ECOLOGY OF THE SOUTHEASTERN POCKET GOPHER (*GEOMYS PINETIS*) IN SOUTHWESTERN GEORGIA

by

ASHLEY ERIN WARREN

(Under the Direction of Steven B. Castleberry)

ABSTRACT

From September 2012 through December 2013 I used telemetry to investigate home range, survival, and movement patterns of southeastern pocket gophers (*Geomys pinetis*) in Southwestern Georgia. I also used a modeling approach to determine whether vegetation or soil characteristics best predicted gopher presence and developed a predictive model using combinations of vegetation and soil variables. Mean home range size of 17 gophers was 921.9 m^2 (range = 43.4-2246.8 m^2). Home range size was positively associated with body mass, percent silt, and soil carbon, and negatively associated with percent sand, percent clay, and grass ground cover. Two individuals were predated and survival rate was 0.78 over 51 weeks. Three individuals dispersed, with maximum dispersal distance of 319.1 m (range = 143.2-319.1 m). Pocket gophers exhibited greater activity at 00:00-4:00 and 16:00-20:00. Soil predicted presence better than vegetation, and the best predictive model combined percent clay, percent silt, pH, nitrogen, and carbon.

INDEX WORDS: southeastern pocket gopher, *Geomys pinetis*, fossorial, burrows, tunnels, longleaf pine, *Pinus palustris*, home range, survival, dispersal, translocation, homing, telemetry, predation, Florida pine snake, *Pituophis melanoleucus*, ground cover, vegetation structure, soil texture, soil carbon, soil nitrogen, soil pH, habitat suitability, modeling, AIC

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Major Professor: Steven B. Castleberry

Committee: L. Mike Conner
Daniel Markewitz

Electronic Version Approved:

Julie Coffield
Interim Dean of the Graduate School
The University of Georgia
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DEDICATION

I would like to dedicate my thesis to my parents, Vaughn and Sharon Warren, and my brother, Matthew Warren. Their love and support has made it possible for me to achieve my goals and ambitions. I would also like to dedicate this to my extended family for their interest and enthusiasm in my endeavors. I would like to thank my past friends who offered encouragement, and all the wonderful new friends I made along this journey.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

The southeastern pocket gopher (*Geomys pinetis*) is a fossorial rodent historically associated with longleaf pine (*Pinus palustris*) communities characteristic of the Coastal Plain physiographic province in southeastern Alabama, southern Georgia, and northern and central Florida (Golley 1962, Pembleton and Williams 1978, Wilkins 1987). Longleaf pine communities of this region have been highly impacted by conversion to other land uses and associated fragmentation, altering the amount and distribution of habitat for a number of species, including the southeastern pocket gopher. Although patches of suitable habitat apparently sustain isolated but locally abundant populations, the species is absent from a large portion of its historical range (Southern Wildlife Consultants 2008). The Alabama, Georgia, and Florida state wildlife agencies have listed the southeastern pocket gopher as a high priority species in their State Wildlife Action Plans (Alabama Department of Conservation and Natural Resources 2005, Georgia Department of Natural Resources 2005, Florida Fish and Wildlife Conservation Commission 2012). Species in this category show combinations of rarity, limited distribution, decreasing size or viability of populations, and biological vulnerability.

Further loss of the southeastern pocket gopher from its historic range may have negative effects on the upland ecosystems of the southeastern coastal plains because of the vital roles they play in the communities they inhabit. In the Sandhills ecosystems, which are characterized by sparse ground cover and a longleaf pine-turkey oak (*Quercus laevis*) overstory, several species of amphibians and reptiles use southeastern pocket gopher mounds as shelter (Funderburg and Lee 1968), including the gopher frog (*Lithobates capito*; Blihovde 2006) and mole skink (*Plestiodon egregius*; Mount 1963). Mounds and tunnels also serve as habitat for several arthropods, a number of which are believed to be obligate commensals (Pembleton and Williams 1978, Skelley and Kovarik 2001). Additionally, southeastern pocket gopher mounds are the most abundant faunal source of soil disturbance within longleaf pine communities (Simkin and Michener 2005). Thus, a conservation strategy for the southeastern pocket gopher would benefit numerous species.

Developing a conservation strategy for any species requires a basic understanding of its ecology, including knowledge of home range size, survival rates, movement patterns, and the criteria for suitable habitat. Unfortunately, the ecology of the southeastern pocket gopher is poorly understood because its fossorial lifestyle makes observational studies difficult. Therefore, I used radio telemetry to investigate home range, survival, cause-specific mortality, dispersal, and daily activity patterns of the southeastern pocket gopher. I also used a modeling approach to identify vegetation and soil criteria important for determining gopher habitat suitability. Information resulting from this study will help us to better understand ecological needs of southeastern pocket gophers, and will be integral in forming a conservation strategy for this species.

LITERATURE REVIEW

Home Range

Currently, there have been no studies using telemetry to estimate the home range size of the southeastern pocket gopher. The only home range data published for the southeastern pocket gopher is a study on mounding activity from which the home range of 8 southeastern pocket gophers in Hillsborough County, Florida were derived based on the rectangular dimensions of areas of mound production ($\bar{x}$=2666.5 m^2, SD=2308.5, range=720-7571 m^2; Hickman and Brown 1973a). However, this methodology likely overestimates home range size. Although home range data are lacking for the southeastern pocket gopher, home range information is available for other Geomyidae. Mean home ranges of the Mazama (*Thomomys mazama*), Ozark (*G. bursarius ozarkensis*), and Botta's (*T. bottae*) pocket gophers are 108 m^2 (SD=37.9 for 4 adult males; Witmer et al. 1996), 291.8 m^2 (SD=162.2 for 14 adult males; Connior and Risch 2010), and 474.4 m^2 (SD=148.2 for 7 adult males; Bandoli 1987), respectively. To explain the wide variety in home range size within species, Connior and Risch (2010) determined that home range size of the Ozark pocket gopher is directly proportional to body size in juvenile females, inversely proportional to body size in adult females, and uncorrelated with body size in males. Conversely, the areas covered by the burrow systems of Attwater's pocket gophers (*G. attwateri*) were also highly variable between individuals, but differences were not correlated with sex, age, or body size (Cameron et al. 1988). Thus, there is no uniform home range size or explanation for variation in home range that holds true for all of the geomyids.

Survival

The protection a fossorial lifestyle affords can be seen in Australia where burrowing conilurine rodents are experiencing less severe declines in response to predation than non-fossorial species (Smith and Quin 1996). Thus, the southeastern pocket gopher likely has a high survival rate due to the protection burrows provide from predators. Brown (1971) suggested that the lifespan of southeastern pocket gophers in Florida was >2 years. The only published study that used radiotelemetry to investigate survival rates in pocket gophers was conducted on the Ozark pocket gopher in north-central Arkansas (Connior and Risch 2010). Connior and Risch

(2010) reported that 33 of 35 pocket gophers survived over 144 days during the nonbreeding season and 26 of 35 survived over 116 days during the breeding season. Literature regarding cause-specific mortality in pocket gophers is equally sparse. Connior and Risch (2010) attributed 7 of the 11 Ozark pocket gopher mortalities to predation, but the predator could only be identified in a single case when a tagged individual was found consumed by a prairie kingsnake (*Lamropeltis calligaster calligaster*). Remaining mortalities were attributed to flooding and unknown causes. The Florida pine snake (*Pituophis melanoleucus mugitus*) is likely the most common predator on southeastern pocket gophers because pine snakes (*Pituophis* spp.) tend to be the primary predators of pocket gophers in regions where they coexist (Rudolph et al. 2002, Sterner et al. 2002) and the Florida pine snake commonly shares habitat with the southeastern pocket gopher (Miller et al. 2012).

Dispersal

Information on dispersal behavior of the southeastern pocket gopher is limited to anecdotal records of a single study in which 2 pocket gophers traveled 184 m and 244 m overland, respectively, before resuming tunneling (Hickman and Brown 1973a). Dispersal is well documented in Botta's pocket gopher (*Thomomys bottae)*, with females dispersing in early spring as juveniles, and males dispersing later as sub-adults (Daly and Patton 1990). Daly and Patton (1990) suggested that females disperse as juveniles to prevent consanguineous mating, and males disperse later to grow more before competing with adult males for territory. Daly and Patton (1990) documented a dispersal distance up to 300 m in a single Botta's pocket gopher, but 63% of individuals in their study remained within 40 m of their natal sites.

Daily Activity Patterns

The only published research conducted to address daily activity patterns in southeastern pocket gophers was conducted in captivity as part of a thermoregulation study (Ross 1980). Ross (1980) concluded that southeastern pocket gophers do not exhibit a bimodal activity pattern, rather they alternate periods of activity throughout the day and night in roughly 40 minute cycles. Although the method for detecting activity in the study was precise, he concluded that gopher activity may have been influenced by the inability of gophers to exhibit natural foraging behavior. Bandoli (1987) also failed to detect a statistically significant activity pattern in Botta's pocket gopher, but he did demonstrate a trend towards higher activity between 15:00 and 18:00.

Vegetation Structure

Suitable habitat is often better characterized by vegetation structure rather than species composition (Garden et al. 2007, Stostad and Menéndez 2014), as may be the case with the southeastern pocket gopher. The historic association of the southeastern pocket gopher with the longleaf pine community is well-established (Golley 1962, Pembleton and Williams 1978), but recent studies have documented southeastern pocket gopher observations in additional habitats such as agricultural fields and utility right-of-ways (Avise and Laerm 1982, Southern Wildlife Consultants 2008). Southern Wildlife Consultants (2008) suggested that older, thinned slash (*P. elliottii*) and loblolly pine (*P. taeda*) stands with open canopies and sufficient understory growth may provide suitable southeastern pocket gopher habitat because southeastern pocket gophers likely select for vegetation structure typical of longleaf pine communities rather than the presence of the longleaf pine itself. Ford (1980) found no associations between southeastern pocket gopher presence and specific plant species, but instead found that southeastern pocket gophers avoided areas that lack grasses and/or were covered by root systems that impeded burrowing. Similarly, Ozark pocket gophers select areas based on availability of abundant forage rather than presence or absence of specific plant species (Connior et al. 2010).

Soil Characteristics

The association of the southeastern pocket gopher with areas of xeric sandy soils is well supported in the literature (McNab 1966, Wilkins 1985, Wilkins 1987, Simkin and Michener 2005, Southern Wildlife Consultants 2008). McNab (1966) suggests that this association may be based on metabolic needs. When the southeastern pocket gopher constructs its burrow, it plugs all above ground openings with soil (Hickman and Brown 1973b). The ability of the southeastern pocket gopher to breathe is therefore dependent on the diffusion of gasses through the soil, limiting it to highly porous soils with low water-holding capacity (McNab 1966). However, Vleck (1981) suggests that southeastern pocket gophers instead select for sandy soils as a means to minimize energy costs when expanding tunnels in search of food. Currently, soil characteristics other than texture, such as pH, nitrogen, and carbon content, have only been described in the context of comparing soil from southeastern pocket gopher mounds to the surrounding matrix (Simkin et al. 2004). Simken et al. (2004) suggests that lower levels of soil nitrogen and carbon found in mound soil indicate the effectiveness of southeastern pocket gophers at turning over the soil and bringing deeper, less nutrient rich soils to the surface.

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CHAPTER 2

HOME RANGE, SURVIVAL, AND MOVEMENT PATTERNS OF THE SOUTHEASTERN POCKET GOPHER IN SOUTHWESTERN GEORGIA[1]

[1] Warren, A. E., S. B. Castleberry, L. M. Conner, and D. Markewitz. To be submitted.

ABSRACT

The southeastern pocket gopher (*Geomys pinetis*) is absent from a large portion of its historical range. However, several aspects of its ecology are poorly known and insufficient data exists to create an effective conservation strategy. Therefore, I used radio telemetry to examine home range, survival, dispersal, and daily activity patterns of the southeastern pocket gopher in southwestern Georgia, USA. Southeastern pocket gophers were captured, implanted with radiotransmitters, and tracked for approximately 3.5 months. Variation in home range size among gophers was examined for correlations with body mass and habitat variables measured within the home range. Mean home range size of 17 radiotagged pocket gophers was 921.9 m^2 (range=43.4-2246.8 m^2). Home range size was positively associated with body mass, percent silt at a depth of 25 cm, and soil carbon content at 75 cm, and negatively associated with percent sand at 25 cm, percent clay at 50 cm, and ground cover of grasses other than wiregrass. Two individuals were known to have been predated, likely by avian predators, and survival rate was 0.78 over 51 weeks of tracking. Three individuals dispersed, with a maximum dispersal distance of 319.1 m (range=143.2-319.1 m). Pocket gophers exhibited greater activity from 00:00 to 04:00 and 16:00 to 20:00, differing from previous data that found southeastern pocket gophers to be equally active throughout the diel period. My estimation of home range size for the southeastern pocket gopher is the first using radio telemetry, and is much lower, and likely more accurate, than estimations from previous studies. Based on the dispersal distance I documented, pocket gopher dispersal into restored areas of suitable habitat may need to be facilitated by translocation.

