Articles

Home Range, Survival, and Activity Patterns of the Southeastern Pocket Gopher: Implications for Translocation

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Abstract

The southeastern pocket gopher *Geomys pinetis* is absent from a large portion of its historical range. Translocation may represent a viable management technique to reestablish populations into suitable habitat. However, several aspects of the species' ecology are poorly understood, making development of an effective translocation approach challenging. Therefore, we used radiotelemetry to examine home range, survival, dispersal, and daily activity patterns of the southeastern pocket gopher in southwestern Georgia. We measured soil and vegetation characteristics within individual home ranges and examined relationships between home range size, habitat variables, and body mass. Mean home range size of 17 radio-tagged pocket gophers was 921.9 m^2 (range = 43.4–2246.8 m^2). Home range size was positively related to body mass, percent silt at a depth of 25 cm, and soil carbon content at 75 cm and was negatively related to percent sand at 25 cm, percent clay at 50 cm, and ground cover of grasses other than wiregrass *Aristida beyrichiana*. Survival rate was 0.78 (range = 0.50–1.00) over the 51-wk study, and we documented predation, likely by avian predators, on two individuals. Three individuals dispersed, with a maximum dispersal distance of 319.1 m (range = 143.2–319.1 m), the farthest known southeastern pocket gopher dispersal. Pocket gophers exhibited greater activity from 0000 to 0400 hours and from 1600 to 2000 hours, contrasting previous research that southeastern pocket gophers were equally active throughout the diel period. Our home range size estimates for southeastern pocket gophers are the first determined using radiotelemetry and are considerably smaller than previous estimates. Although we documented dispersal distances more than 300 m, the fragmented nature of current and restored habitats likely will prevent large-scale natural colonization. Our results provide information important for maximizing success in future southeastern pocket gopher translocation efforts.

Keywords: *Geomys pinetis*; southeastern pocket gopher; home range; survival; activity patterns; translocation

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Introduction

The southeastern pocket gopher *Geomys pinetis* was historically associated with the longleaf pine *Pinus palustris* community 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 forests have been highly impacted by conversion and fragmentation, resulting in habitat loss and alteration for many associated species, including the southeastern pocket gopher. Although southeastern pocket gophers can be abundant in suitable habitat, the species is absent from a large portion of its historical range (Georgia Department of Natural Resources 2005). As a result, 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 southeastern pocket gopher ecology are poorly understood, primarily because its fossorial lifestyle makes observational studies difficult. The only existing home range estimates are based on a single study that determined maximum dimensions of mound patterns (Hickman and Brown 1973a) that likely included considerable unused area and subsequently overestimated home range sizes. Although southeastern pocket gopher home range data are lacking, information is available for other *Geomys* species. Cameron et al. (1988) concluded that the area covered by the burrow systems of Attwater's pocket gopher *Geomys attwateri* was highly variable between individuals, and uncorrelated differences with sex, age, or body size. Conversely, home range size of the Ozark pocket gopher *Geomys bursarius ozarkensis* was 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). Although presence of southeastern pocket gophers is influenced by soil (Warren et al., in press) and vegetation (Ross 1976) characteristics, how those habitat features influence home range size is unknown. Given the variability within and among studies, generalizing results from other *Geomys* species to the southeastern pocket gopher could lead to erroneous conclusions.

Southeastern pocket gophers likely have a high survival rate due to the protection burrows provide from predators. Brown (1971) suggested that longevity of southeastern pocket gophers in Florida was more than 2 y. The only published study that used radiotelemetry to investigate survival rates in pocket gophers occurred on the Ozark pocket gopher in north central Arkansas (Connior and Risch 2010). They reported that 33 of 35 pocket gophers survived over 144 d during the nonbreeding season and 26 of 35 survived over 116 d during the breeding season. Literature regarding cause-specific mortality in pocket gophers is equally sparse. Connior and Risch (2010) attributed 7 of 11 Ozark pocket gopher mortalities to predation, but the predator could only be identified in a single case when a tagged individual was predated by a prairie kingsnake *Lampropeltis 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).

Because suitable habitat currently exists in fragmented patches (Georgia Department of Natural Resources 2005), information on dispersal periodicity, timing, and distance is needed to determine whether dispersal behavior would facilitate establishment of southeastern pocket gopher populations in patches of suitable habitat. If not, a successful conservation strategy may include reestablishment of populations through translocation. Although fragmentation may be limiting natural dispersal, information on dispersal behavior is limited to anecdotal reports in which two southeastern pocket gophers dispersed 184 and 244 m, respectively (Hickman and Brown 1973a). Dispersal has been 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). Whether the same pattern occurs for southeastern pocket gophers is unknown.

