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Population Structure and Burrow Placement of *Gopherus polyphemus* in a Small, Declining Southeast Florida Conservation Area

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Abstract

Gopherus polyphemus **has been declining throughout its range since the 1800s primarily due to urbanization, which often leads to the creation of island habitats. This confines populations and eliminates natural management by wildfires resulting in degraded island habitats. To maximize conservation efforts in rapidly developing regions it is critically important to investigate not only the natural ecology of native species, but also how they are doing in habitats set aside for them. We studied a gopher tortoise population to determine its sustainability and burrow placement across different soil and vegetation types in a conservation area on the Florida Atlantic University campus in Boca Raton, Florida. We conducted complete burrow surveys using belt transects, directly captured tortoises, and performed vegetation and soil analyses through aerial photos and United States Geological Survey data, respectively. The sustainability of the population was based directly on age structure, gained from carapace length measurements, and indirectly on ratios of active to abandoned burrow categories. Tortoises burrowed densely in areas of low vegetation and completely avoided areas with closed canopies, which comprised about 15% of the habitat. Soil types had a significant correlation to the spatial distribution of burrows. We found a high ratio of active to abandoned burrows, which could indicate an active and healthy population; however, age structure data compiled from captured tortoises revealed a lack of sub-adults, suggesting an unsustainable population. We concluded that tortoise surveys which solely collect data on burrow numbers and activity level and not tortoise sizes may provide misleading results on the status of gopher tortoise populations in confined, degraded habitats. More direct population assessment methods such as tortoise captures or burrow measurements need to be used.**

Introduction

Since the 1980s, when conservation biology gained its contemporary definition, efforts to protect our planet's biodiversity through the establishment of national and local parks and conservation areas has grown significantly (2010a). However, establishing such areas may not be enough to protect certain species(Ervin 2003, 2010a). For example, the greater prairie chicken's declines in the Midwest United States continued in the mid 1990s despite a significant increase in the amount of favorable habitat set aside for its recovery(Westemeier et al. 1998). Habitat management and species assessment are equally important to ensure that our conservation efforts are effective (Ervin 2003).

South Florida is home to an abundant array of imperiled species and habitats, such as Gopherus polyphemus, the gopher tortoise (Holder et al. 2007). The gopher tortoise is a long lived, slow maturing species, whose burrows provide shelter to more than 300 invertebrate and 60 vertebrate species (Breininger et al. 1991, Butler and Sowell 1996, Schwartz and Karl 2005). As a result of their disproportionately large impact on other species, they are considered a keystone species and receive a great deal of conservation attention (Ashton and Ashton 2008). Tortoise populations have been declining since the early 1800s as a result of human activity (Ashton and Ashton 2008). Populations west of the Mobile and Tombigbee Rivers in Alabama, Mississippi, and Louisiana have been listed as threatened since 1987 by the United States Fish and Wildlife Service (USFWS) while those to the east of the rivers in Florida Georgia, Alabama, South Carolina were listed as a candidate species for threatened status (Service 2011, USFWS 2011). Evidence suggests that tortoises continue to decline throughout their range today despite increases in land set aside for the recovery of gopher tortoises (McCoy et al. 2006, Ashton and Ashton 2008). Monitoring and management have been incomplete and it has been shown that tortoises on some protected lands in northern and central Florida continue to decline (McCoy et al. 2006).

Little is known about the status of tortoises in southeastern Florida and no data are available on population change over time. Preserves have been set aside for gopher tortoises but monitoring efforts have been incomplete as they have focused solely on locating and counting sub-adult and adult burrows(McCoy et al. 2006, Ashton and Ashton 2008). Observation of tortoise burrow numbers alone may not be indicative of the sustainability of a population (McCoy et al. 2006). More information such as population age structure obtained either through indirect measurements of burrow widths or direct measurements of tortoise carapace length should also be obtained (Alford 1980, Mushinsky et al. 1997, McCoy et al. 2006). King conducted a study in 2005 on a tortoise population in a conservation area managed for tortoises in southeastern Florida. Using systematic stratified sampling King surveyed the entire habitat for tortoises and also captured most of them (King 2005). King also measured the carapace lengths of captured tortoises and found that the population consisted almost entirely of adults (King 2005). In addition active to abandoned burrow ratios can be used to elucidate some factors about populations in conjunction with age structure data (McCoy et al. 2006). Our first goal in this study was to investigate hypotheses of population declines on protected habitats by surveying the tortoise population that King studied in 2005 and comparing our results with King's.

