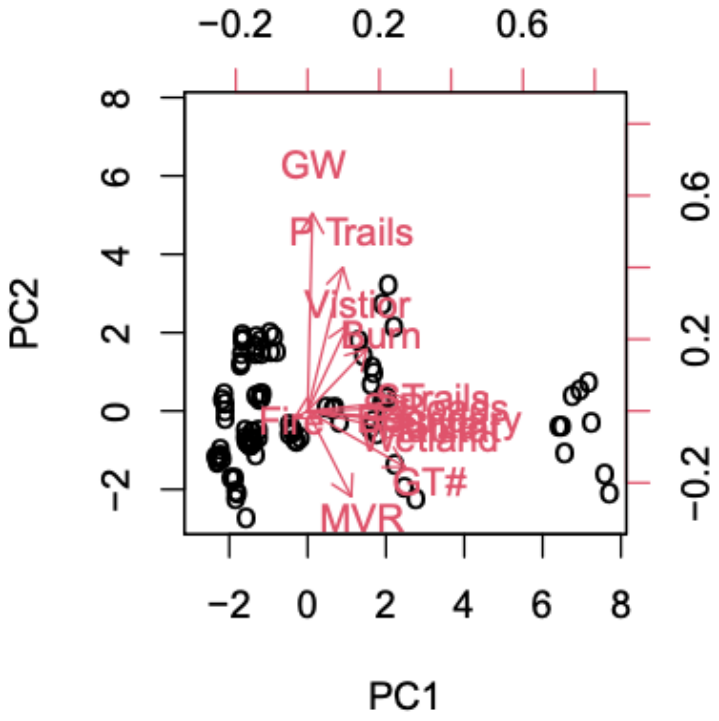
The results of the initial PCA (Figure 1) provided no insight into which site characteristics have the most effect on gopher tortoise population numbers. This is a result of each site characteristic value correlating to the size of the site. Thus, the larger the site size, the larger all of the other site characteristic values, providing no clarity on which site characteristics effect gopher tortoise population numbers. As a result, a second PCA (PCA 2) was conducted evaluating gopher tortoise population density values instead of population numbers with many

site characteristics measured as percentages of the site to avoid the size correspondence issue from PCA 1.

29.6% of PCA 2 was explained by principal component 1 (PC1), and 16.2% was explained by principal component 2 (PC2). Gopher tortoise density correlated with PC1, but not PC2. Thus, only PC1 was used to evaluate site characteristics. The results of the second PCA (Figure 2) suggested that seven of the twelve examined natural area site characteristics were worth evaluating for significance: the percent of paved walking trails present on sites, the percent of prescribed burn management applied to sites, the percent of sand utility trails present on sites, the percent of boundary present on sites , the visitor count of each site, the size of each site, and the percent of wetland and/or open water present on sites.

Figure 1:

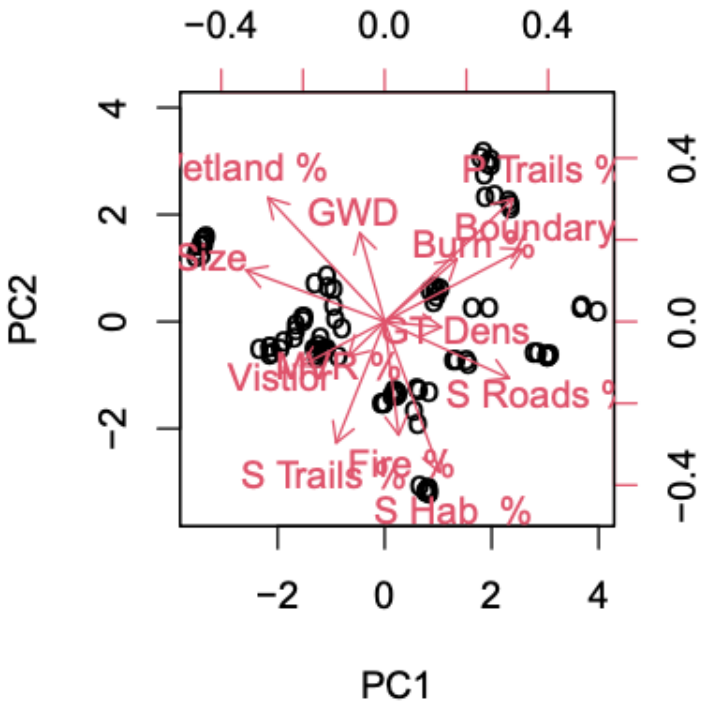
PCA 1 Plot



Note: PCA 1 shows the correlation of raw site characteristic data (Table 2) to gopher tortoise population data. No conclusions of which characteristics were most influential on gopher tortoise populations could be made due to site size correspondence issues.

Figure 2:

PCA 2 Plot



Note: PCA 2 shows the correlation of gopher tortoise population density with site characteristic data normalized by site size (Table 3). This plot identifies characteristics with positive correlation to population density, characteristics with negative correlation to population density, and characteristics with no correlation to population density.

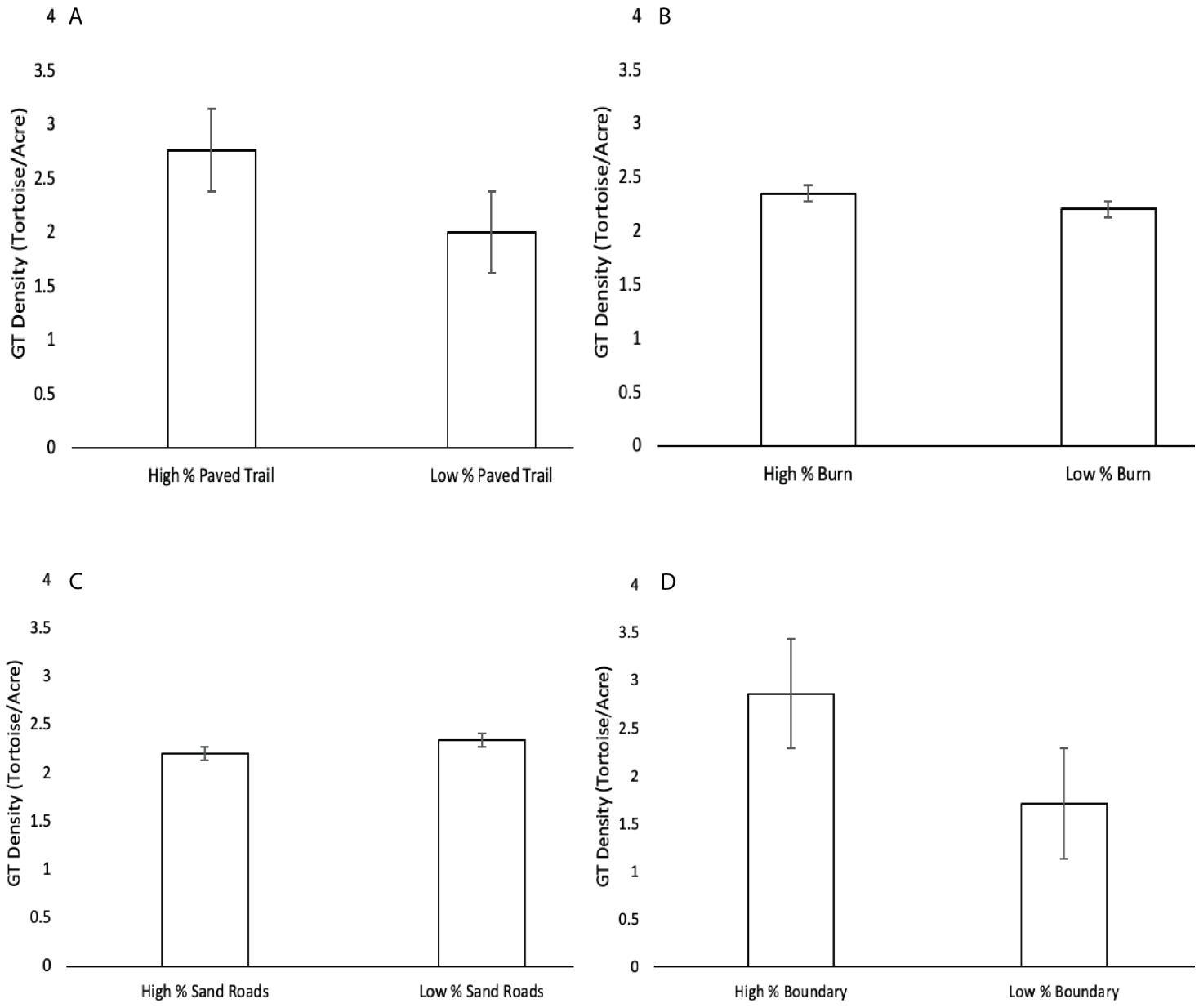
The site characteristics identified by PCA 2 which positively correlated with gopher tortoise population density were: the percent of paved walking trails present on sites, the percent of the sites that were managed through prescribed burn techniques, the percent of the sites that were occupied by sand utility trails, and the percent of boundary present on the sites. The site characteristics identified by PCA 2 that negatively correlated with gopher tortoise population density were: the visitor count of each site, the size of each site, and the percent of wetland and/or open water present on sites. The positively correlating site characteristic values were