The only published research directly addressing daily activity patterns in southeastern pocket gophers was conducted in captivity as part of a thermoregulation study. Ross (1980) concluded that southeastern pocket gophers alternate periods of activity throughout the day and night in roughly 40-min cycles. Although the method for measuring activity in the study was precise, activity may have been influenced by the inability to exhibit natural foraging behavior. In contrast, anecdotal field observations suggest that most mounding activity occurs at dusk and dawn (Hickman and Brown 1973a). Mounding activity may be useful as a proxy for activity; however, other daily activities may occur completely below ground and would not be detected through mounding activities alone.

Further loss of the southeastern pocket gopher from its historic range may have profound negative effects on upland ecosystems of the southeastern Coastal Plain, because they play vital roles in the communities they inhabit. Their mounds are the most common source of faunal soil disturbance within longleaf pine communities (Simkin and Michener 2005). In the Sandhills ecosystem of the southeastern Coastal Plain, 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, many of which are believed to be obligate commensals (Pembleton and Williams 1978; Skelley and Kovarik 2001). Given their importance in maintaining the integrity of these systems, an effective conservation strategy is needed, yet the current information regarding several aspects of their natural history is insufficient. Therefore, we used radiotelemetry to investigate home range, survival, cause-specific mortality, dispersal, and daily activity patterns. Information resulting from this study will be integral in forming an effective conservation strategy to restore the species into suitable habitat within its historic range.

Methods

Study site

We conducted our study from September 2012 to September 2013 at the Joseph W. Jones Ecological Research Center at Ichauway in Baker County, Georgia (Figure 1). Ichauway covers 117 km^2 of predominately longleaf pine forest surrounded primarily by agriculture. Other cover types include slash pine *Pinus elliottii* and loblolly pine *Pinus taeda* forests, mixed pine–hardwoods, riparian hardwood forests, live oak *Quercus virginianus* depressions, isolated wetlands, creek swamps, agricultural fields, and areas impacted by human development. Wiregrass *Aristida beyrichiana* is the dominate understory species covering approximately one-third of the property. Habitat structure and composition are maintained through prescribed fire. Stands are burned at least every other year, primarily during March and April (Atkinson et al. 1996). Ichauway is located in the Dougherty Plain physiographic district that is characterized by marine and fluvial deposited parent material that now comprise Entisols and Ultisols over highly fractured Ocala limestone, and a flat to rolling karst topography (Beck and Arden 1984; Hayes et al. 1983; Couch et al. 1996).

Animal capture and transmitter implantation

We selected locations for pocket gopher trapping through opportunistic sightings of mounds. We maintained more than 250 m between radio-tagged individuals, which represented the furthest documented dispersal of southeastern pocket gophers prior to our study. We captured pocket gophers by placing live traps described by Hart (1973) and Connior and Risch (2009a) in excavated tunnels. We checked traps every 3 h. We placed captured individuals in ventilated 45.4-L plastic containers partially filled with moist soil from the site and transported them to the lab for transmitter implantation.

We surgically implanted 3-g VHS radio transmitters (SOPI-2070, Wildlife Materials Inc., Murphysboro, IL), representing a mean of 1.73% (standard deviation [SD] = 0.48, range = 0.89–2.38) of body mass, either subcutaneously between the scapulae or within the peritoneal cavity of subadult and adult pocket gophers (body mass >100 g; Wing 1960). We inserted a passive integrated transponder tag subcutaneously away from the surgery site. Transmitter and PIT tag implantation occurred under continuously inhaled sevoflurane. We held gophers 3 d postsurgery to monitor recovery and manage inflammation and pain with intramuscular injections of meloxicam and butorphanol. We provided gophers with sweet potatoes from the time of capture until returned to their original burrows. We did not replace failed or lost transmitters. Animal capture and transmitter implantation followed guidelines of the University of Georgia Animal Welfare Assurance A3437-01 and were approved by the Institutional Animal Care and Use Committee of the University of Georgia (Animal Use Proposals 04-002-Y1-A0, A2012 04-002-A1, A2012 04-002-R1).