One factor speculated to contribute to the continued decline of tortoises on conservation lands is insufficient habitat management (Mushinsky et al. 1997, McCoy et al. 2006). Burrowing preferences have not been investigated in southeastern Florida and thus existing management strategies may not be maximizing efforts to provide the tortoise with a suitable habitat (King 2005). A suitable tortoise habitat is composed of upland, dry scrub habitat which is also prized by humans because it is ideal for real estate development (Mushinsky et al. 2006, Ashton and Ashton 2008). Such habitat consists of well drained, sandy soils, low canopy coverage, and high herbaceous vegetation which aids tortoise burrowing, thermoregulation and foraging, respectively (Mushinsky et al. 2003). Low canopy coverage and abundant herbaceous vegetation are maintained naturally by wildfires. Fragmentation of habitats and proximate human settlement eliminates natural management regimes causing canopy closure and associated reduction of herbaceous vegetation, both unfavorable to tortoises (McCoy et al. 2006).

Our second goal in this study was to gain insight into burrowing preferences of gopher tortoises in degraded habitats such as ours. We compared those to preferences found in northern Florida populations to determine if management strategies at our site would benefit from being tailored to our population.

For our first goal, we hypothesized that the population of gopher tortoises would still consist primarily of adults though the population probably increased as a result of illegal relocations to our study site. For our second goal we hypothesized that tortoises would exhibit burrowing preferences for well drained, sandy soils and areas of low vegetation, similar to those observed in the northern portion of their range.

Methods

Study site

Our study was conducted at the Florida Atlantic University (FAU) conservation area in Boca Raton, Florida (26° 23' N, 80° 7' W). Although its acreage is not protected in perpe-

Figure 1. Aerial photograph of the FAU Conservation Area on the Florida Atlantic University campus in Boca Raton, Florida.The site consists of two habitat fragments separated by Palm Beach Avenue and a long parking lot. The larger fragment to the west of Palm Beach Avenue consists of xeric oak scrub mixed with patches of oak hammock and saw palmetto (Serenoa repens) stands. Invasive species including Brazilian pepper tree (Schinus terebinthifolius), umbrella tree (Schefflera spp.), and Acacia exist throughout the scrub. An old, drift-fence line from past tortoise relocations crosses the center of the fragment. Other trails exist from human disturbance such as dirt bikers and hikers. The smaller portion lies to the east of Palm Beach Avenue and is regularly mowed. It consists of grasses and a few lone slash pine and palm trees. The black bar represents 200 meters. Both fragments are bordered by aregional airport to the north and west, FAU to the south, and Palm Beach State College to the east.

tuity for tortoises it is currently protected and managed for them. The areas herbaceous vegetation changes seasonally with green grass and other herbaceous vegetation primarily evident during South Florida's rain season from late spring to late fall. During the dry season most annual grasses and plants wither and only perennial grasses remain along with shrubs and trees. The site consists of two habitat fragments separated by Palm Beach Avenue and a long parking lot. In our study, the two sites were considered as one as numerous tortoise crossings were observed between the sites. The larger fragment is to the west of Palm Beach Avenue and consists of xeric oak scrub mixed with patches of oak hammock and saw palmetto stands. Invasive species including Brazilian pepper tree, umbrella tree, and acacia exist throughout the scrub. An old path bisects the larger fragment, remnant of the path of a former drift-fence line created to increase site fidelity of past tortoise relocations to the site. Other trails exist from human disturbance such as dirt bikers and hikers. The smaller portion lies to the east of Palm Beach Avenue and is regularly mowed. It consists of grasses and a few lone slash pine and palm trees. Both fragments are bordered by a regional airport to the north and west, FAU to the south, and Palm Beach State College to the east.

The area is composed of 36.83ha (368,300 m2) of upland habitat filled with well-drained soils suitable for the gopher tortoise (King 2005). The area is an island habitat as artificial barriers that include a busy road, an airport, and the FAU and Palm Beach State College campuses, prevent tortoises from dispersing (King 2005).