defined as being greater than 0.175 as this was beyond the gopher tortoise population density vector, while the negatively correlating characteristic values were defined as less than -0.175 as it would indicate an effect in the opposite direction.

The seven characteristics that were identified from the second PCA as being most influential on gopher tortoise population densities were then evaluated for significance via t-test ($p < 0.05$). The results (Figures 3 A-D and Figures 4 A-C) show that only two of the seven characteristics had a significant impact on gopher tortoise population density: the size of site (Figure 4B, $p < 0.01$) and the percent of boundary present on a site (Figure 3D, $p < 0.01$). The influence of the percent of paved trails present on a site was nearly statistically significant (Figure 3 A, $p= 0.098$).

Figure 3:

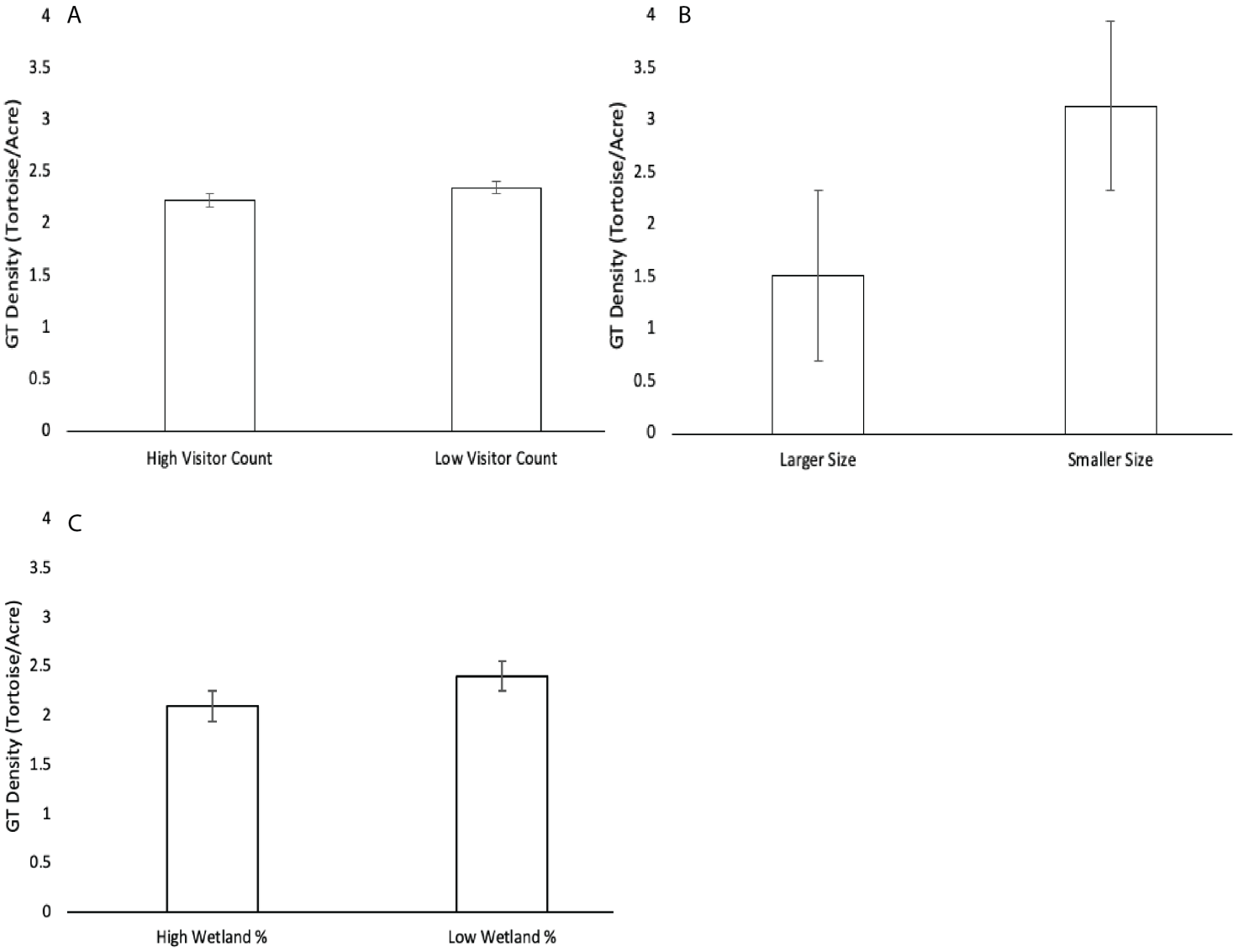
T-test results for site characteristics with positive PCA correlation on gopher tortoise population density.