Radio tracking

We determined the location of radio-tagged pocket gophers during tracking periods conducted every other day by using a telemetry receiver (Communication Specialists, Inc., R-1000) and three-element Yagi antenna. We began each tracking period 2 h later than the previous to account for activity around the diel period. We began tracking 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 while walking to avoid influencing gopher movements. We recorded one location for each individual during each tracking period by 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 less than 0.6 m with 95% confidence. In cases of dispersal, we continued tracking the dispersed individual at its new location. We defined dispersal as complete abandonment of one area of concentrated activity to a new area where the individual had not previously been recorded.

We tracked individual pocket gophers until the transmitter failed, mortality occurred, or the individual could not be relocated. We attempted to relocate lost individuals by first covering as much of the immediately surrounding area by foot as could be traversed by one person in 1–2 h. We then spent another 2–3 h using property roads to search the area by vehicle, spanning outwards from the last known location of the individual. We confirmed transmitter failure either by a marked decrease in signal strength before loss of signal, or by recapturing the animal. In cases of mortality, we determined cause of death by investigating conditions at the mortality site, and by performing a necropsy. When we determined predation as the cause of death, we identified the suspected predator to the lowest taxon possible based on carcass condition, tooth marks, surrounding prints, and scat identification.

We conducted focal telemetry (extended tracking periods focusing on fine-scale movements of an individual study animal) for nine pocket gophers from May through August 2013 to investigate daily activity patterns. Focal telemetry was conducted by tracking each individual for 8 h/d on three separate days, all conducted within a 2-wk period. Each day's tracking