INTRODUCTION

The southeastern pocket gopher (*Geomys pinetis*) is a fossorial rodent historically associated with longleaf pine (*Pinus palustris*) communities characteristic of the Coastal Plain physiographic province in southeastern Alabama, southern Georgia, and northern and central Florida (Golley 1962, Pembleton and Williams 1978, Wilkins 1987). Longleaf pine communities of this region have been highly impacted by conversion and fragmentation, resulting in habitat alteration for a number of associated species, including the southeastern pocket gopher. Although southeastern pocket gophers can be abundant in suitable habitats, the species is absent from a large portion of its historical range (Southern Wildlife Consultants 2008). The Alabama, Georgia, and Florida state wildlife agencies have listed the southeastern pocket gopher as a high priority species in their State Wildlife Action Plans (Alabama Department of Conservation and Natural Resources 2005, Georgia Department of Natural Resources 2005, Florida Fish and Wildlife Conservation Commission 2012). Species in this category show combinations of rarity, limited distribution, decreasing size or viability of populations, and biological vulnerability.

Developing a conservation strategy for any species requires a basic understanding of its ecology. However, several aspects of the ecology of the southeastern pocket gopher are poorly known because its fossorial lifestyle makes observational studies difficult. Currently, the only home range data for the southeastern pocket gopher is from a study on mounding activity that reported areas of activity in rectangular dimensions, likely overestimating home range size (Hickman and Brown 1973a). Furthermore, how sex, age, body size, and habitat features influence home range size is unknown. Although home range data for the southeastern pocket gopher generally are lacking, home range information is available for other *Geomys* species. Cameron et al. (1988) concluded that the area covered by the burrow systems of Attwater's pocket gophers (*G. attwateri*) was highly variable between individuals, and differences were not correlated with sex, age, or body size. Conversely, home range size of the Ozark pocket gopher (*G. bursarius ozarkensis*) is directly proportional to body size in juvenile females, inversely proportional to body size in adult females, and uncorrelated with body size in males (Connior and Risch 2010). Therefore, generalizing results from studies of other *Geomys* species to the southeastern pocket gopher could lead to erroneous conclusions.

The southeastern pocket gopher likely has a high survival rate due to the protection burrows provide from predators. Brown (1971) suggested that the lifespan of southeastern pocket gophers in Florida was >2 years. The only published study that used radiotelemetry to investigate survival rates in pocket gophers was conducted on the Ozark pocket gopher in north-central Arkansas (Connior and Risch 2010). Connior and Risch (2010) reported that 33 of 35 pocket gophers survived over 144 days during the nonbreeding season and 26 of 35 survived over 116 days during the breeding season. Literature regarding cause-specific mortality in pocket gophers is equally sparse. Connior and Risch (2010) attributed 7 of the 11 Ozark pocket gopher mortalities to predation, but the predator could only be identified in a single case when a tagged individual was found consumed by a prairie kingsnake (*Lamropeltis calligaster calligaster*). The Florida pine snake (*Pituophis melanoleucus mugitus*) is likely the most common predator on southeastern pocket gophers due to its presence in the same habitats and its ability to exploit fossorial prey (Miller et al. 2012).

A successful conservation strategy for the southeastern pocket gopher should promote the re-establishment of new populations in suitable habitat. Suitable habitat for the southeastern pocket gopher currently exists only in fragmented patches (Southern Wildlife Consultants 2008). Information on dispersal periodicity, timing, and distance is needed to determine if pocket gopher dispersal behavior is sufficient to establish new populations in patches of suitable habitat. Fragmentation may be limiting natural dispersal, but information on dispersal behavior is limited to anecdotal records of a single study in which 2 pocket gophers traveled 184 m and 244 m overland, respectively, before resuming tunneling (Hickman and Brown 1973a). Dispersal is commonly observed in Botta's pocket gopher (*Thomomys bottae)*, with most dispersal activity occurring during the spring and summer before reproductive age (Daly and Patton 1990). Daly and Patton (1990) documented one individual dispersing 300 m, but 63% of individuals remained within 40 m of their natal sites.

The only published research addressing daily activity patterns in southeastern pocket gophers was conducted in captivity as part of a thermoregulation study (Ross 1980). Ross (1980) concluded that southeastern pocket gophers do not exhibit a bimodal activity pattern, rather they alternate periods of activity throughout the day and night in roughly 40 minute cycles. Although the method for detecting activity in the study was precise, he concluded that gopher activity may have been influenced by the inability of gophers to exhibit natural foraging behavior.

Southeastern pocket gophers play vital roles in the communities they inhabit. Their mounds are the most abundant faunal source of soil disturbance within longleaf pine communities (Simkin and Michener 2005). In the Sandhills ecosystems of the southeastern Coastal Plain, which are characterized by sparse ground cover and a longleaf pine-turkey oak (*Quercus laevis*) overstory, several species of amphibians and reptiles use southeastern pocket gopher mounds as shelter (Funderburg and Lee 1968), including the gopher frog (*Lithobates capito*; Blihovde 2006) and mole skink (*Plestiodon egregius*; Mount 1963). The mounds and tunnels also serve as habitat for several arthropods, a number of which are believed to be obligate commensals (Pembleton and Williams 1978, Skelley and Kovarik 2001).

Given its important ecological roles, further loss of the southeastern pocket gopher from its historic range may have negative effects on upland ecosystems of the southeastern Coastal Plain. However, insufficient information exists to develop an effective conservation strategy. Therefore, I used radio telemetry to investigate home range, survival, cause-specific mortality, dispersal, and daily activity patterns. Information resulting from this study will improve our understanding of the natural history of the southeastern pocket gopher, and will be integral in forming a conservation strategy.

METHODS

Study Site

My study was conducted from September 2012 through September 2013 at the Joseph W. Jones Ecological Research Center at Ichauway in Baker County, Georgia, USA. Ichauway covers 117 km^2 of predominately longleaf pine forest surrounded primarily by center pivot agriculture. Other cover types found at Ichauway are slash pine (*P. elliottii*) forests, loblolly pine (*P. taeda*) stands, mixed pine hardwoods, riparian hardwood forests, live oak (*Quercus virginianus*) depressions, isolated depressional wetlands, creek swamps, agricultural fields, shrub-scrub uplands, and areas impacted by human development (Goebel et al. 1997). Ichawaynochaway creek runs north to south through the center of the property, and the property is bordered by the Flint River to the southeast. Ichauway has high floral and faunal species diversity, including many native species, such as wiregrass (*Aristida stricta*), the dominate understory species covering approximately 1/3 of the property. Habitat structure and composition is maintained through prescribed fire. Stands are burned at least every other year, primarily during March and April (Atkinson et al. 1996). Ichauway is situated within the Dougherty Plain physiographic district, which is characterized by marine and fluvial deposited Entisols and

Ultisoils over highly fractured Ocala limestone, and a flat to rolling karst topography (Beck and Arden 1983, Hayes et al. 1983, Couch et al. 1996).

Animal Capture and Processing

I selected locations for gopher trapping through opportunistic sightings of mounds, but maintained >250 m between radiotagged individuals; the furthest documented dispersal of southeastern pocket gophers. I captured gophers using live-traps described by Hart (1973) and Connior and Risch (2009a). To capture gophers, I dug into a gopher mound until I broke into a tunnel. I removed soil along the path of the tunnel to accommodate one of the two trap styles. I then fully covered the trap with soil. Traps were checked every 3 hours. I placed captured gophers in ventilated 45.4 L plastic containers partially filled with moist soil from the site and transported them to the lab for transmitter implantation.

I surgically implanted 3-g VHS radio transmitters (SOPI-2070, Wildlife Materials Inc., Murphysboro, Illinois), representing a mean of 1.73% (SD=0.48 Range=0.89-2.38) of body mass, either subcutaneously between the scapulae or within the peritoneal cavity. I also inserted a PIT tag subcutaneously away from the area of transmitter implantation. Transmitter and PIT tag implantation occurred under continuously inhaled sevoflurane for anesthesia. I recorded mass while gophers were under anesthesia. Juvenile gophers were defined as weighing less than 100 g (Wing 1960). I could not determine sex for most study animals due to the difficulty of determining sex based on external morphology (Baker et al. 2003). I held gophers 3 days post-surgery to monitor recovery, and managed inflammation and pain with intramuscular injections of moloxicam and butorphanol. I continuously provided each gopher sweet potatoes from the time of capture until I returned it to its original burrow. I did not replace failed or lost transmitters. All animal capture and handling followed guidelines of the UGA Animal Welfare

Assurance #A3437-01 and were approved by the Institutional Animal Care and Use Committee of the University of Georgia (AUP# A2012 04-002-Y1-A0, A2012 04-002-A1, A2012 04-002-R1).

Radiotelemetry

I tracked gophers once/day, every other day, using a telemetry receiver (Communication Specialists, Inc, R-1000) and 3-element yagi antenna. I began each tracking period 2 hours later than the previous tracking period to account for activity around the diel period. I began tracking several meters outside the known area of gopher activity and homed in on the point of greatest signal strength with the antenna pointed downward, being careful to limit ground vibration when walking. I recorded the location, along with date and time of observation, for each gopher during a tracking period using a Nomad® Global Positioning System (GPS; Trimble Navigation, Ltd., Sunnyvale, CA) equipped with a GPS antenna (Crescent A100, Hemisphere GPS, Inc., Mountain View, CA) that provided a horizontal accuracy of < 0.6 m with 95% confidence (Hemisphere GPS, Inc. 2007). I inserted a flag marked with the date and time into the soil at each recorded location.

I tracked individual gophers until the transmitter failed, the gopher died, or the gopher could not be relocated. Transmitter failure was confirmed either by a marked decrease in signal strength prior to loss of signal, or by recapturing the animal and scanning for the PIT tag. In cases of mortality, I determined cause of death by investigating conditions at the site where the carcass was found, and by performing a necropsy. When predation was indicated, I identified the suspected predator to the lowest taxonomic group possible based on carcass condition, tooth marks, surrounding prints, and scat identification.

In cases of dispersal, I continued tracking the dispersed individual at its new location. I defined dispersal as an obvious and complete abandonment of one area of concentrated activity to a new area where the gopher had never been recorded, including capture location.

I conducted focal telemetry (extended tracking periods focusing on the movements of an individual study animal) for 9 pocket gophers from May through August 2013 to investigate daily activity patterns. I conducted focal telemetry on one gopher at a time, tracking the gopher for 8 hours a day on three separate days, all conducted within a two-week period. Each day's tracking session covered a different 8-hour portion of the 24-hour diel period. During each 8-hour tracking session, I located the gopher every 20 minutes. Locations were flagged and recorded using the same Nomad® and antenna configuration described above.

I described activity as the distance a gopher traveled in each 20-min interval between recordings and as the distance of each gopher from its nest at each location. I determined distance traveled by measuring between each sequential location using a meter tape. I used the Near tool in ArcMAP 9.3.1 to measure distance between each recorded location and the location of the nest. I assumed pocket gopher nests were located where telemetry point density was the greatest. Because some gophers were more active than others, I converted distances to proportions by dividing each measured distance by the longest distance recorded for each individual.

Vegetation and soil sampling

To investigate possible associations between home range size and habitat features, I sampled vegetation and soil variables within the home range of each radiotracked individual (Table 2.1). At each site, I randomly selected 5 1-m^2 subplots within 18 m of the center of the home range. Habitat structure was quantified by visually estimating percent ground cover of pine straw, hardwood leaf litter, woody vegetation, forbs and vines, wiregrass, and other grass species in each quadrant of the subplot and averaging the quadrants.

I used a 7-cm diameter bucket auger to collect soil samples at depths of 0-10, 15-25, 40-50, 65-75, and 90-100 cm at the center of each home range. Data were collected at multiple depths because I had observed differences in gopher digging behavior at different depths while trapping. I used the qualitative field texture method to estimate soil texture at each depth (Thien 1979). I used the estimated soil textures at each depth to create a texture profile for each site. I selected representatives of each unique texture profile to be quantified at a professional testing lab (Waters Agricultural Testing Lab, Camilla, Georgia) using the hydrometer method for determining percent sand, silt, and clay (Gee and Bauder 1986) and I assigned the quantified results of each representative profile to the remaining samples from the sites that shared the same profile. Percent nitrogen and carbon of each soil sample were determined using a Flash 2000 carbon nitrogen analyzer (CE Elantech, Lakewood, NJ) at the University of Georgia Forest Soil Laboratory (Athens, Georgia). I determined pH for each sample by combining 5 g of soil with 10 ml deionized water and immersing an electronic pH probe in the solution (McLean 1982).