Burrow survey

We surveyed our site during the final month of the tortoises' 2010 active season to ensure that burrows located were representative of tortoise preference and selection. We conducted a complete burrow survey using belt transects (McCoy et al. 2006, Ashton and Ashton 2008). Our GPS unit (Trimble ProXH) was only accurate to +/- 5m. We placed our belt transects inside 50 meter by 50 meterplots to ensure that transects were traced precisely with low error (+/- 1m). To ensure complete coverage within each plot while maintaining a manageable width, we set our transect width to five meters and length to 50 meters (McCoy et al. 2006). We used the dependent double observer method in which two observers survey the same belt transect(Nichols et al. 2000). Burrows were determined as belonging to tortoises based on their evidence of a dome shaped burrow (Mushinsky et al. 2006). All burrows found were categorized as either active or abandoned; the inactive burrow category has been lumped into the active category because it has been demonstrated to be very difficult to differentiate reliably between the two (Ashton and Ashton 2008, FWC 2008). Active burrows were described by very little vegetative growth in the burrow entrance, footprints or plastral drag marks, or tortoise presence (Ashton and Ashton 2008). Abandoned burrows lacked all of the characteristics of active burrows and were collapsed and required significant excavation effort by a tortoise for re-use (Ashton and Ashton 2008).Burrows were digitally marked using the GPS unit and mapped using ArcGIS 9.3 software.

Habitat characterization

Vegetation characteristics were determined from aerial images (2.54 cm = 91.44 m) taken in 2009 and verified by ground surveys. We characterized vegetation into three height categories: Canopy coverage (>3m), shrub cover (1.5m-3.0m), and herbaceous ground cover (<1.5m). Soil maps were derived from the Natural Resource Conservation Service and soil types are explained in King's papers(King 2005, 2010b). These data were projected, as digital layers, over burrow points in ArcGIS 9.3 to create maps for analysis of the spatial distribution of burrows across soil and vegetation classes.

Tortoise survey

Gopher tortoises were captured from June

2010 to March 2011. We visited every burrow at our site once a month and attempted to capture every tortoise we saw inside or outside of their burrows. Tortoises that we spotted inside of their burrows were captured by coaxing them to their burrow entrance by eliciting a territorial response. Such a response is displayed equally by males and females (Mushinsky et al. 2006, Ashton and Ashton 2008). However, during the breeding season, typically between March and November in South Florida, males are more active and thus more likely to be captured (Ashton and Ashton 2008). However, given our exhaustive efforts and their duration throughout a calendar year we are confident this did not significantly impact our results. We marked tortoises' scutes, with a file according to an established coding system for long term identification (Ashton and Ashton 2008). We used water based paint to write numbers on tortoise scutes which allows in-burrow re-identification and thus avoids unnecessary recapture and stress to the animal. We also measured the carapace (top shell) length of all captured tortoises and sexed each according to plastral (bottom shell) concavity. Sub-adults (<23cm) were not sexed due to the lack of distinguishing features between males and females (Mushinsky et al. 1994). All research efforts for this particular project were carried out under FWC permit number LSSC-10-00208 and an approved animal care (IACUC) protocol number A10-28 from FAU.

Population estimates

We used the carapace length measurements to create a population demographic profile. We classified tortoises into three life stages based on carapace length: Juveniles (<13 cm), sub adults (13-22 cm) and adults (>22 cm)(Diemer 1992, Mushinsky et al. 1994). Tortoises in the adult categories are considered sexually mature and thus are potential contributors to population growth (Mushinsky et al. 1994). Tortoises in the sub-adult and juvenile categories are usually sexually immature but their relative abundances allow estimation of the reproductive success of the population(Mushinsky et al. 1994). Gopher tortoises mature at a carapace length of about 22-24 cm which, in South Florida, correlates to about 9-15 years of age (Mushinsky et al. 1994).

Analysis

We used chi-squared goodness of fit tests for independent samples to evaluate burrow placement across the different soil and vegetation types. We used the statistical package R to calculate chi-squared and p-values for our samples. Our null hypothesis stated that burrow placement was random and did not depend on soil or vegetation types. We did not include the high vegetation category in our analysis because it did not contain any burrows. We also removed any portion covered by high vegetation from the areas of the respective soil types in which the high vegetation occurred. Beyond this, we were not able to account for interactions between soil and vegetation types. We analyzed active burrows and their distribution across the different soiland vegetation types to elucidate burrowing preferences in current conditions. Abandoned burrows were analyzed against soil and vegetation types to shed light on abandonment rates in these characteristics.