Note: A- Paved Trail (p=0.097), B- Prescribed Burn (p=0.705), C- Sand Utility Roads (p=0.708), D- Boundary Present (p=0.002).

Figure 4:

T-test results for site characteristics with negative PCA correlation on gopher tortoise population density.



Note: A- Visitor Count (p=0.737), B-Site Size (p < 0.001), C- Wetland/ Open Water Present (p=0.396).

Discussion

The results of this exploratory study were quite surprising and did not align much with the original hypothesis. While the predicted number of characteristics that would be worth evaluating for their significance was close (seven instead of nine), the content of those characteristics was quite different. While all management types were predicted to be influential, the only management type that was shown to be worth evaluating for significance was prescribed burn. While this is not surprising as it is widely accepted that prescribed burning is an effective management technique, it is surprising that this did not result as a significant influence on gopher tortoise populations. The collective view of only one of the three management techniques being worth evaluating for significance and then that management technique not resulting as significantly influential on gopher tortoise populations suggests that site management, while important to continue, may not be the most significantly impactful site characteristic to gopher tortoises living in protected natural areas. Previous research has established that prescribed burns and MVR are essential management techniques for the prevention of vegetation overgrowth enabling tortoise movement and supporting their survival (Ashton & Ashton, 2008; Howell, et al., 2020; Hunter & Rostal, 2021; Jones & Dorr, 2004; Kowal, et al., 2104; Tuberville, et al, 2014; Whitfield, et al., 2022). Because habitat management is typically perceived as very important in the gopher tortoise conservation community, this would be worth examining more thoroughly on its own. Perhaps with a study of broader and more controlled gopher tortoise population survey evaluations surrounding management treatments.