Data Analysis

I created an area-observation (AO) curve using the bootstrap function in R 2.3.1 (R Foundation for Statistical Computing) to determine the minimum number of locations required to calculate an accurate home range (Odum and Kuenzler 1955). I used a <5% increase to indicate the asymptote (Laundré and Keller 1984, Springer 2003) to prevent excluding an excessive number of gophers and overly decreasing sample size. I created minimum convex polygons for each gopher that met the required number of locations using the Hawth’s tools extension in

ArcMAP 9.3.1. For gophers that dispersed, I created the minimum convex polygon from the area for which the gopher had the greatest number of locations.

I conducted correlation analyses using the CORR procedure in SAS 9.3 (SAS Institute, Inc. 2012) to determine associations between home range size and gopher body mass or habitat features. I used Pearson's product moment correlation for variables that were normally distributed and Spearman rank correlation for non-normal variables (Table 2.2).

I created a survivorship curve using the Kaplan-Meier Staggered Entry method (Pollock et al 1989). I based the curve on weekly counts of individuals added to the study set, lost to mortality, or censored. Instances of mortality and dispersal were described anecdotally due to a low number of documented mortalities and dispersals.

I separated daily activity data into 6 4-hour segments, and treated the proportional distances traveled and proportional distances from the nest within each 4-hour segment as subsamples for each individual. I ran two analyses of variance (ANOVA), one using distance traveled and the other using distance from nest, with the GLM procedure in SAS 9.3 to determine if there was a significant difference in gopher activity among any of the 4-hour segments. I used a Fisher's protected least significant difference (LSD) procedure for mean separation. Significance was indicated at $P<0.10$ for all statistics.

RESULTS

I captured 27 gophers between 26 September 2012 and 30 April 2013. I implanted 25 adult gophers ($\bar{x}$=194 g, SD= 65, range=122-338 g) with transmitters. One juvenile (100 g) was too small to accept the transmitter and 1 adult female (180 g) was not tagged due to apparent late-stage gestation. Other studies occurring on the study site experienced non-target captures of juvenile gophers on 12 September 2012, 25 October 2012, 28 October 2012, and 12 April 2013.

The 4 juvenile gophers (89-95 g) were considered incidental evidence of southeastern pocket gopher dispersal.

The first 12 gophers captured received subcutaneously implanted transmitters, whereas the remaining 13 had transmitters implanted within the peritoneal cavity. Of the 12 gophers with subcutaneous transmitters, 4 lost transmitters 12-20 days post-surgery. None of the 13 gophers with peritoneal transmitters lost transmitters, but 1 died prior to release due to complications from surgery.

I tracked the 20 individuals that survived and retained transmitters >20 days for a mean of 103 days (SD=40, range=27-170) from 4 October 2012 through 18 September 2013 resulting in a mean of 50 locations/gopher (SD=20, range=10-79). I tracked 12 of the 20 gophers until transmitter failure ($\bar{x}$=120 days, SD=31, range=43-170 days). I was unable to relocate 5 gophers after 32, 92, 95, 99, and 110 days ($\bar{x}$=86, SD= 31) with no indication of their final outcome (there was no marked decrease in signal strength prior to loss of signal and attempts to recapture were unsuccessful). Two of the 20 gophers died after 27 and 30 days. The remaining gopher lost its subcutaneous transmitter after 129 days of tracking.

Home Range

Based on the AO curve, a minimum of 17 locations was necessary to accurately determine home range. I collected the minimum number of locations for 17 of the 20 tracked gophers. Mean home range size for all gophers was 921.9 m^2 (SD= 805.3, range=43.4-2246.8 m^2; Appendix 1). Home range size was positively associated with body mass (r=0.4596, P=0.0634) percent silt at 25 cm (r=0.5539, P=0.0211) and carbon content at 75 cm (r=0.4574, P=0.0649), and negatively associated with percent sand at 25 cm (r=-0.5948, P=0.0118), percent clay at 50 cm (r=-0.5283, P=0.0293), and ground cover of grasses other than wiregrass (r=-0.4247, P=0.0893;Table 2.2).

Survival

Survival rate dropped from 1.000 to 0.857 with a mortality event at week 16, then dropped to 0.779 with a second mortality event at week 35 where it remained until the end of the 51 week study (Figure 2.1). In the first mortality event, I recovered a gopher from its burrow showing a puncture wound to the left shoulder and extensive bruising to the face and muzzle. I found an opening into the burrow 3-5 m from where the gopher was recovered. The opening appeared to be the beginning of a gopher mound. In the second mortality event, I recovered a transmitter near the gopher's burrow on top of the leaf litter under a tree. There were no signs of the gopher carcass. Again, I found an opening into the burrow 10-15 m from the transmitter which also appeared to be the beginning of a gopher mound.

Dispersal

Three of the 20 tracked gophers dispersed during the tracking period. These 3 gophers were smaller than the average body mass of gophers in my study (137 g, 131 g, and 155 g respectively), but they were not juveniles (<100 g), and sex could not be determined. The first gopher dispersed on 25 October 2012 after 22 days of tracking, traveled 264.9 m over 3 days, and settled at a new location for the remaining 75 days of the tracking period. On 12 November 2012, this gopher made a 305.7 m excursion over 3 days to a third location, but returned to the second location 3 days later. The second gopher dispersed on 4 November 2012 after 32 days of tracking, traveled 319.1 m over 9 days, and settled at a new location for the remaining 70 days of the tracking period. The third gopher dispersed on 15 June 2013 after 77 days of tracking, traveled 143.2 m over 10 days, and settled at a second location for the remaining 84 days of the tracking period. Other than 1-2 small mounds where the gopher would stop 1-3 days, there were no mounds between gophers' first and final locations.

Daily Activity Pattern

Mean maximum distance gophers traveled from nests over 24 hours of tracking was 17.3 m (SD=14.1, range=4.0-42.4 m). Mean maximum distance gophers traveled during 20-min intervals over 24 hours of tracking was 20.5 m (SD=18.4, range=4.0-51.0 m). There was no difference in proportional distance from the nest among the 6 4-hour segments (P= 0.1387; Figure 2.2). However, there was a difference in proportional distance traveled between successive locations among the 6 4-hour segments (P=0.0846). Distance traveled from16:00-20:00 was greater than distance traveled from 8:00-12:00, 12:00-16:00, and 20:00-24:00, and distance traveled from 00:00-4:00 was greater than distance traveled from 12:00-16:00, and 20:00-24:00 (Figure 2.3).

DISCUSSION

Although subcutaneous transmitter implantation has been used and recommended for radiotracking other pocket gopher species (Cameron et al 1988, Connior and Risch 2009b, Connior and Risch 2010), based on my results I recommend intra-peritoneal implantation for future studies of the southeastern pocket gopher. Occurrence of dropped transmitters was 33% for sub-cutaneous implantation in my study. It was apparent during the sub-cutaneous implantations that the southeastern pocket gopher has thin skin because markings on the transmitters could sometimes be faintly seen through the skin after implantation. I suspect that the thinness of the skin contributed to the loss of sub-cutaneous transmitters, whether due to the closing sutures tearing out or eruption of the transmitter through the skin. Once intra-peritoneal implantations were employed, there was no further loss of transmitters, but one gopher died post-surgery. Zinnel and Tester (1991) also experienced surgery related fatalities with intra-peritoneal implantation in the plains pocket gopher (*Geomys bursarius*), but, similar to my study, occurrence was low.

Home Range

Because mine was the first study to use telemetry to investigate southeastern pocket gopher home range, there are no similar studies for comparison. However, Hickman and Brown (1973a) estimated mean home range size of 8 southeastern pocket gophers in Hillsborough County, Florida at 2666.5 m^2 (SD=2308.5 range=720-7571 m^2) based on the area in which new mounds were produced. Their estimate is almost 3 times larger than my estimate ($\bar{x}$=921.9 SD=805.3 m^2) likely due to differences in methodologies used to determine home range. They delineated home ranges in rectangles that may have included unused area, and they could not ensure that mounding was by a single gopher rather than two or more in close proximity. Additionally, they did not take dispersal into account when delineating home range dimensions. In contrast, I considered areas used by gophers pre- and post-dispersal as separate home ranges, and only used the home range with the most locations to calculate mean home range. In comparison to other Geomyidae, home range of southeastern pocket gophers from my study is larger than the Ozark pocket gopher ($\bar{x}$=291.8 m^2 SD=162.2 for 14 adult males; Connior and Risch 2010), Botta's pocket gopher ($\bar{x}$=474.4 m^2 SD=148.2 for 7 adult males; Bandoli 1987), and the Mazama pocket gopher (*Thomomys mazama*) ($\bar{x}$= 108 m^2 SD=37.9 for 4 adult males; Witmer et al. 1996). Body mass of southeastern pocket gophers (122-338 g) in my study was only slightly larger than Ozark (130-260 g; Connior and Risch 2010) and Botta's pocket gophers (111-262 g; Jones and Baxter 2004), but substantially larger than the Mazama pocket gopher (61-147 g; Verts and Carraway 2000). Therefore, body mass likely does not explain the home range size differences among the four species. However, one consistency among geomyid home range sizes is the high variability among individuals within species, as indicated by the high standard deviations reported for all species.

Similar to the Ozark pocket gopher (Connior and Risch 2010), home range size for the southeastern pocket gopher was associated with body mass. However, I could not determine if sex or age influenced associations between body mass and home range size, as in the Ozark pocket gopher (Connior and Risch 2010), because only adult gophers were implanted with transmitters and sex could not be determined. The observed relationship between body mass and home range size is likely the result of the increase in metabolism associated with increased body mass (McNab 1963). As metabolism increases, the area which the pocket gopher must cover to procure sufficient resources to sustain its metabolic requirements also increases.

Home range size may be based on the ability to expand and maintain tunnels, which likely explains the observed relationship between home range and soil texture. Because southeastern pocket gophers select for sandy soils (McNab 1966, Wilkins 1985, Wilkins 1987, Simkin and Michener 2005, Southern Wildlife Consultants 2008), it is counterintuitive that home range size would be negatively associated with percent sand and positively associated with percent silt. However, in comparison to silt, sand does not compact well (Plaster 2013), making any voids in the soil less stable. Thus, an increasing silt to sand ratio at 25 cm likely increases stability of the gopher tunnels, reducing collapse and allowing gophers to maintain larger tunnel systems. However, too much clay in the soil can limit home range size by increasing the energetic cost of expansion, explaining the observed decrease in home range size with increasing percent clay, and similar results found in other pocket gophers (Romañach et al. 2005). According to Vleck (1981), foraging in Botta's pocket gopher is a balance between acquiring energy from food and expending energy while expanding tunnels in search of food. Burrowing wolf spiders (*Geolycosa* spp.) expended 5.6 J of energy burrowing in clayey subsoils, but only 1.9 J in sandy/sandy loam subsoils (Suter et al. 2011). Thus, pocket gophers likely minimize expansion in soils with increasing clay content to conserve energy.

Because southeastern pocket gophers feed on roots, tubers, and other underground portions of plants (Golley 1962), the percent vegetative ground cover that was estimated at each home range should represent the density of available food resources. The negative association observed between home range size and ground cover of other grasses is likely due the ability of pocket gophers to procure sufficient food in smaller areas when food resources are denser. Foraging in pocket gophers is a balance of procuring food and expanding tunnels (Vleck 1981). Thus, it would be inefficient to expand a tunnel larger than what is needed to gather sufficient food, limiting home range size. A negative association between home range size and resource availability is commonly observed in rodents (Emsens et al. 2013, Lovari et al. 2013), and has been documented in other geomyids (Romañach et al. 2005).

The positive association between home range size and soil carbon content at 75 cm was a curious result. Based on my observations, tunneling at this depth was limited, and organic matter at this depth should not have an impact on the gopher's ability to procure food. Thus, the correlation between home range and carbon at this depth is likely the artifact of a shared relationship with an unknown variable.