Results

Tortoise Population

Our gopher tortoise burrow survey revealed 199 active burrows and 63 abandoned burrows. This translates to an active to abandoned burrow ratio of about 3:1. Using a burrow correction factor of active burrows divided by two, as established by the Florida Fish and Wildlife Conservation Commission (FWC), we estimated that 100 tortoises inhabit this 36.8 ha site (FWC 2008). We captured 63 tortoises during our study period from June 2010 to March 2011(Fig.3). Of those captured, five were juveniles, two were sub-adults and

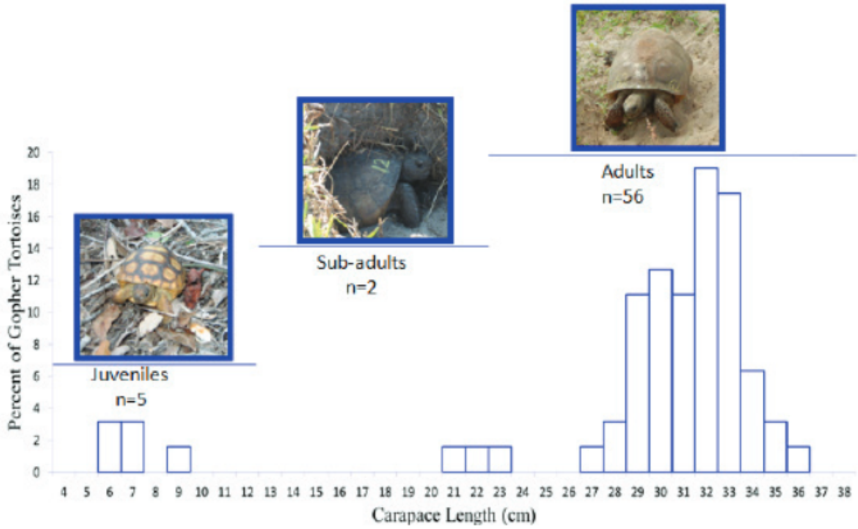

Figure 2. Carapace length distribution of gopher tortoises captured in the FAU conservation area. We caught 63 tortoises from June 2010 to March 2011. An additional 5 juveniles or hatchlings and 12 adults were observed but not captured.

56 were adults. We observed five additional juveniles and 12 adults but were not able to capture them for direct measurements. Tortoise carapace length ranged from 6 cm to 36 cm. We captured several small juvenile tortoises with a carapace length of < 7cm ranging between 1 and 2 years old based on growth annuli (Mushinsky et al. 2006). One older juvenile was captured with a carapace length of 7cm and an estimated age of 4 years. We also captured two sub-adults with a carapace length of 22cm and about 14-16 years old based on carapace length (Mushinsky et al. 1994). No tortoises with carapace lengths between 7 and 22 cm were captured.

Burrowing Preferences

Our site contained four different soil types. Urban Land, Basinger Fine Sand, Pompano Fine Sand, and Immokalee Fine Sand covered 0.81ha, 3.24ha, 4.45ha, and 28.33ha, respectively (Table 1). In Urban Land we found 18 total burrows, in Basinger we located 31, Pompano contained 48, and Immokalee had 165. Seventeenactive burrows were located in Urban Land, 20 in Basinger Fine Sand, 40 in Pompano Fine Sand, and 122 in Immokalee Fine Sand (Table 1 & Fig. 2). One abandoned burrow was located in Urban Land, 11 in Basinger Fine Sand, eight in Pompano Fine Sand, and 43 in Immokalee Fine Sand (Table 1 & Fig. 2).
We did not find a significant difference in the distribution of abandoned burrows across different soil types ($x^2 = 4.4102$, df = 3, p-value = 0.2204) (Table 2). We found a statistical significance in the distribution of active burrows across the different soil types ($x^2 = 35.7096$, df = 3, p-value = 8.625e-08) (Table 3). Active

burrows were most dense in Urban land at 21.0 burrows/ha. Active burrow densities were also high in Pompano fine sand at 9.0/ha. In Immokalee fine sand and Basinger fine sand, the density of active burrows was 5.3/ha and 4.3/ha, respectively.

Low vegetation covered 21.04ha, medium vegetation covered 10.12ha, and high vegetation covered 5.67ha (Table 4). We found 190 total burrows in low vegetation, 72 in medium vegetation, and zero in high vegetation. High vegetation occupied 5.67ha or about 15% of the study site (Table 4). 141 Active burrows were located in low vegetation and 58 in me-

Table1. Burrow distribution across different soil types in the FAU conservation area. Immokalee soil covered 28.33ha and made up the greatest portion of our study area. Basinger and Pompano soil types made up small portions of the habitat at 3.24 ha and 4.45ha, respectively. With 0.81ha, Urban Land had the least representation at our site.