While site size did result as one of the characteristics worth evaluating as significant, as hypothesized, the PCA data did not correspond positively to gopher tortoise population density

as predicted. This could possibly be explained in a few ways. Firstly, it could be that gopher tortoises are harder for surveyors to find on larger natural sites and therefore less are identified. Building off of that explanation, per the Wildlife Survey Protocol for Palm Beach County Natural Areas gopher tortoise surveys must only be conducted in designated suitable habitat areas and only need to represent 15% of that suitable habitat area at minimum. Since only sections of natural area sites are surveyed for gopher tortoise populations, as opposed to the whole site at once, and the populations are then estimated based of the number of potentially occupied burrows in that section, it could be that the tortoises are in different areas of the site than at the time the survey takes place. Since gopher tortoises move burrows, and with more room to spread out, their active burrows could be more easily missed when that section of the site is surveyed. Another potential explanation for this negative PCA correlation is that perhaps with larger size sites gopher tortoises have a more difficult time finding one another for reproduction. This could be examined further through another study exploring the ideal carrying capacity of tortoise habitat sizes and then potentially relocating some gopher tortoises from sites that are above that ideal value to sites that are below it, conducting new surveys, and reevaluating the collected data in the same manner as was conducted in this study to support or refute the results that were found here.

While length of sand utility trails was selected for further evaluation and had a positive PCA correlation with gopher tortoise populations as predicted, length of sand hiking trails did not. This is surprising as they are similar features within the natural area sites. This could possibly be explained by the idea that the sand utility trails are not occupied by human activity as frequently as sand hiking trails, providing quiet navigation routes for the tortoises, but this would require further examination to support. Additionally, as sand utility trails are wider than sand

hiking trails this provides a trail with more open canopy and sparse understory for gopher tortoises to use for navigation which could be another explanation as to its PCA selection over hiking trails. Without either of these features being significantly influential on gopher tortoise populations it may not be worth the resources required for additional study. Further against the hypothesis, the length of paved walking trails was selected as worth evaluating and was nearly significant with a positive correlation to populations. This suggests that the paved walking trails of natural area sites slightly influence gopher tortoise populations in good any way and can possibly be explained as way for gopher tortoises to navigate around sites more easily, as it has been previously observed that gopher tortoises will use road shoulders to navigate habitats that are overgrown with thick vegetation (Baskaran, et al., 2006)

The size of wetland and or/open water present on the sites was selected to be further evaluated for significance and had a negative PCA correlation to gopher tortoise populations as hypothesized. However, this characteristic does not significantly affect gopher tortoise populations which is slightly surprising as gopher tortoises cannot swim, cannot dig their burrows in wet areas, and previous studies show that they prefer dry environments further from bodies of water (Ashton & Ashton, 2008; Baskaran, et al., 2006). This result suggests that site managers should keep wetland and open water presence on a site smaller if gopher tortoise conservation is a priority for a site, but that gopher tortoises are capable of finding dry areas of a site for their burrows when wetland and/or open water is present in their habitat.

Size of designated suitable habitat was not selected as an influential characteristic on gopher tortoise populations as was hypothesized it would. This suggests that the habitat that is evaluated as suitable living area for gopher tortoises does not affect the population presence in a natural area site, that these evaluations may not be worth doing, and that resources designated for

these evaluations may be better used in other aspects of natural area site gopher tortoise conservation.

Depth to groundwater was not identified as being worth further evaluation as hypothesized it would be. This is surprising because if ground water levels are too high gopher tortoises cannot dig their burrows beneath the ground's surface and therefore cannot survive (Ashton & Ashton, 2008; Baskaran, et al., 2006). This characteristic would need further examination as to why it did not result as influential nor significant. Perhaps revisiting the measurements used for this study and comparing them to existing literature which states the average depth for Florida gopher tortoise burrows is 6.5 feet would be a good first step (FWC, n.d.). If the values align with this existing knowledge, a study comparing gopher tortoise populations on sites with ground water depth measurements taken specifically on site at the time of population surveys is needed in order to support or disprove the lack of influence ground water depth seems to have on populations as suggested here.

Again opposing the hypothesis, visitor count was selected as a characteristic to be evaluated for significance and was found to have a negative PCA correlation to gopher tortoise populations but was found not to be significantly influential. This suggests that while lots of visitors to natural area sites could have a negative influence on resident gopher tortoise populations it is not a significant influence. This is good news as part of what aids in the development of protected natural area sites, and by default the restoration and protection of gopher tortoise habitat, is that the human population enjoys visiting them. Natural area sites can continue to be acquired and restored for human enjoyment while conserving gopher tortoises without significant disruption to the resident populations.