Survival

The survival rate observed in my study supports the prediction of Brown (1971) that southeastern pocket gophers likely live >2 years. My results are also similar to the high survival rate in Ozark pocket gophers documented by Connior and Risch (2010). The observed survival rate of the southeastern pocket gopher is greater than non-fossorial and semi-fossorial rodents sharing habitat on my study site, such as the hispid cotton rat (*Sigmodon hispidus;* Conner et al. 2011.), cotton mouse (*Peromyscus gossypinus*), and oldfield mouse (*Peromyscus polionotus*; Morris et al. 2011). It is likely that the southeastern pocket gopher has a higher survival rate because its fossorial lifestyle protects it from high levels of predation. The apparent predator avoidance advantage to fossorial species is evident in burrowing conilurine rodents in Australia, which are experiencing less severe declines in response to predation than non-fossorial species (Smith and Quin 1996).

Although predators could not be definitively identified for the two mortalities, a raptor was suspected in both cases. When a gopher emerges above ground to dispose soil to a new mound, it is vulnerable to predation, and repeated trips to the surface likely attract predator attention (Hickman and Brown 1973b). The puncture wounds to the shoulder and bruising to the muzzle found on the carcass of the first mortality could be attributed to raptor talons. The gopher was apparently able to escape, but later died from the injuries. In the second mortality, the transmitter was found under a tree and was likely dropped by a raptor feeding on the gopher in the tree above. Although pine snakes (*Pituophis* spp.) are the primary predators of pocket gophers in regions where they coexist (Rudolph et al. 2002, Sterner et al. 2002), I do not think a pine snake was the predator in either mortality because a pine snake would have been able to enter the burrow to consume the first gopher, and the transmitter of the second gopher would have been recovered in snake feces. I expected most mortality in this study to be attributed to the Florida pine snake because pine snakes are prominent on the study site. However, the small number of mortalities that occurred during this study, along with the five gophers that disappeared with no indication of outcome, likely does not represent the full range of potential southeastern pocket gopher predators.

Dispersal

The above-ground dispersal of 4 ancillary juveniles documented, along with the dispersals of the 3 small (sub-adult) pocket gophers from my study, suggests that dispersal of the southeastern pocket gopher may be similar to Botta's pocket gopher (Daly and Patton 1990). Juvenile female Botta's pocket gophers disperse soon after weaning and prior to coming into estrus during the first breeding season. Males, however, do not reach sexual maturity until after the first breeding season, and disperse later as larger sub-adults (Daly and Patton 1990). Daly and Patton (1990) suggested that females disperse as juveniles to prevent consanguineous mating, while males disperse later because they are larger and can better compete with adult males for territory. However, I was unable to determine sex of the dispersing southeastern pocket gopher juveniles or study animals, and thus could not confirm that the juveniles were female and the sub-adults male.

The instances of dispersal I documented increases the maximum known dispersal distance for a southeastern pocket gopher from 244 m (Hickman and Brown 1973a) to 319.1 m. The maximum number of days a single gopher traveled before settling at a location to construct a new burrow system was 10 days. During these periods of traveling, gophers spent 1-3 days at intermediary locations, possibly either seeking shelter or testing the area for suitability, where they constructed 1-2 small mounds. Other than the mounds at these intermediary locations, there were no other mounds between the first and final location of gophers, indicating that their dispersals were above-ground. Of the 7 dispersals, 5 occurred during the fall. This would suggest a pattern in the time of year that gophers disperse. However, the gophers that were non-target captures of other studies should be ignored in this case because the trapping schedules of the studies were not uniform throughout the year. The remaining dispersals documented by telemetry, 2 occurring in the fall and 1 occurring in the summer, are too few to infer conclusions about dispersal timing.

The observation of a pocket gopher traveling 305.7 m away from its burrow and then returning within a week indicates that the southeastern pocket gopher is capable of homing. Homing is a common ability among rodents, and suggests the utilization of one of many advanced navigational strategies, such as memorizing landscape elements (Griffo 1960, Van Vuren et al. 1997), geomagnetic orientation (August and Ayvazian 1989), and dead reckoning (Etienne 1992). Further research is needed to fully evaluate the spatial capabilities of the southeastern pocket gopher and determine the mode of navigation.

Daily Activity Pattern

My results on daily activity patterns differ from Ross (1980) who found that captive southeastern pocket gophers were equally active throughout the diel period. In my study, based on focal telemetry sessions conducted once over the summer months for 9 gophers, southeastern pocket gophers were more active from 00:00 to 4:00 and 16:00 to 20:00, with the highest activity from 16:00 to 20:00 (Figure 2.3). Ross (1980) likely failed to detect the variation in daily activity I detected because of the admitted inconsistencies between the captive environment of the gophers in his study and a natural environment. However, my results are similar to Bandoli (1987) who detected a trend towards higher activity between 15:00 and 18:00 in Botta’s pocket gophers, although he did not detect a second peak.

Management Implications

Recent recognition of the vital importance of longleaf pine communities as floral biodiversity hotspots (Peet and Allard 1993) and critical habitat for rare fauna such as the gopher tortoise (*Gopherus polyphemus*; U. S. Fish and Wildlife Service 1990) and Red-cockaded Woodpecker (*Picoides borealis*; U. S. Fish and Wildlife Service 2003) has resulted in the promotion of longleaf pine habitat restoration (Van Lear et al. 2005, Aschenbach et al. 2010). As longleaf pine is restored in the Southeast, suitable habitat for southeastern pocket gopher colonization will likewise become available.

Although my study indicates that the southeastern pocket gopher is capable of dispersing further than previously thought, the highly fragmented nature of some of these newly available habitats will likely inhibit dispersal to a degree that can prevent the natural colonization of southeastern pocket gopher populations into some restored habitats. Therefore, some instances of dispersal may need to be facilitated through translocations. At this time there have been no published studies on translocation of the southeastern pocket gopher, but the results of my study do provide for some recommendations.

First, the solitary nature (Golley 1962) of the southeastern pocket gopher suggests that translocated animals should be spaced so that their home ranges will not overlap. Based on the results of my study, translocated southeastern pocket gophers should therefore be allocated approximately 1,000 m^2 per individual. Also, my study found an increase in southeastern pocket gopher activity after dusk, suggesting that traps set to capture pocket gophers for translocation should be monitored until after dark. Current literature concerning pocket gopher trapping does not make any suggestions regarding timing (Hart 1973, Gates et al. 1988, Connior and Risch 2009a). Finally, I documented a southeastern pocket gopher homing up to 305.7 m. The ability to home can lower site fidelity (Van Vuren et al 1997, Villaseñor et al. 2013) affecting success of translocation efforts.

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Table 2.1 Abbreviations used for ground cover and soil texture variables measured within 18 m of the center of radiotagged southeastern pocket gopher home ranges in Baker County, Georgia, 2012-2013.

Variable	Description
Vegetation Ground Cover	
Pine Straw (PS)	Percent of 5 1-m^2 plots covered by pine straw.
Leaf Litter (LL)	Percent of 5 1-m^2 plots covered by hardwood leaf litter.
Woody Vegetation (WO)	Percent of 5 1-m^2 plots covered by woody vegetation.
Forbs/Vines (FV)	Percent of 5 1-m^2 plots covered by forbs and vines.
Wiregrass (WG)	Percent of 5 1-m^2 plots covered by wiregrass.
Other Grass (OG)	Percent of 5 1-m^2 plots covered by grasses other than wiregrass.
Soil Texture	
Sand at 10 cm (SA)	Percent sand of soil samples collected at 10 cm.
Sand at 25 cm (SB)	Percent sand of soil samples collected at 25 cm.
Sand at 50 cm (SC)	Percent sand of soil samples collected at 50 cm.
Sand at 75 cm (SD)	Percent sand of soil samples collected at 75 cm.
Sand at 100 cm (SE)	Percent sand of soil samples collected at 100 cm.
Silt at 10 cm (TA)	Percent silt of soil samples collected at 10 cm.
Silt at 25 cm (TB)	Percent silt of soil samples collected at 25 cm.
Silt at 50 cm (TC)	Percent silt of soil samples collected at 50 cm.
Silt at 75 cm (TD)	Percent silt of soil samples collected at 75 cm.
Silt at 100 cm (TE)	Percent silt of soil samples collected at 100 cm.
Clay at 10 cm (CA)	Percent clay of soil samples collected at 10 cm.
Clay at 25 cm (CB)	Percent clay of soil samples collected at 25 cm.
Clay at 50 cm (CC)	Percent clay of soil samples collected at 50 cm.
Clay at 75 cm (CD)	Percent clay of soil samples collected at 75 cm.
Clay at 10O cm (CE)	Percent clay of soil samples collected at 100 cm.
Soil Chemistry	
Nitrogen at 10 cm (NA)	Percent nitrogen of soil samples collected at 10 cm.
Nitrogen at 25 cm (NB)	Percent nitrogen of soil samples collected at 25 cm.
Nitrogen at 50 cm (NC)	Percent nitrogen of soil samples collected at 50 cm.
Nitrogen at 75 cm (ND)	Percent nitrogen of soil samples collected at 75 cm.
Nitrogen at 100 cm (NE)	Percent nitrogen of soil samples collected at 100 cm.
Carbon at 10 cm (RA)	Percent carbon of soil samples collected at 10 cm.
Carbon at 25 cm (RB)	Percent carbon of soil samples collected at 25 cm.
Carbon at 50 cm (RC)	Percent carbon of soil samples collected at 50 cm.
Carbon at 75 cm (RD)	Percent carbon of soil samples collected at 75 cm.
Carbon at 10O cm (RE)	Percent carbon of soil samples collected at 100 cm.
pH at 10 cm (PA)	pH of soil samples collected at 10 cm.
pH at 25 cm (PB)	pH of soil samples collected at 25 cm.
pH at 50 cm (PC)	pH of soil samples collected at 50 cm.
pH at 75 cm (PD)	pH of soil samples collected at 75 cm.
pH at 100 cm (PE)	pH of soil samples collected at 100 cm.

Table 2.2 Mean (standard deviation), range, correlation coefficient (R), and P-value for variables examined for an association with home range size of 17 radiotagged southeastern pocket gophers in Baker County, Georgia, 2012-2013. Abbreviations are defined in Table 2.1.

Variable	Mean(SD)	Range	R	P-value
Body Mass[a]	180.5(56.7) g	122-338 g	0.4596	0.0634
PS	10.3(8.6)%	0-32%	0.0195	0.9407
LL	6.6(8.5)%	0-27%	0.1718	0.5098
WO	5.8(3.9)%	0-13%	0.2820	0.2728
FV	19.9(11.6)%	6-43%	-0.0525	0.8413
WG	12.1(20.1)%	0-64%	0.3622	0.1531
OG[a]	27.8(18.3)%	4-59%	-0.4247	0.0893
SA	86.8(7.8)%	57.2-89.6%	-0.0166	0.9495
SB[a]	86.8(6.4)%	68.8-93.6%	-0.5948	0.0118
SC	87.4(7.0)%	72.8-93.2%	0.2868	0.2643
SD	81.2(10.2)%	60.8-91.6%	0.0550	0.8339
SE	79.7(13.0)%	56.4-93.2%	-0.0174	0.9473
TA	8.6(3.9)%	6.4-22.4%	0.1350	0.6055
TB[a]	8.8(4.6)%	4.4-20.8%	0.5539	0.0211
TC	6.4(3.6)%	4.8-18.8%	0.0835	0.7502
TD	7.6(4.2)%	4.4-20.8%	0.2469	0.3395
TE	6.0(2.2)%	4.4-13.2%	-0.0078	0.9762
CA	4.6(4.2)%	0.8-20.4%	-0.0654	0.8032
CB	4.4(2.8)%	0.4-14.4%	0.3245	0.2038
CC[a]	6.1(6.2)%	0.4-16.4%	-0.5283	0.0293
CD	11.2(10.4)%	2.0-30.4%	-0.1266	0.6282
CE	14.3(11.5)%	2.0-30.4%	0.1190	0.6491
NA	0.058(0.020)%	0.030-0.123%	0.1165	0.6561
NB	0.031(0.010)%	0.000-0.043%	-0.0504	0.8476
NC	0.022(0.011)%	0.000-0.036%	-0.1950	0.4534
ND	0.021(0.011)%	0.000-0.033%	0.2572	0.3189
NE	0.022(0.009)%	0.000-0.033%	0.0308	0.9067
RA	1.173(0.591)%	0.257-2.615%	0.2182	0.4002
RB	0.435(0.193)%	0.095-0.826%	0.0526	0.8412
RC	0.199(0.060)%	0.116-0.307%	-0.4019	0.1098
RD[a]	0.143(0.109)%	0.000-0.504%	0.4574	0.0649
RE	0.095(0.047)%	0.000-0.205%	0.2962	0.2484
PA	5.59(0.60)	5.06-7.29	0.2230	0.3895
PB	5.56(0.58)	4.95-7.35	0.3236	0.2052
PC	5.51(0.54)	4.90-7.32	0.3252	0.2027