Soil types	Active Burrows	Abandoned Burrows	Area (ha)
Urban	17	1	0.81
Basinger	20	11	3.04
Pompano	40	8	4.45
Immokalee	122	43	22.86
Totals	199	63	31.16

Table 2. Contingency table summarizing the chi-squared test for abandoned burrow distribution among the four different soil types in the FAU conservation area. Expected frequencies were based on area. Not significant (x^2= 4.4102, df = 3, p-value = 0.2204).

	Pompano Fine Sand	Basinger Fine Sand	Urban Land	Immokalee Fine Sand	Row Totals
Observed count	8	11	1	43	63
Expected frequencies	8.9971 (0.1428)	6.1463 (0.0976)	1.6377 (0.0260)	46.2189 (0.7336)	63 (1)
Area (ha)	4.45	3.04	0.81	22.86	36.83

Table 3. Contingency table summarizing the chi-squared test for active burrow distribution among the four different soil types in the FAU conservation area. Expected frequencies were based on area. Significant (x^2 = 35.7096, df = 3, p-value = 8.625e-08).

	Pompano Fine Sand	Basinger Fine Sand	Urban Land	Immokalee Fine Sand	Row Totals
Observed count	40	20	17	122	199
Expected frequencies	28.4194 (0.1428)	19.4146 (0.0976)	5.1730 (0.0260)	145.9929 (0.7336)	199 (1)
Area (ha)	4.45	3.04	0.81	22.86	36.83

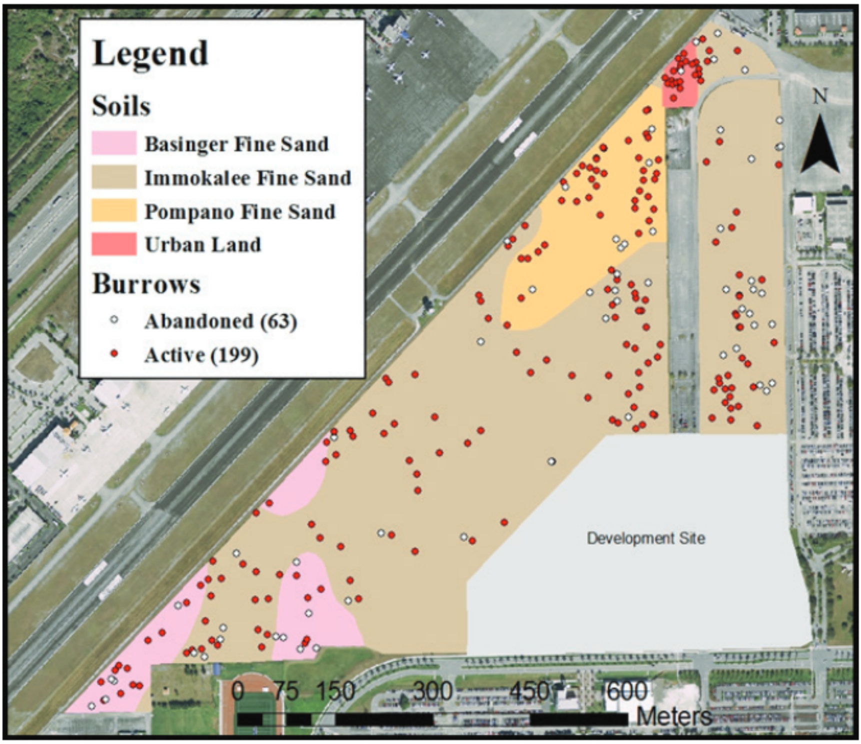

Figure 3. The distribution of gopher tortoise burrows in different soil types in the FAU conservation area. Four soil types were found to occur in the FAU conservation area, namely Urban Land, Basinger Fine Sand, Pompano Fine Sand, and Immokalee Fine Sand. Active burrows were very dense in Urban Land at 21.0/ha. Active burrow densities were also high in Pompano Fine Sand at 9.0/ha. In Immokalee and Basinger Fine Sand, the density of active burrows was 5.3/ha and 6.6/ha, respectively.

Table 4. Burrow distribution across different vegetation types in the FAU conservation area. Low vegetation covered 21.04ha and covered the largest portion of our study site. Medium and high vegetation covered 10.12ha and 5.67ha, respectively.