The last and perhaps most surprising characteristic evaluated was boundary length. This characteristic defied the hypothesis fully by not only being selected as worth evaluating for significance, but also by being statistically influential on gopher tortoise populations. The positive PCA correlation along with the significant *p*-value suggests that the more boundary present on a natural area site the higher the gopher tortoise population density will be. Boundary was qualified in this study as any physical barrier that inhibits tortoises from leaving a natural area site and is present around the designated perimeter of a natural area site. Examples of boundary are fencing that tortoises cannot fit underneath or through and bodies of water. Ideal fencing for gopher tortoise conservation is described in the 2008 publication by Ashton & Ashton as being a minimum of 18 inches underground, a minimum of 4 feet tall, and has small enough openings that juveniles may not pass through it. This result indicates that the containment of tortoises in the natural area sites, thereby preventing them from leaving the site to live in a different location or getting hit by vehicles on the roadways that often surround natural area sites, significantly impacts population levels within the sites.

While this study evaluated many different characteristics of natural area sites and their influences on the resident gopher tortoise populations, it was not without its limitations. This study was unable to evaluate the effect of noise pollution on gopher tortoises living in protected natural areas as there was no appropriate data measurements to evaluate this characteristic's effect and the resources and time needed to measure this data were outside the scope of this study. Additionally, soil sample data and vegetation density data were not available for evaluation nor were they able to be gathered, again due to the restrictions on resources and time. Given the importance of these features as described in previous gopher tortoise habitat studies, it would have been valuable to include it in the examination (Ashton & Ashton, 2008; Baskaran, et

al., 2006; Jones & Dorr, 2004; Kowal, et al., 2014; Whitfield, et al., 2022; Yager, et al., 2007). Additionally, burrow location data from population surveys and tortoise tracking data was not available for evaluation. These would have been valuable pieces of information in understanding the site characteristic effects on populations as it would have given deeper insight into the populations on each site (Ashton & Ashton, 2008; Kowal, et al., 2014; Yager, et al., 2007). Lastly, Gopher tortoises are a long living, slow to adapt species and therefore to examine them with the highest effectiveness studies should be done over long periods of time to reflect this (Goessling, et al., 2021; Hunter & Rostal, 2021). Due to time and resource constraints, this study was a short one based on data already available, as opposed to data that was measured purposefully for this study at specific times for specific reasons.

To summarize, this exploratory study found that certain natural area site characteristics, such as management type, site size, and depth to groundwater warrant further exploration through their own studies to better understand the significance of their influence on gopher tortoise conservation. Additionally, this study's results suggest that the presence of humans, and the trails that accompany them, do not have any significant impact on natural area site gopher tortoise populations. This indicates we can live in harmony with gopher tortoises, protecting their natural habitat both for their survival and our enjoyment of nature. Further the size of wetland and/or open water on natural area sites is something for managers to be mindful of for gopher tortoise conservation, but they are quite capable of finding their way around it to preferred habitat space. Lastly, the evaluation of suitable habitat within a site does not seem as though it is a productive use of management resources and that those resources could be directed towards creating and maintaining full perimeter boundaries on every natural area site given the positive PCA correlation and significant influence boundary presence has on gopher tortoise populations.

Overall, this study shows the importance of protected natural area sites to gopher tortoise conservation, and wildlife conservation in general. They have many characteristics that support the threated gopher tortoise species, thereby supporting the hundreds of other species dependent on the tortoise and its burrows. The protected natural area sites also present many opportunities for continuous gopher tortoise conservation research as well as research of many other species. Further, they provide a place for humans to connect with nature, providing opportunities for appreciation of the natural world and supporting physical and mental health. They are a great example of sustainable biological conservation. To quote Ashton and Ashton (2008) “Biological sustainability as a concept encompasses us all.