PD	5.53(0.38)	5.04-6.57	-0.2148	0.4078
PE	5.26(0.54)	4.52-6.69	-0.3606	0.1551

[a]Variable was significantly correlated with home range size

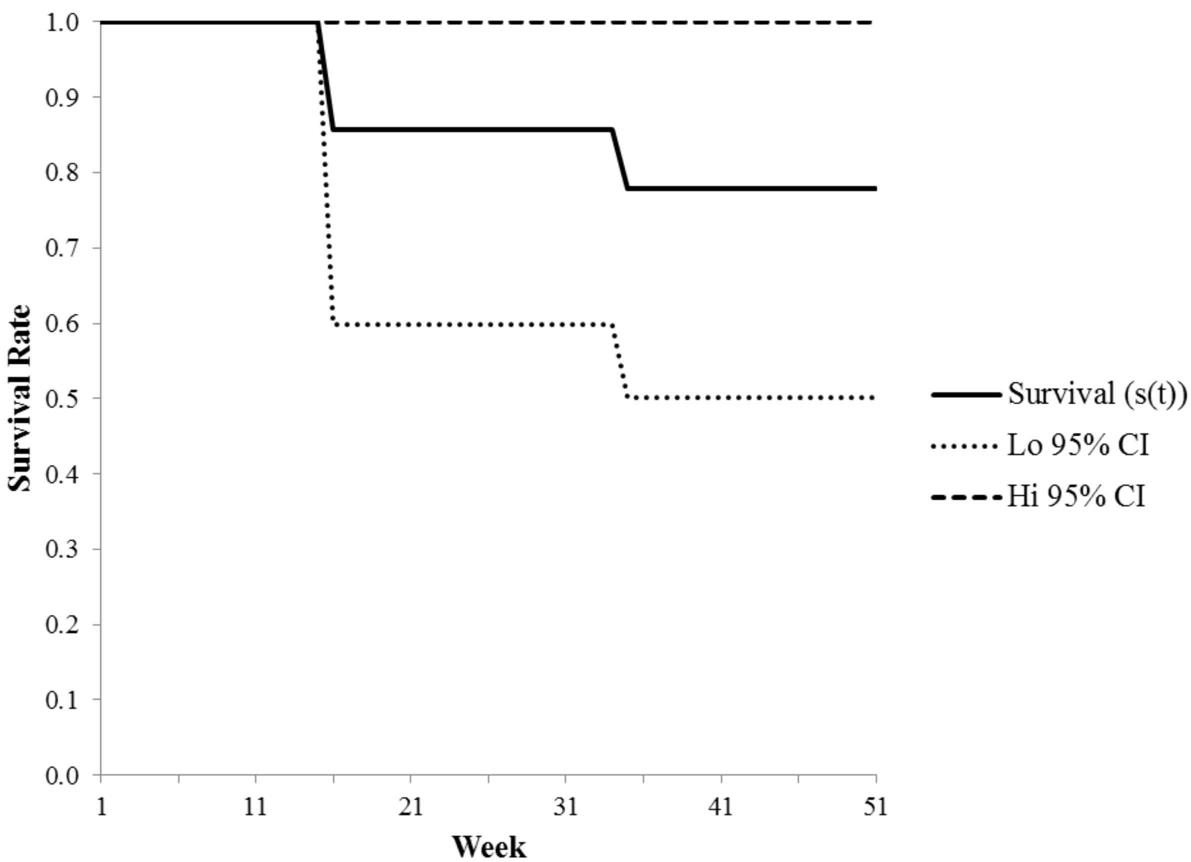

Figure 2.1 Survival rate of 25 radiotagged southeastern pocket gophers over 51 weeks in Baker County, Georgia, 2012-2013.

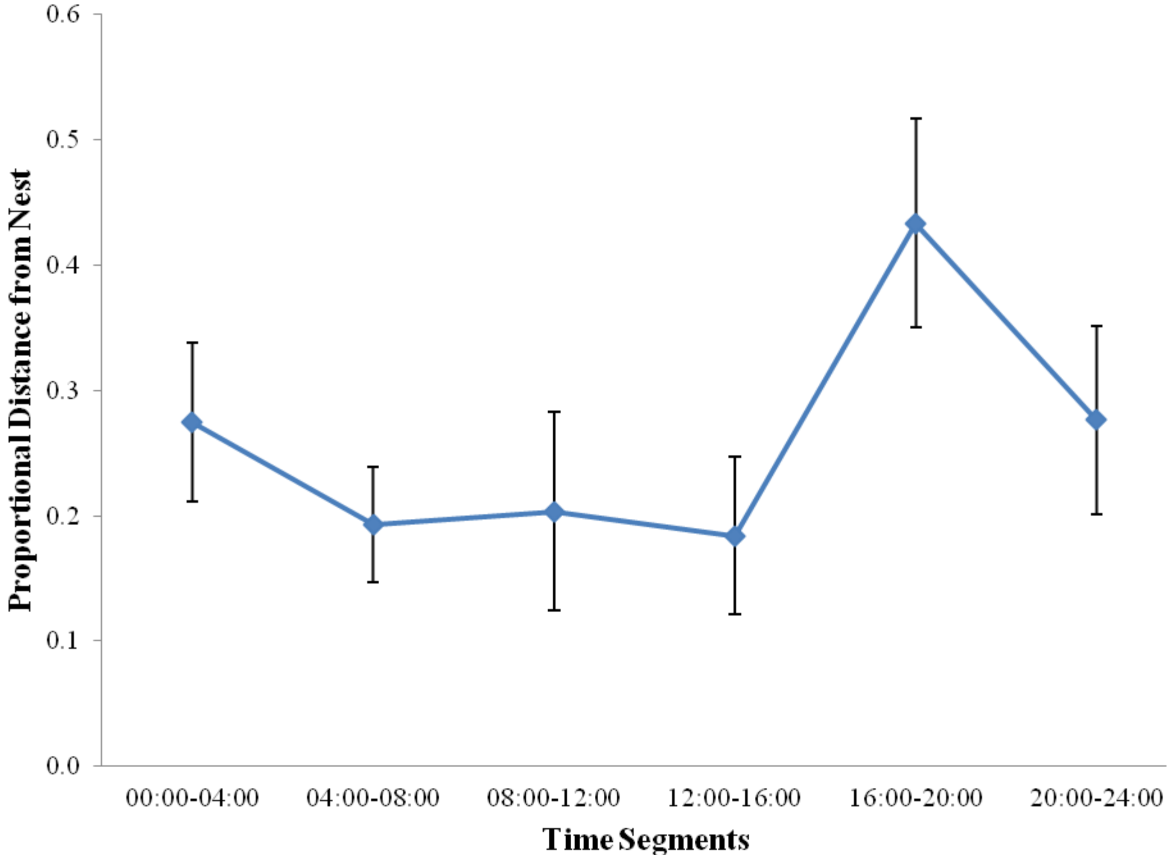

Figure 2.2 Proportional distance from nest during 4-hour time segments throughout the diel period by 9 radiotagged southeastern pocket gophers in Baker County, Georgia, 2013. Bars show standard error.

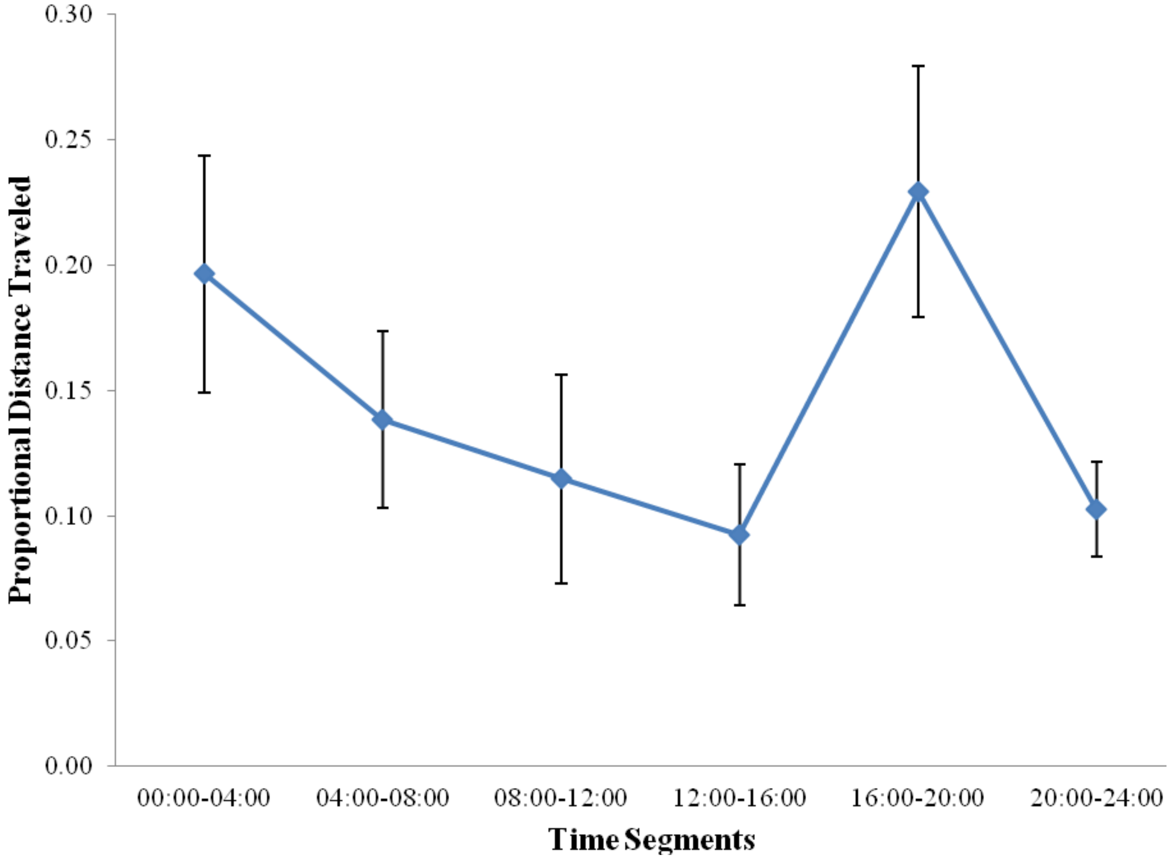

Figure 2.3 Proportional distance traveled during 4-hour time segments throughout the diel period by 9 radiotagged southeastern pocket gophers in Baker County, Georgia, 2013. Bars show standard error.

CHAPTER 3

VEGETATION STRUCTURE AND SOIL CHARACTERISTICS OF SOUTHEASTERN POCKET GOPHER HABITAT IN SOUTHWESTERN GEORGIA[2]

[2] Warren, A. E., S. B. Castleberry, L. M. Conner, D. Markewitz. To be submitted.

ABSTRACT

The southeastern pocket gopher (*Geomys pinetis*) is a fossorial rodent historically associated with longleaf pine (*Pinus palustris*) communities. However, conversion and fragmentation of longleaf pine communities has reduced quality and quantity of southeastern pocket gopher habitat. I quantified vegetation structure in terms of simple ground cover categories, and soil texture, pH, nitrogen, and carbon at multiple depths, in areas with gopher activity and those lacking activity. I developed a suite of models to determine whether vegetation structure or soil characteristics were better predictors of gopher presence. I also developed models using combinations of vegetation and soil variables to predict southeastern pocket gopher presence. Soil characteristics predicted pocket gopher presence better than vegetation structure. The best overall model for predicting southeastern pocket gopher presence combined percent clay, percent silt, pH, nitrogen and carbon. Percent clay, percent silt, pH, and nitrogen were important predictor variables with confidence intervals excluding zero, while no vegetation structure variables were important. I conclude that soil characteristics, rather than vegetation structure, should be used to identify and evaluate suitable habitat for the southeastern pocket gopher. Even with suitable vegetation structure, some areas may be inappropriate for southeastern pocket gopher translocation because soil characteristics may not be suitable.

INTRODUCTION

The southeastern pocket gopher (*Geomys pinetis*) is a fossorial rodent historically associated with longleaf pine (*Pinus palustris*) communities characteristic of the Coastal Plain physiographic province in southeastern Alabama, southern Georgia, and northern and Central Florida (Golley 1962, Pembleton and Williams 1978, Wilkins 1987). Longleaf pine communities of this region have been highly impacted by conversion to other land uses and fragmentation, altering the amount and distribution of southeastern pocket gopher habitat. Patches of suitable habitat apparently sustain isolated populations, but the species is absent from a large portion of its historical range (Southern Wildlife Consultants 2008). It is therefore important to understand characteristics of suitable habitat so that areas meeting these criteria can be maintained or restored in future conservation efforts.