Vegetation types	Active Burrows	Abandoned Burrows	Area (ha)
Low	141	49	21.04
Medium	58	14	10.12
High	0	0	5.67
Totals	199	63	36.83

Table 5. Contingency table summarizing the chi-squared test for the distribution of abandoned burrows among the three different vegetation types in the FAU conservation area. Expected frequencies were based on area. Not significant ($x^2 = 3.02$, df = 1, p-value = 0.08).

	Low	Medium	Row Totals
Observed counts	49	14	63
Expected frequencies	0.6752	0.3248	1
Area (ha)	21.04	10.12	31.16

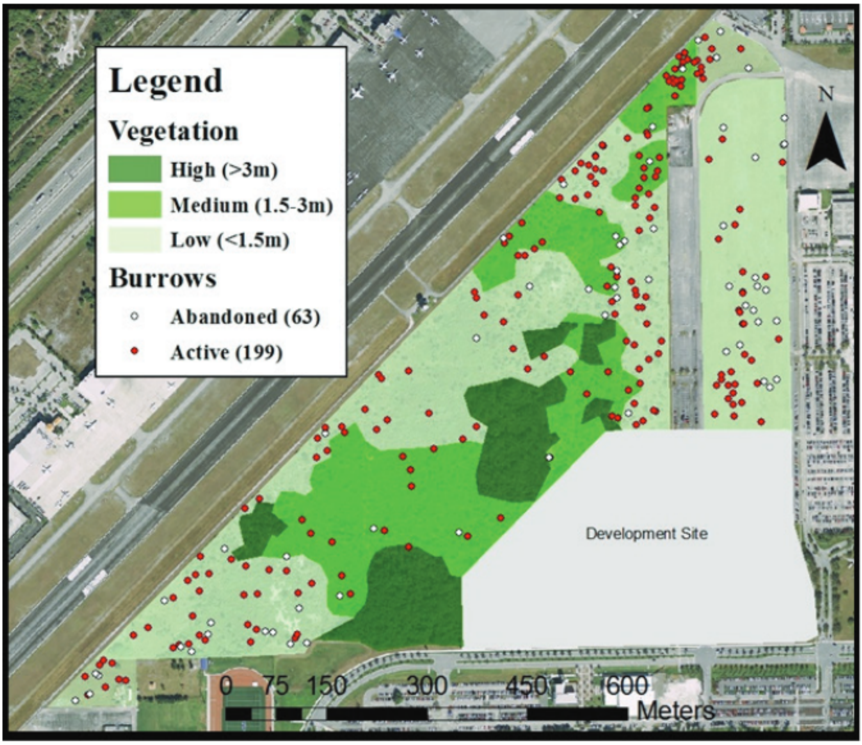

Figure 4. The spatial distribution of gopher tortoise burrows in different vegetation heights in the FAU conservation area. A total of 199 active and 63 abandoned burrows were found. We found no significant difference between the spatial distribution of burrows in medium and low vegetation ($x^2 = 3.0$; df = 1; $p < 0.05$). Active burrow densities were 6.7/ha in low vegetation and 5.7/ha in medium vegetation. No burrows were located in high vegetation.

Table 6. Contingency table summarizing the chi-squared test for the distribution of active burrows among the three different vegetation types in the FAU conservation area. Expected frequencies were based on area. Not significant (x^2 = 1.01, df = 1, p-value = 0.31).

	Low	Medium	Row Totals
Observed counts	141	58	199
Expected frequencies	0.6752	0.3248	1
Area (ha)	21.04	10.12	31.16

dium vegetation (Table 1, Fig. 3). In low vegetation we found 49 abandoned burrows and in medium vegetation we located 14 abandoned burrows (Table 4& Fig. 3).
We did not find a significant difference in the distribution of abandoned burrows across different vegetation types (x^2 = 3.02, df = 1, p-value = 0.08) (Table 5). In addition, we found no statistical significance in the distribution of active burrows across the different vegetation types (x^2 = 1.01, df = 1, p-value = 0.31) (Table 6). Active burrow densities were 6.7/ha in low vegetation and 5.7/ha in medium vegetation.

Discussion

Our data coupled with King's data from 2005, presents evidence that the tortoise population in the FAU conservation area may not be sustainable. In addition, we were able to shed light on some of the tortoises' burrowing preferences, albeit more research must be conducted on this topic in South Florida before conclusions can be drawn to inform management strategies.