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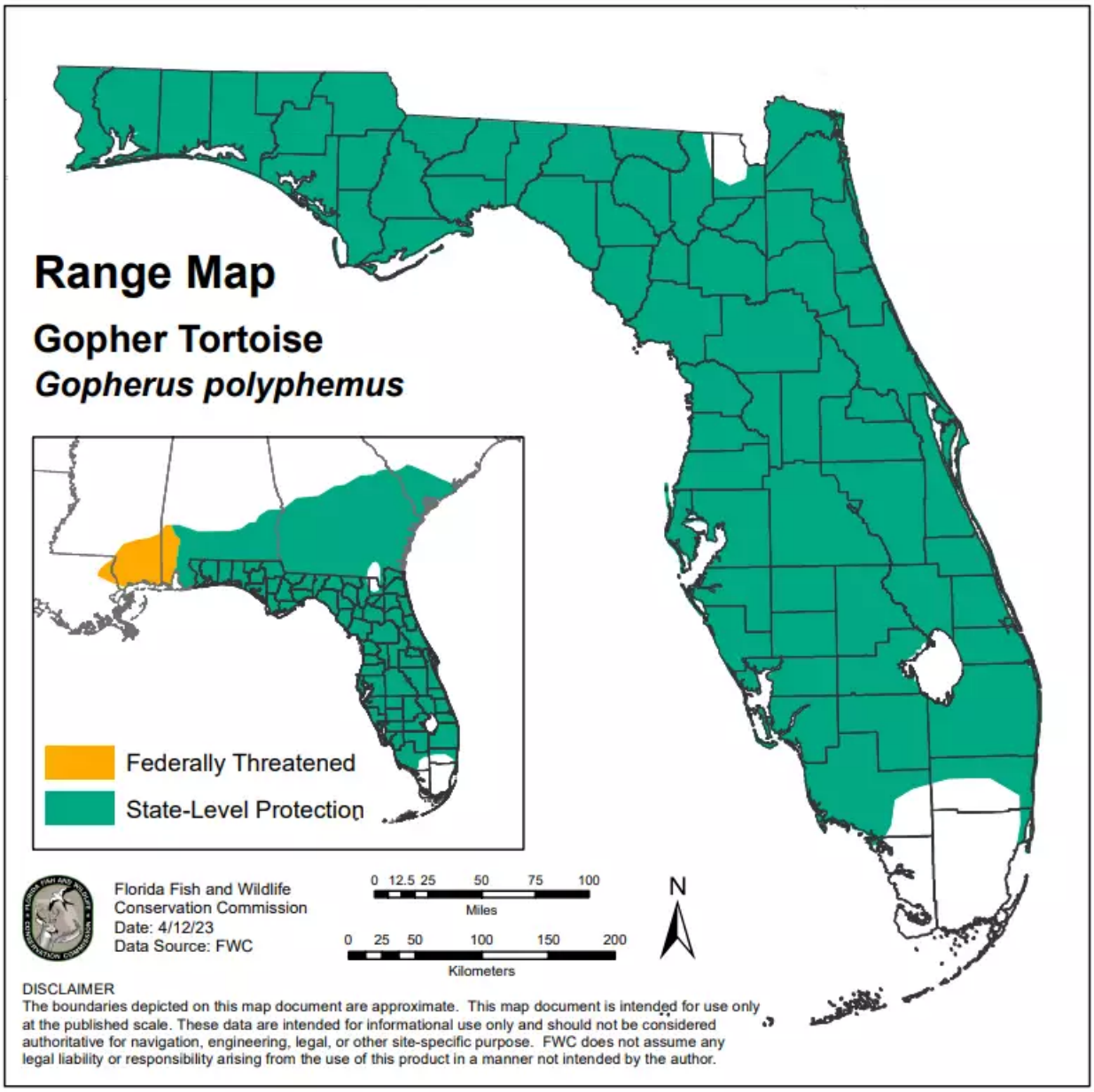
Appendix A: Gopher Tortoise Native Habitat Range



(FWC, n.d.)