For many species, suitable habitat is better characterized by vegetation structure than by species composition (Garden et al. 2007, Stostad and Menéndez 2014). The historic association of the southeastern pocket gopher with the longleaf pine community is well-established (Golley 1962, Pembleton and Williams 1978), but studies have documented southeastern pocket gopher presence in additional habitats such as agricultural fields and utility right-of-ways (Avise and Laerm 1982, Southern Wildlife Consultants 2008). Southern Wildlife Consultants (2008) suggested that older, thinned slash (*P. elliottii*) and loblolly pine (*P. taeda*) stands with open canopies and sufficient understory growth can provide suitable habitat. Southeastern pocket gophers likely select for vegetation structure typical of longleaf pine communities rather than the presence of the longleaf pine itself. Ford (1980) found no associations between southeastern pocket gopher presence and specific plant species, but found that southeastern pocket gophers avoided areas that lacked grasses and/or were covered by root systems that impeded burrowing. Similarly, Ozark pocket gophers select areas based on availability of abundant forage rather than presence or absence of specific plant species (Connior et al. 2010). Thus, vegetation structure is a potentially important determinate of suitable southeastern pocket gopher habitat.

The fossorial lifestyle of the southeastern pocket gopher suggests that soil characteristics may also be an important determinate for suitable habitat. During burrow construction, all above ground openings are plugged with soil (Hickman and Brown 1973a). The ability to breathe is therefore dependent on diffusion of gasses through the soil, limiting pocket gopher occurrence to highly porous soils with low water-holding capacity (McNab 1966). The association of the southeastern pocket gopher with areas of xeric sandy soils is well supported in the literature (McNab 1966, Wilkins 1985, Wilkins 1987, Simkin and Michener 2005, Southern Wildlife Consultants 2008). However, specific soil characteristics, such as soil texture, or the chemical parameters of pH, nitrogen, and carbon content, have not been described at the spatial scale of the individual burrow, except in the context of comparing gopher mound soil to the surrounding matrix (Simkin et al. 2004).

It is difficult, if not impossible, to conserve a species when characteristics determining suitable habitat for that species are not clearly defined. Southeastern pocket gopher habitat may be defined by vegetation structure, soil characteristics, or a combination (McNab 1966, Ford 1980, Wilkins 1985, Wilkins 1987, Simkin and Michener 2005, Southern Wildlife Consultants 2008). I quantified vegetation structure in terms of simple ground cover categories, and soil texture, pH, nitrogen, and carbon at multiple depths, in areas with gopher activity and those lacking activity. I used a modeling approach with these variables to determine whether vegetation structure or soil characteristics were better predictors of gopher presence. I also used combinations of vegetation and soil variables to develop the best predictive model of southeastern pocket gopher presence. With a better understanding of factors related to southeastern pocket gopher presence, efficient methods and criteria can be developed to identify and evaluate areas of suitable southeastern pocket gopher habitat for maintenance or restoration.

METHODS

Study Site

My study was conducted from August 2012 through December 2013 at the Joseph W. Jones Ecological Research Center at Ichauway in Baker County, Georgia, USA. Ichauway is situated within the Dougherty Plain physiographic district, which is characterized by marine and fluvial deposited Entisols and Ultisols over highly fractured Ocala limestone, and a flat to rolling karst topography (Beck and Arden 1983, Hayes et al. 1983, Couch et al. 1996). Ichawaynochaway creek runs north to south through the center of the property, and the property is bordered by the Flint River to the southeast. Ichauway covers 117 km^2 of predominately longleaf pine forest surrounded by center pivot agriculture. Other cover types found at Ichauway are slash and loblolly pine stands, mixed pine hardwoods, riparian hardwood forests, live oak (*Quercus virginianus*) depressions, isolated depressional wetlands, creek swamps, agricultural fields, shrub-scrub uplands, and areas impacted by human development (Goebel et al. 1997; Figure 3.1). The habitats of Ichauway allow for high floral and faunal species diversity, including many native species, such as wiregrass (*Aristida stricta*), the dominate understory species for approximately 1/3 of the property. The site is uniformly managed with prescribed fire to maintain vegetation composition and structure. Stands are burned at least every other year, primarily during March and April (Atkinson et al. 1996).

Sample Site Selection

I selected 50 locations exhibiting fresh pocket gopher mounding activity (hereafter, active sites). The mounds were sighted opportunistically from roads while trapping gophers for a concurrent telemetry study (Chapter 2). Gopher presence was confirmed at each active site by successful capture of a gopher, or the gopher filling traps with soil. I also identified 50 locations with no evidence of pocket gopher activity (hereafter, inactive sites; Figure 3.2). To identify inactive sites, I first used ArcGIS version 10.x (Esri, Redlands, California) to overlay a grid of random points generated by Geospatial Modeling Environment (SpatialEcology.com) onto the study sight with > 250 m between random points and >250 m between active sites and random points. I selected 250 m as the minimum distance based on the farthest known dispersal distance by a southeastern pocket gopher (Hickman and Brown 1973b). I then surveyed random points in random order by walking 50 m transects in each cardinal and sub-cardinal direction until 50 locations with no apparent gopher activity were identified. I used the Clip tool in ArcMap 9.3.1 to determine the percent of landcover types represented within 18 m buffers around active and inactive sites.

Vegetation Structure and Soil Sampling

At each active and inactive site, I randomly selected 5 1-m^2 subplots within an 18 m radius based on the mean home range of gophers in a concurrent telemetry study (Chapter 2). The radius was centered on the centroid of activity (mounds or telemetry locations) for active sites, and on the plotted point for inactive sites. Vegetation structure was quantified by estimating percent ground cover in each subplot. I visibly estimated percent cover of pine straw, hardwood leaf litter, woody vegetation, forbs and vines, wiregrass, and other grass species in each quadrant of the subplot and averaged the quadrants to represent the subplot.

At each active and inactive site, I used a 7-cm diameter bucket auger to collect soil samples at depths of 0-10, 15-25, 40-50, 65-75, and 90-100 cm. I used the qualitative field texture method to estimate soil texture at each depth (Thien 1979). I used the estimated soil textures at each depth to create a texture profile for each site. I selected representatives of each unique texture profile to be quantified for particle size at a professional testing lab (Waters

Agricultural Testing Lab, Camilla, Georgia) using the hydrometer method for determining percent sand, silt, and clay (Gee and Bauder 1986). I assigned the quantified results of each representative profile to the remaining samples from the sites that shared the same profile. Percent nitrogen and carbon of each soil sample was determined using a Flash 2000 carbon nitrogen analyzer (CE Elantech, Lakewood, NJ) at the University of Georgia Forest Soils Laboratory (Athens, Georgia). I determined pH for each sample by combining 5 g of soil with 10 ml deionized water and immersing an electronic pH probe in the solution (McLean 1982).

Data Analysis

Prior to constructing models, I used Pearson's product moment correlation to examine variables for collinearity ($|r|>0.80$). Correlation analyses revealed multicollinearity among the five depths for each of the soil variables (percent sand, percent silt, percent clay, pH, nitrogen, and carbon). Therefore, I represented each variable in the models with mean values from the five depths. Percent sand was negatively collinear to percent clay and was excluded from the models because the correlation between percent sand and percent silt was higher than correlation between percent clay and percent silt.

Using the 11 remaining variables (Table 3.1), I constructed 13 models testing hypotheses regarding the relative importance of vegetation structure or soil characteristics in predicting southeastern pocket gopher presence or absence based on previous literature. I also included a global model of the 11 variables and a null model. Each variable was present in equal number of models and had equal probability of occurring in the best model to determine the predictive value of each measured variable (Conner and Godbois 2003). I performed logistic regression to test the models with gopher presence or absence as the binary response variable. Using the same set of 15 models, I then determined the best overall model for predicting southeastern pocket gopher presence by selecting the model that returned the lowest AIC score adjusted for small sample size (AICc). I used <2 ΔAICc as the cutoff for a set of competing models (Akaike 1973, Burnham and Anderson 2002). I used model averaging to calculate parameter estimates, 95% confidence intervals, and variable weights (Σw_i) for each variable. I considered variables with confidence intervals excluding zero to be important predictors.

RESULTS

Natural longleaf pine and longleaf pine-hardwood mixed forest composed 76.4% of buffers surrounding active sites but only 25.8% of buffers surrounding inactive sites (Table 3.2). Active sites generally were characterized by higher percent ground cover of wiregrass and other grasses, and lower percent ground cover of hardwood leaf litter. Active sights had higher percent sand and lower percent clay than inactive sights, classifying the soil texture at active sights as loamy sand and inactive sights as sandy loam. Percent silt was similar between active and inactive sites. Active sites averaged within the strongly acidic range (5.1-5.5), while inactive sites averaged within the very strongly acidic range (4.5-5.0). Soil nitrogen and carbon content generally was lower for active sites than inactive sites (Table 3.3). Soil profiles differed between active and inactive sites. Active sites were sand at 10 cm, then loamy sand at 25-100 cm. Inactive sites were loamy sand at 10-25 cm, sandy loam at 50 cm, and sandy clay loam at 75-100 cm (Table 3.4).

The best soil characteristics model had an Akaike weight (w_i) of 0.892, while the best vegetation structure model had an Akaike weight (w_i) *of* 0.000 (Table 3.5). The model with the lowest AICc value combined all five soil variables and had an Akaike weight (w_i) of 0.892, and there were no closely competing models. Model averaged 95% confidence intervals for nitrogen, percent clay, pH and percent silt excluded zero, indicating that they were informative predictors

(Table 3.6). Nitrogen, pH, percent clay, carbon, and percent silt had the highest variable weights (Σw_i).

DISCUSSION

My data suggests soil characteristics are more important than vegetation structure for predicting southeastern pocket gopher presence. The overall best predictive model combined all five soil characteristics measured. Although percent clay, percent silt, pH, and nitrogen were indicated as important variables for predicting southeastern pocket gopher presence, percent clay was correlated with percent silt, pH and nitrogen. Clay particles have a much larger surface area to volume ratio than sand particles, and thus a higher cation exchange capacity, causing clayey soils to generally have a lower pH than sandy soils (Manahan 2001). In addition, soils with higher clay content typically have higher plant productivity than sandy soils, creating more soil organic matter that contributes to higher nitrogen content (Olk 2008). Based on this evidence and the strong negative collinearity (r=-0.9864) between percent clay and percent sand, the significance of silt, pH, and nitrogen as important predictor variables could be an artifact of the southeastern pocket gopher selecting for areas with sandier soils, as evident from gophers in my study selecting loamy sands rather than sandy loams.

The association between southeastern pocket gophers and sandy soils is well-documented (McNab 1966, Wilkins 1985, Wilkins 1987, Simkin and Michener 2005, Southern Wildlife Consultants 2008), but no previous study has quantified the preferred percent sand/silt/clay at which habitat is preferable. Based on my results, a 7.4% decrease in sand and a 7.5% increase in clay, in this case the difference between a loamy sand and a sandy loam, differentiates unsuitable southeastern pocket gopher habitat from suitable habitat (Table 3.3). Texture profiles of soil collected at 10, 25, 50, 75, and 100 cm gives an even more detailed look, showing that southeastern pocket gophers prefer sand-loamy sand throughout the profile over profiles with increases in clay content at deeper horizons (Table 3.4). Southeastern pocket gophers may select loamy sands based on metabolic needs (McNab 1966). The southeastern pocket gopher has a low basal metabolism, a convergent trait shared among fossorial rodents allowing them to thrive in the hypoxic environments of their burrows and tunnels (McNab 1966). However, this reduction in metabolic rate is limited in the southeastern pocket gopher by the need to thermoregulate in response to its sub-tropical habitat, mandating that gas exchange through the soil still be substantial to meet the gopher's metabolic needs. Therefore, soil texture may be an important predictor of southeastern pocket gopher presence due to the greater porosity of sand relative to silt or clay. Gas exchange through the soil increases as percent sand in the soil increases, allowing the gopher greater flexibility with regards to activity level and burrow depth in soils with higher percent sand, such as a loamy sand versus a sandy loam.