The age structure profile created from our direct captures further corroborates speculation of an unsustainable population because reproduction and juvenile survival seem to be very low, even for this small population. Our age structure graph shows that the FAU population consists almost entirely of adult gopher tortoises unlike healthy populationswhich tend to have continuous representation throughout the life stages (Diemer 1992, Mushinsky et al. 1997). Our tortoise captures show only two sub-adults and a gap of about ten years between the youngest juvenile and smallest sub-adult. On account of the ten juveniles and lack of sub-adults found, we suggest that the population is reproducing successfully but the offspring are not surviving. This demographic is consistent with King's who captured 36 adults and one sub-adult and observed an additional 30 adults (2005). Contrasted to King's survey, the number of tortoises captured or observed in our study increased by two adults, one sub-adult and ten juveniles. The increase in sub-adults and adults is likely due to relocations. From the FAU-employed consultant, we know that several tortoises were relocated to our site from other areas of the FAU Boca Raton campus (M. Brandenburg, Miller Legg and Assoc., unpubl. data). We also speculate that tortoises have been moved to the site illegally by the public. Juveniles may have increased for several reasons. King conducted her surveys during the late spring and early summer months while we conducted ours at the end of summer and the beginning of fall (2005). Hatchling tortoises tend to hatch in the fall (Mushinsky et al. 2006, Ashton and Ashton 2008). In addition, juveniles are very secretive and do not necessarily burrow (Douglass 1978, Epperson and Heise 2003, Pike 2006, Ashton and Ashton 2008). They may have simply gone undetected in King's survey and we too may have missed some. Consequently we base our discussion of juveniles on the relative abundance of sub-adult and adult tortoises and their burrows which are much easier to locate.

Juvenile tortoises have very low survival rates and it is possible that the lack of sub-adults seen in our study is a result of natural fluctuations (Butler and Sowell 1996, Epperson and Heise 2003). However, the consistency in the lack of sub-adults between 2005 and 2011 weaken this hypothesis by suggesting that almost all juveniles perished during this period.Reasons for theconsistently low survival rate of juveniles may include a complex of factors involving habitat loss, degradation, and predators. Adult tortoises are robust, versatile foragers consuming over 200 plant genera and able to forage across home ranges greater than 3 acres (Mushinsky et al. 2003, Mushinsky et al. 2006, Ashton and Ashton 2008). Juvenile tortoises are less versatile foragers and have home ranges under 0.5 acres as a result of their smaller size and increased susceptibility to predators (Mushinsky et al. 2003, Mushinsky et al. 2006). Since a habitat is fragmented and begins decreasing in available herbaceous vegetation, adult tortoises may stand a better chance of survival than juveniles. In particular, the lower abundance of food may require hatchling tortoises to forage in a wider range and as a result make them more susceptible to predation. Adult reproductive success may also be lowered due to increased stress levels imposed by a declining habitat. Assessment methods usually focus on adult tortoise counts and fail to assess their reproductive success or survival of the juvenile tortoises (McCoy et al. 2006). Due to the longevity of adult tortoises, population declines can take several decades to become noticeable (McCoy and Mushinsky 2007).

The high active to abandoned burrow ratio in this particular habitat is a cause for concern as well. Active to abandoned tortoise burrow ratios can be used to indicate the tendency of gopher tortoises to dig new burrows which relates directly to the status of a population (Mushinsky et al. 1997, McCoy et al. 2006). Our active to abandoned burrow ratio was about 3:1 and similar to studies on other small habitats and true island habitats that support gopher tortoises (Mushinsky et al. 1997, Eubanks et al. 2003). Studies in unrestricted tortoise habitats generally report ratios in which the number of abandoned burrows is very similar to the number of active burrows (Mushinsky et al. 1997, Jones and Dorr 2004). The high ratio found at the FAU site and other small habitats suggests that tortoises in these habitats are limited in their ability to disperse freely to create new burrows and abandon old ones. This pattern of behavior has been demonstrated to be a result of decliningh abitat conditions (Mushinsky et al. 1997, McCoy et al. 2006).

Burrow activity changes over time are important. In 2005, King reported 181 active burrows and 38 abandoned burrows (we have lumped King's inactive burrows into the active burrow category as described in the methods section). The figures translate to an active to abandoned burrow ratio of about 4:1 and reveal a relative increase in the number of abandoned burrows. Other studies have demonstrated that increases in the abandoned burrow category accompanied by decreases in the active burrow category suggest overall habitat declines (Mushinsky et al. 1997, McCoy et al. 2006). Such habitat declines may also be evidenced by a population age structure represented primarily by adults (McCoy et al. 2006). Both predictors are evident in the tortoise population at FAU.

The significant correlation found between the spatial distribution of gopher tortoise burrows and soil types was expected. Tortoises have been shown to choose well-drained soils supportive of their extensive burrowing habits (Mushinsky et al. 2006). The high density of tortoise burrows in urban land suggests that this soil type is well-suited for tortoise burrowing. Immokalee, Basinger, and Pompano fine sand appear to be less suitable which may be due to poorer drainage thus accumulating more water than urban land and threatening burrow infrastructure.

Spatial distribution of burrows throughout different vegetation types (Fig. 4) displayed unexpected trends for the FAU site. The lack of significance seen in the spatial distribution of burrows in low versus medium vegetation suggests overcrowding or novel habitat preferences among gopher tortoises. Contrary to typical gopher tortoise ecology, tortoises in certain parts of the conservation area preferred to dig their burrows in areas with medium vegetation (1.5 -3.0m) although open patches with low herbaceous vegetation were available (Mushinsky et al. 2006, Ashton and Ashton 2008). We suggest that this may be due to distribution of a combination of different soil types and the presence of more roots in dense vegetation. Higher root densities may help to sustain tortoise burrow infrastructure where certain soil types would not. Roots may also increase moisture content of the burrow, a potentially important aspect in such dry environments as our study site (Ashton and Ashton 2008). The relatively high density of burrows located in medium vegetation suggests novel habitat use among tortoises atthe FAU site and warrants further investigation. Complete avoidance of habitat with complete canopy coverage is frequently reported in gopher tortoise ecology research and was corroborated by our study (Diemer 1986, King 2005, Mushinsky et al. 2006, Ashton and Ashton 2008).

Based on active to abandoned burrow ratios and the demographic profile we suggest that the FAU tortoise population may not be sustainable without increased habitat management. Additional management may include mechanical clearing of tall woody plants and removal of raccoons and other unnaturally large concentrations of predators such as feral cats.

Additionally, adult gopher tortoises are able to survive for decades in habitat patches unsuitable for juveniles: therefore burrow observations alone may be deceiving (McCoy and Mushinsky 2007). Without investigating burrows beyond their mere existence, it is not possible to determine whether a population consists of primarily adults or comprises a continuous distribution from juveniles to adults. Ultimately, when burrow surveys are coupled with age structure profiles more accurate results may be obtained. However, capturing individual tortoises is a time consuming effort because they primarily remain underground. An alternative solution may be to measure burrow widths as these have been shown to correlate well with carapace length and could be used to indirectly obtain an age structure profile (Alford 1980, McCoy et al. 2006). We are currently investigating these correlations in southeastern Florida habitatsto determine how different soils throughout the tortoises' range may or may not skew them.

In conclusion, a combination of active to abandoned gopher tortoise burrow ratios, direct tortoise captures, and habitat analyses should be used to comprehensively assess tortoise population status and, when necessary, develop management techniques. Southeast Florida contains several fragmented habitats that support tortoise populations. Unfortunately most of these sites are degraded and not monitored thoroughly. The remaining tortoises on these sites, like those on the FAU preserve, may simply be the last remnants of a once thriving population now unsustainable without significant human intervention. Nevertheless, small populations such as the one we studied can maintain healthy, sustainable populations with proper habitat management and are valuable to the conservation of the tortoise and its numerous commensal species (McCoy and Mushinsky 2007, Mushinsky et al. 1997). In fact, a site in Jupiter Florida hosts a healthy, sustainable tortoise population on a much smaller tract of land than the FAU site (Moore et al. 2009). The Jupiter site is managed heavily by a combination of roller chopping, or clear cutting, and invasive species removal by hand (per. comm. J. Moore). Additionally, small habitats are isolated from disease outbreaks, and may serve as potential sources for genetic diversity and restocking efforts for other larger tracts of land where tortoises have become extinct (Mushinsky et al. 1997).

The primary driver of worldwide species declines is habitat loss and fragmentation (2010a). In addition, human development often contributes to the elimination of beneficial natural disturbances such as fire which among other things prevents the establishment of invasive species (2010a). We must also monitor more effectively our conservation areas and the status of the targeted, imperiled species (Bruner et al. 2001, McCoy et al. 2006). Consequently, setting aside protected conservation areas to aid species recovery is only a first step and must be supplemented by intense habitat management to mimic natural disturbances as well as thorough evaluation of our efforts (Mushinsky et al. 1997, Bruner et al. 2001, 2010a).

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