Pocket gophers may also select for loamy sands throughout the soil profile to decrease energy expended when burrowing. According to Vleck (1981), foraging in Botta's pocket gopher (*Thomomys bottae*) is a balance between acquiring energy from food and expending energy while expanding tunnels in search of food. Thus, pocket gophers may minimize energy expenditure by selecting sandier soils. The relative energetic cost of digging in clayey versus sandy soils was quantified in burrowing wolf spiders (*Geolycosa* spp.) that expended 5.6 J of energy burrowing in clayey subsoils, but only 1.9 J in sandy/sandy loam subsoils (Suter et al. 2011). This difference in energy expenditure likely explains why the areas of pocket gopher burrow systems have been observed to decrease with increasing soil clay content (Romañach et al. 2005, Chapter 2).

Although my results suggest that southeastern pocket gophers select areas with lower nitrogen and carbon content and higher pH, it is possible that the observed differences between active sites and inactive sites are a result of pocket gopher presence. Burrowing by fossorial mammals can have extensive effects on the physical, chemical, and vegetative properties of their environments, and several have even been labeled as ecosystem engineers (Zhang et al. 2003, Hagenah et al. 2013), including pocket gophers (Reichman and Seabloom 2002). Studies involving northern pocket gophers (*Thomomys talpoides*) in Colorado (Litaor et al. 1996) and southeastern pocket gophers on Ichauway (Simkin et al. 2004) have similarly reported lower levels of nitrogen and carbon content related to pocket gopher activity. Both studies examined the soil of the gopher mounds as compared to the surrounding matrix. Therefore, differences in nitrogen and carbon were not explained by differences in soil texture. Litaor et al. (1996) and Simkin et al. (2004) explained the differences in nitrogen and carbon between mounds and the surrounding matrix as a result of pocket gophers bringing deeper, less nutrient dense soils to the surface. An increase in pH has also been observed relative to the activity of other fossorial mammals, such as Brant's whistling rat (*Parotomys brantsii*; Desmet and Cowling 1999) and the American badger (*Taxidea taxus*; Eldridge and Whitford 2009). Higher pH associated with badger activity is a result of increased soil aeration, increased microbial activity, and mixing of litter caused by badger digging (Eldridge and Whitford 2009). It is possible that a history of southeastern pocket gopher activity at active sites could affect soil nitrogen, carbon and pH in similar ways. Therefore, it may be inappropriate to use pH and/or soil nitrogen to evaluate potential southeastern pocket gopher habitat if levels are actually a result of pocket gopher presence rather than pre-existing characteristics selected for by gophers.

Vegetation structure, as quantified by ground cover, was not important for predicting southeastern pocket gopher presence. However, my results should not be interpreted to suggest that habitat suitability for the southeastern pocket gopher is determined by soil alone. I observed differences in some ground cover categories between active and inactive sites (Table 3.3), but the predictive abilities of these variables may be outweighed by the soil variables, or be a function of the soil variables. Another factor is that my study was conducted on a property that is uniformly managed (Atkinson 1996), and pocket gopher activity is observed over the majority of the site. Even though buffers around inactive sites were composed of more varied landcover than those around active sites, only 2 out of 15 potential landcover types composed a full quarter of the buffers around inactive sites (Table 3.2). Thus, the variety of vegetation structure within my study site may not have been sufficient to accurately demonstrate the importance of vegetation structure in southeastern pocket gopher habitat selection. However, vegetation structure variables may prove significant in predicting habitat selection at more heterogeneous sites, or at larger scales, such as county or region-wide.

Management Implications

Recent recognition of the vital importance of longleaf pine communities as floral biodiversity hotspots (Peet and Allard 1993) and critical habitat for rare fauna such as the gopher tortoise (*Gopherus polyphemus*; U. S. Fish and Wildlife Service 1990) and Red-cockaded Woodpecker (*Picoides borealis*; U. S. Fish and Wildlife Service 2003) has resulted in the promotion of longleaf pine habitat restoration (Van Lear et al. 2005, Aschenbach et al. 2010). As areas of longleaf pine are restored in the Southeast, suitable habitat for southeastern pocket gopher colonization will likewise expand. Results of my study indicate that suitability of potential southeastern pocket gopher habitat is primarily dependent on soil characteristics. Of the soil characteristics, soil texture is the most useful for evaluating areas for potential southeastern pocket gopher relocation because pH, nitrogen, and carbon levels found in areas of southeastern pocket gopher activity likely covary with soil texture (Manahan 2001, Olk 2008), or result from pocket gopher activity itself (Litaor et al. 1996, Desmet and Cowling 1999, Simkin et al. 2004, Eldridge and Whitford 2009). Due to the ability of longleaf pine to proliferate on a variety of soils, from the xeric loamy sands southeastern pocket gophers prefer (McNab 1966, Wilkins 1985, Wilkins 1987, Simkin and Michener 2005, Southern Wildlife Consultants 2008) to more clayey soils, such as those of the Georgia Red Hills (Outcalt 2000), translocation of the southeastern pocket gopher will not be appropriate at all sites of longleaf pine restoration within the southeastern pocket gopher's geographic range. Thus, the results of this study can help focus future southeastern pocket gopher translocations into restored areas with loamy sands, insuring greater potential for success.

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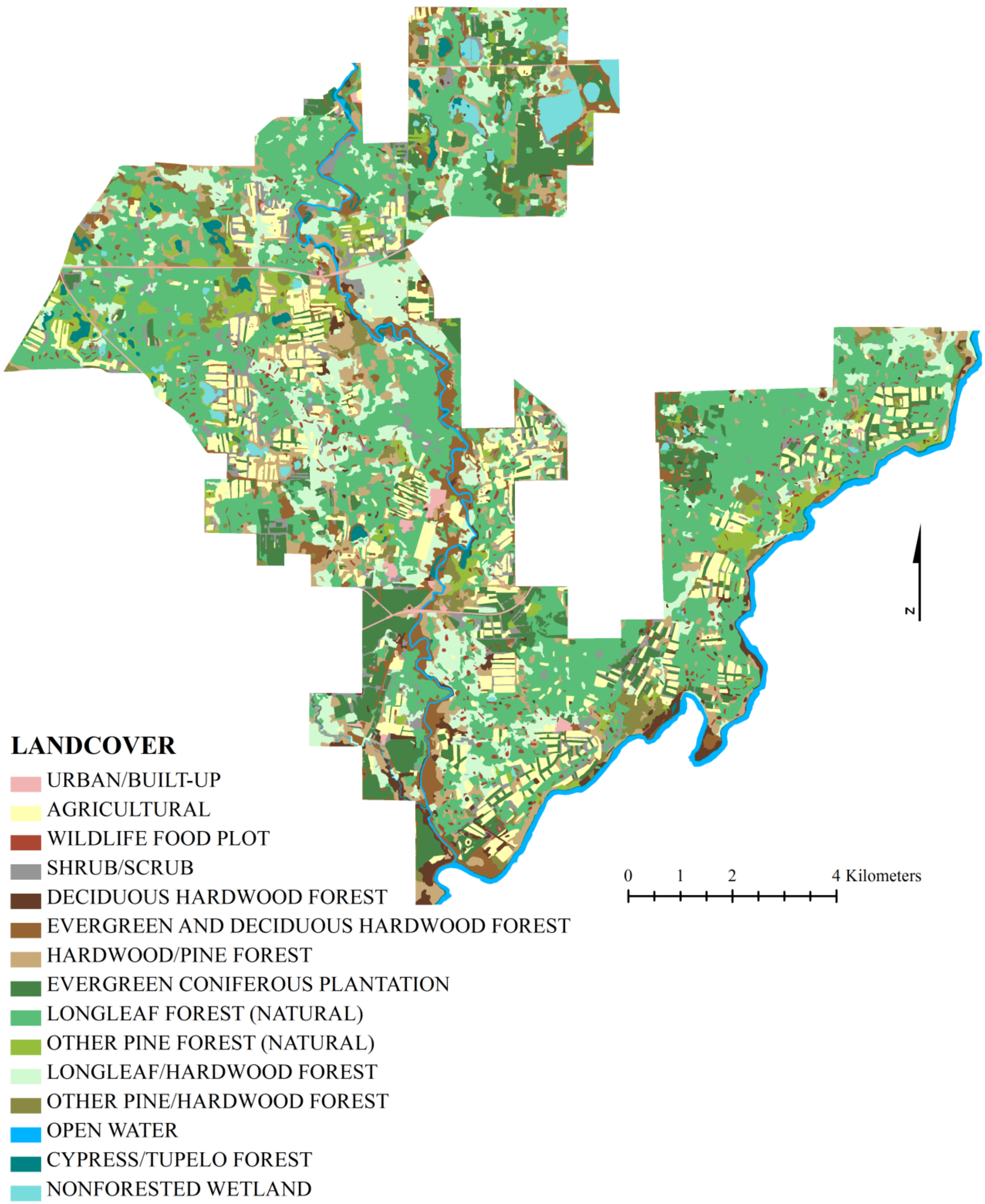

Figure 3.1 Distribution of landcover types found on Ichauway in Baker County, Georgia, 2013.

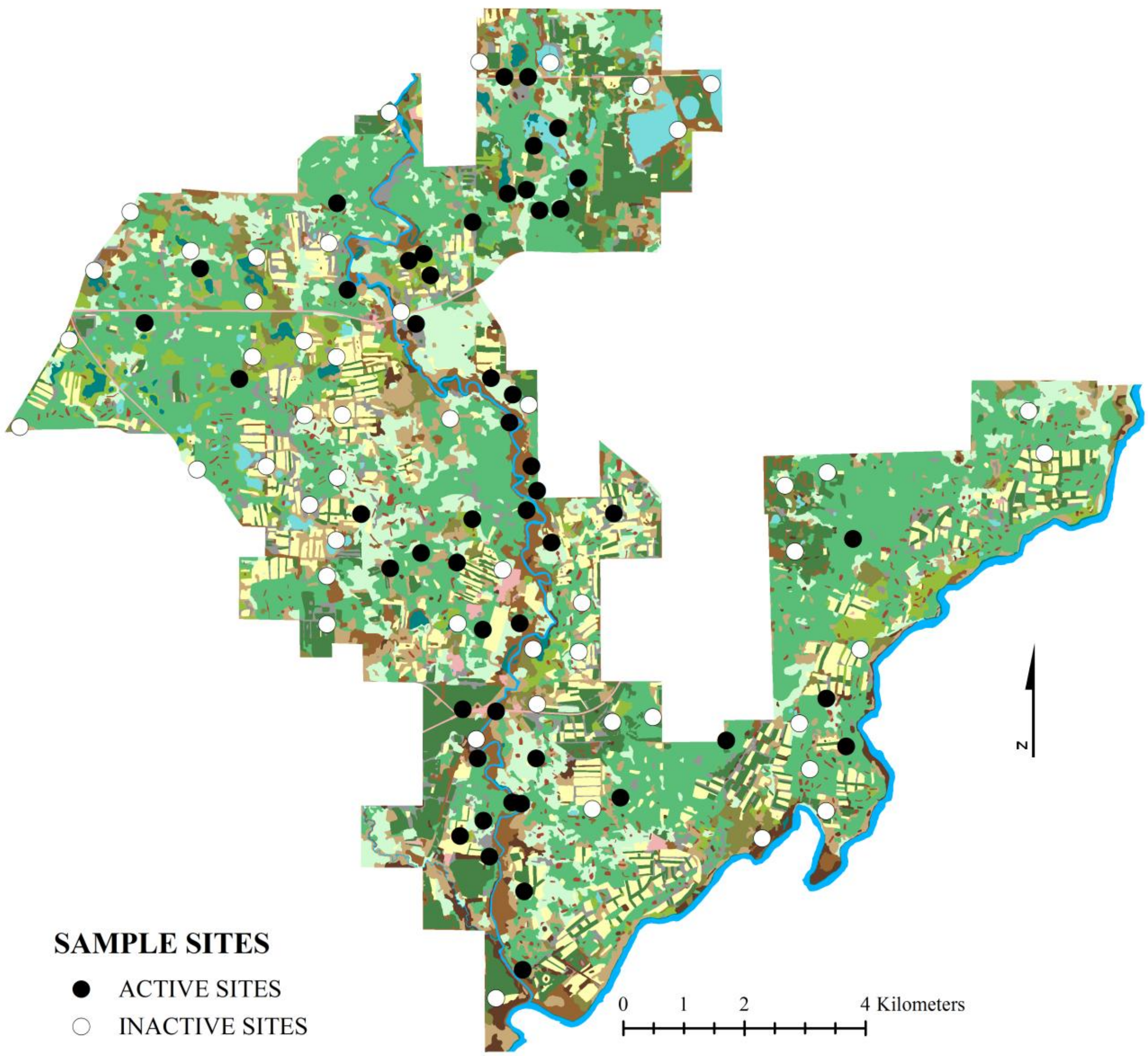

Figure 3.2 Distribution of 50 sites with southeastern pocket gopher activity (Active Sites) and 50 sites without activity (Inactive Sites) on Ichauway, Baker County, Georgia, 2013. Landcover types identified in Figure 3.1.

Table 3.1 Descriptions of vegetation structure and soil characteristic variables measured within an 18 m radius of 50 sites with southeastern pocket gopher activity and 50 sites without activity in Baker County, Georgia, 2012-2013.

Variable	**Description**
Vegetation Structure	
Pine Straw (PS)	Percent of 5 1-m^2 plots covered by pine straw.
Leaf Litter (LL)	Percent of 5 1-m^2 plots covered by hardwood leaf litter.
Woody Vegetation (WO)	Percent of 5 1-m^2 plots covered by woody vegetation.
Forbs/Vines (FV)	Percent of 5 1-m^2 plots covered by forbs and vines.
Wiregrass (WG)	Percent of 5 1-m^2 plots covered by wiregrass.
Other Grass (OG)	Percent of 5 1-m^2 plots covered by grasses other than wiregrass.
Soil Characteristics	
Silt	Mean percent silt of soil samples collected at 10, 25, 50, 75, and 100 cm.
Clay	Mean percent clay of soil samples collected at 10, 25, 50, 75, and 100 cm.
Nitrogen	Mean percent nitrogen of soil samples collected at 10, 25, 50, 75, and 100 cm.
Carbon	Mean percent carbon of soil samples collected at 10, 25, 50, 75, and 100 cm.
pH	Mean pH of soil samples collected at 10, 25, 50, 75, and 100 cm.

Table 3.2 Percent of 18 m buffers surrounding 50 sites with southeastern pocket gopher activity (Active Sites) and 50 sites without activity (Inactive Sites) composed of each landcover type in Baker County, Georgia, 2012-2013.

Landcover	**Active Sites (%)**	**Inactive Sites (%)**
Longleaf Forest	60.5	24.3
Longleaf/Hardwood Forest	15.9	1.5
Hardwood/Other Pine Forest	7.1	17.6
Shrub/Scrub	3.7	4.1
Urban/Built-up	3.0	1.0
Evergreen Coniferous Plantation	2.5	11.3
Other Pine Forest	2.4	5.3
Other Pine/Hardwood Forest	2.3	9.3
Agricultural	1.8	5.9
Evergreen and Deciduous Hardwood Forest	0.5	10.1
Nonforested Wetland	0.1	5.2
Wildlife Food Plot	0.1	0.2
Cypress/Tupelo Forest	0.0	1.5
Deciduous Hardwood Forest	0.0	2.0
Open Water	0.0	0.7

Table 3.3 Means and standard errors (SE) for variables measured within an 18 m radius of 50 sites with southeastern pocket gopher activity (Active Sites) and 50 sites without activity (Inactive Sites) in Baker County, Georgia, 2012-2013. Variables defined in Table 3.1. All units are percent except pH

	Active Sites		**Inactive Sites**	
Variable	**Mean**	**SE**	**Mean**	**SE**
Vegetation Structure				
PS	9.8	1.1	11.4	2.2
LL	6.3	1.2	18.0	3.1
WO	8.2	0.9	8.9	1.3
FV	21.7	1.5	22.9	2.0
WG	8.8	2.4	2.1	0.9
OG	28.6	2.6	22.8	3.1
Soil Characteristics				
Sand	85.7	0.8	78.3	2.2
Clay	7.1	0.6	14.6	2.0
Silt	7.2	0.3	7.1	0.3
pH	5.40	0.07	5.01	0.07
Nitrogen	0.035	0.001	0.052	0.004
Carbon	0.385	0.019	0.497	0.041

Table 3.4 Means and standard errors (SE) for percent sand, clay, and silt, and corresponding textures, measured at 10, 25, 50, 75, and 100 cm at 50 sites with southeastern pocket gopher activity (Active Sites) and 50 sites without activity (Inactive Sites) in Baker County, Georgia, 2012-2013.

	Active Sites				Inactive Sites			
Depth	**Sand**	**Clay**	**Silt**	**Texture**	**Sand**	**Clay**	**Silt**	**Texture**
10 cm	88.1(0.7)	4.1(0.4)	7.8(0.4)	Sand	82.2(1.9)	8.4(1.4)	9.4(0.6)	Loamy Sand
25 cm	86.9(0.7)	4.6(0.4)	8.5(0.4)	Loamy Sand	83.7(2.1)	9.0(1.9)	7.3(0.4)	Loamy Sand
50 cm	86.9(1.1)	6.6(0.9)	6.5(0.4)	Loamy Sand	78.3(2.7)	15.2(2.7)	6.5(0.3)	Sandy Loam
75 cm	83.2(1.2)	9.7(1.2)	7.1(0.4)	Loamy Sand	73.0(2.6)	20.4(2.6)	6.6(0.4)	Sandy Clay Loam
100 cm	83.5(1.5)	10.5(1.3)	6.0(0.3)	Loamy Sand	74.2(2.3)	20.0(2.2)	5.8(0.4)	Sandy Clay Loam

Table 3.5 Variables, number of variables in the model (K), Akaike's Information Criterion adjusted for small sample size (AICc), difference in AICc value between the model and the model with the lowest AICc value (ΔAICc), and Akaike weight (w_i) for models used to predict southeastern pocket gopher presence in Baker County, Georgia, 2012-2013. Models are categorized as testing the competing hypotheses that vegetation structure (Vegetation) or soil characteristics (Soil) better predict gopher activity. Variables are defined in Table 3.1.

Model	K	AICc	ΔAICc	Wi	Category
Silt+Clay+pH+Nitrogen+Carbon	5	92.807	0.000	0.892	Soil
Global	11	97.024	4.217	0.108	
Nitrogen	1	110.516	17.708	0.000	Soil
pH	1	123.080	30.272	0.000	Soil
Clay	1	124.852	32.044	0.000	Soil
LL	1	128.122	35.314	0.000	Vegetation
WG	1	132.577	39.769	0.000	Vegetation
Carbon	1	132.819	40.011	0.000	Soil
PS+LL+WO+FV+WG+OG	6	133.403	40.596	0.000	Vegetation
OG	1	137.724	44.916	0.000	Vegetation
Null	0	137.816	45.009	0.000	
WO	1	139.444	46.636	0.000	Vegetation
PS	1	139.535	46.727	0.000	Vegetation
FV	1	139.560	46.752	0.000	Vegetation
Silt	1	139.837	47.029	0.000	Soil

Table 3.6 Variable, parameter estimate, lower 95% confidence interval (CI), upper 95% confidence interval (CI), and variable weight (Σw_i) for variables in models used to predict southeastern pocket gopher presence in Baker County, Georgia, 2012-2013. Abbreviations are defined in Table 3.1.

Variable	Estimate	Lower 95% CI	Upper 95% CI	ΣWi
Nitrogen[a]	-142.4593	-234.703	-50.216	1.0000
pH[a]	1.7143	0.430	2.999	0.9999
Clay[a]	-0.1216	-0.213	-0.030	0.9999
Carbon	-0.3600	-5.403	4.683	0.9999
Silt[a]	0.5964	0.115	1.077	0.9999
LL	-0.0062	-0.019	0.007	0.1083
WG	0.0003	-0.008	0.008	0.1083
OG	0.0011	-0.005	0.007	0.1083
WO	0.0022	-0.008	0.012	0.1083
PS	0.0003	-0.006	0.006	0.1083
FV	-0.0038	-0.013	0.006	0.1083

[a]Variables with confidence intervals that exclude zero, indicating that they are informative predictor variables.

CHAPTER 4

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Recent recognition of the vital importance of longleaf pine communities as floral biodiversity hotspots (Peet and Allard 1993) and critical habitat for rare fauna such as the gopher tortoise (*Gopherus polyphemus*; U. S. Fish and Wildlife Service 1990) and Red-cockaded Woodpecker (*Picoides borealis*; U. S. Fish and Wildlife Service 2003) has resulted in the promotion of longleaf pine habitat restoration (Van Lear et al. 2005, Aschenbach et al. 2010). As areas of longleaf pine are restored in the Southeast, suitable habitat for southeastern pocket gopher colonization will likewise become available.

Although my study indicates that the southeastern pocket gopher is capable of dispersing further than previously thought, the highly fragmented nature of some of these newly available habitats will still likely inhibit dispersal to a degree that can prevent the natural colonization of southeastern pocket gopher populations into some restored habitats. Therefore, some instances of dispersal may need to be facilitated through translocations. At this time there have been no published studies on translocation of the southeastern pocket, but the results of my study can be used to inform restoration efforts.

The solitary nature of the southeastern pocket gopher (Golley 1962) suggests that translocated animals should be spaced so that their home ranges will not overlap. Based on the results of my home range study, translocated southeastern pocket gophers should be allocated approximately 1,000 m^2 per individual. Also, I found an increase in southeastern pocket gopher activity after dusk, suggesting that traps set to capture pocket gophers for translocation should be monitored until after dark. Current literature concerning pocket gopher trapping does not make these suggestions regarding timing (Hart 1973, Gates et al. 1988, Connior and Risch 2009). Finally, this study documented a southeastern pocket gopher homing 305.7 m. The ability to home can lower site fidelity (Van Vuren et al 1997, Villaseñor et al. 2013) affecting the success of translocation efforts. A clear output from this study is the need for continued research in the area of developing and comparing translocation methods.

Translocation of the southeastern pocket gopher into suitable areas of restored longleaf pine likely will enhance habitat quality of the area due to the ecosystem services that the pocket gopher provides, such as the creation of refugia for amphibian (Funderburg and Lee 1968, Blihovde 2006), reptile (Mount 1963, Funderburg and Lee 1968) and arthropod commensals (Pembleton and Williams 1978, Skelley and Kovarik 2001), and soil turnover (Simkin and Michener 2005). My study suggests that suitability of potential southeastern pocket gopher habitat is primarily dependent on soil characteristics. Of the soil characteristics, soil texture is the most useful for evaluating areas for potential southeastern pocket gopher relocation because pH, nitrogen, and carbon levels found in areas of southeastern pocket gopher activity likely covary with soil texture (Manahan 2001, Olk 2008), or result from pocket gopher activity itself (Litaor et al. 1996, Desmet and Cowling 1999, Simkin et al. 2004, Eldridge and Whitford 2009). Due to the ability of longleaf pine to thrive on a variety of soils, from the xeric loamy sands southeastern pocket gophers prefer (McNab 1966, Wilkins 1985, Wilkins 1987, Simkin and Michener 2005, Southern Wildlife Consultants 2008) to more clayey soils, such as those of the Georgia Red Hills (Outcalt 2000), translocation of the southeastern pocket gopher will not be appropriate at all sites of longleaf pine restoration within the southeastern pocket gopher’s geographic range. Thus, my results can focus future southeastern pocket gopher translocations into restored areas with loamy sands throughout a 100 cm profile, insuring greater potential for success.

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APPENDICES

Appendix 1. Telemetry data for 25 radiotagged southeastern pocket gophers in Baker County Georgia, 2012-2013, including whether the gopher dispersed, the reason the gopher went offline, the number of telemetry locations used to calculate the gopher's home range, whether the gopher's home range was excluded from the average calculated because the minimum number of locations were not met, and the area of the home range.

Gopher	Dispersal	Reason Offline	# of Relocations	Excluded from HR Average	Area
PG1	Yes	Unknown	36	NO	47.8
PG2	Yes	Trans Failure	33	NO	621.8
PG3	No	Trans Failure	79	NO	2246.8
PG4	No	Dropped	69	NO	1836
PG5	No	Trans Failure	66	NO	2083
PG6	No	Unknown	47	NO	674.8
PG7	No	Dropped	8	**YES**	508.9
PG8	No	Dropped	9	**YES**	119.1
PG9	No	Dropped	9	**YES**	12.8
PG10	No	Dropped	3	**YES**	38.4
PG11	No	Predation	10	**YES**	534.3
PG12	No	Unknown	12	**YES**	3744.1
PG13	No	Trans Failure	47	NO	208
PG14	No	Unknown	55	NO	2076.5
PG15	No	Trans Failure	21	NO	1869.1
PG16	No	Trans Failure	52	NO	590.8
PG18	Yes	Trans Failure	37	NO	209.8
PG19	No	Trans Failure	56	NO	480.3
PG20	No	Unknown	45	NO	160.7
PG21	No	Trans Failure	65	NO	1279
PG22	No	Trans Failure	56	NO	228.3
PG23	No	Predation	15	**YES**	159.6
PG24	No	Trans Failure	54	NO	43.4
PG25	No	Trans Failure	60	NO	1016.9