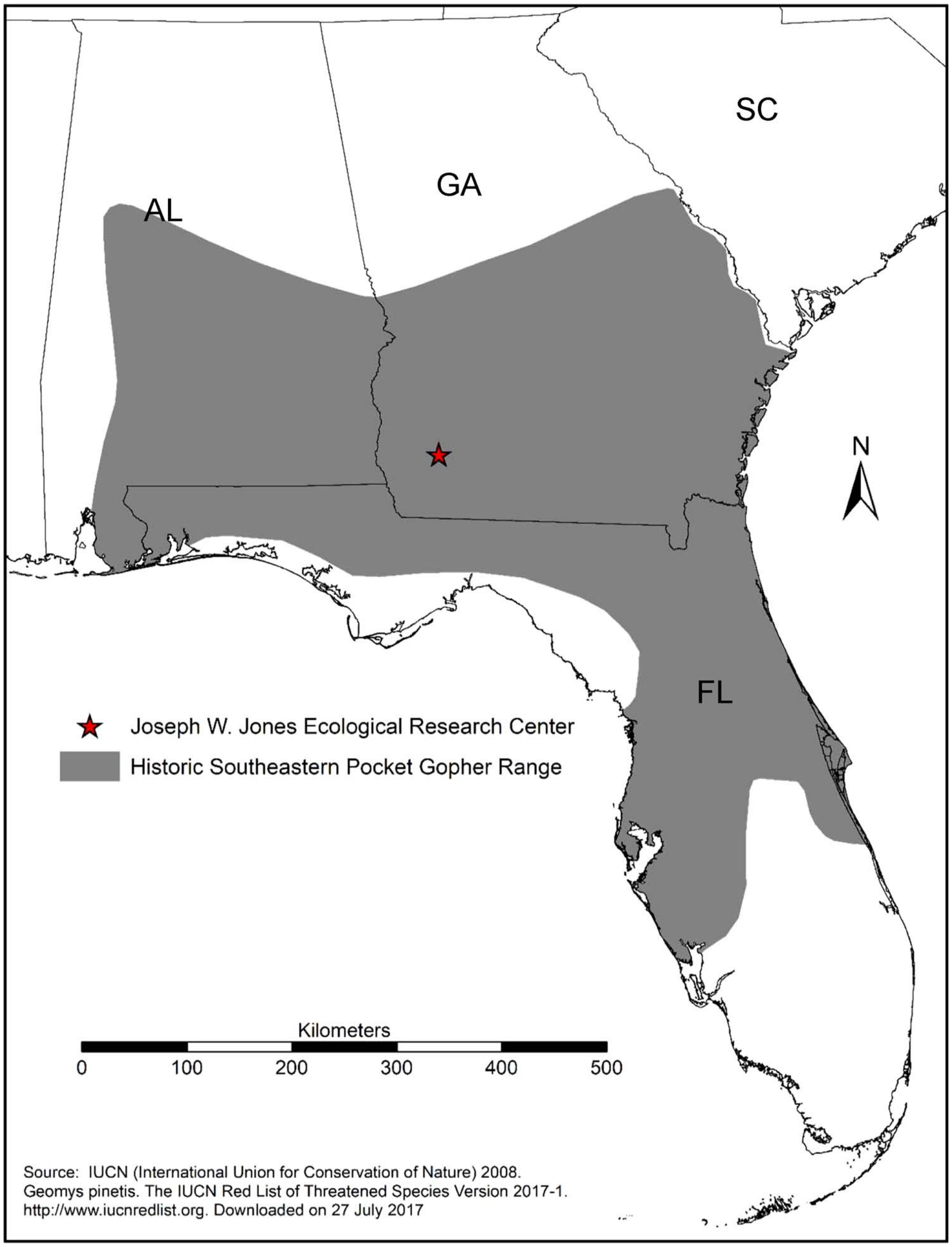

Figure 1. Historic range of the southeastern pocket gopher *Geomys pinetis* and location of the Joseph W. Jones Ecological Research Center at Ichauway in Baker County, Georgia.

session covered a different 8-h portion of the 24-h diel period. During each 8-h tracking session, we located the gopher every 20 min. We recorded locations using a GPS as described above. We quantified daily activity by recording the distance traveled in each 20-min interval between recordings and the distance from the nest at each location. We determined distance traveled by measuring between each sequential location by using a meter tape. We used the Near tool in ArcMAP 9.3.1 to measure distance between each recorded location and the location of the nest. We assumed pocket gopher nests were located where telemetry point density was highest. To standardize for individual activity differences, we converted distances to proportions by dividing each measured distance by the longest distance recorded for that individual during the 24 h of focal telemetry.

Vegetation and soil sampling

To investigate associations between home range size and habitat features, we quantified vegetation and soil characteristics within the home range of each radio-tracked individual (Table 1). At each site, we randomly selected five 1-m^2 subplots within 18 m of the center of the home range. We quantified vegetation structure by visually estimating percent ground cover of pine litter, hardwood leaf litter, woody vegetation, forbs and vines,

Table 1. Ground cover and soil texture variables (abbreviations in parentheses) within 18 m of the center of radio-tagged southeastern pocket gopher *Geomys pinetis* home ranges measured as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Variable	Description
Vegetation ground cover	
Pine straw (PS)	Percent area of five 1-m^2 plots covered by pine straw
Leaf litter (LL)	Percent area of five 1-m^2 plots covered by hardwood leaf litter
Woody vegetation (WO)	Percent area of five 1-m^2 plots covered by woody vegetation
Forbs/vines (FV)	Percent area of five 1-m^2 plots covered by forbs and vines
Wiregrass (WG)	Percent area of five 1-m^2 plots covered by wiregrass
Other grass (OG)	Percent area of five 1-m^2 plots covered by other grasses
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 100 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 100 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

wiregrass, and other grass species in each quadrant of the subplot and averaging the quadrants.

We 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. We used the qualitative field texture method to estimate soil texture at each depth (Thien 1979) and used the soil textures at each depth to create a texture profile for each site. Selected representatives of each unique texture profile were quantified at a commercial testing laboratory (Waters Agricultural Testing Lab, Camilla, GA) by using the hydrometer method for determining percent sand, silt, and clay (Gee and Bauder 1986). We 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, GA). We determined pH for each sample by combining 5 g of soil with 10 mL of deionized water and immersing an electronic pH probe in the solution (McLean 1982).

Data analysis

Due to the difficulty in determining sex of pocket gophers based on external morphology (Baker et al. 2003), we pooled all individuals for analysis. We created an area-observation curve using the bootstrap function in R 2.3.1 (R Foundation for Statistical Computing) to determine the minimum number of locations required to estimate an accurate home range (Odum and Kuenzler 1955). We used a less than 5% increase to indicate the asymptote (Laundré and Keller 1984; Springer 2003) to prevent excluding an excessive number of individuals and overly decreasing sample size. We created minimum convex polygons for each pocket gopher that met the

Table 2. Mean (SD), range, correlation coefficient (*R*), and *P* value for variables correlated with home range size of 17 radio-tagged southeastern pocket gophers *Geomys pinetis* examined as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013. All variables are percent except pH and body mass (g). Bold variables are significantly correlated ($P < 0.10$) with home range size.

Variable	Mean (SD)	Range	*R*	*P* value
Body mass[a]	180.5 (56.7)	122–338	0.4596	0.0634
Pine straw[a]	10.3 (8.6)	0–32	0.0195	0.9407
Leaf litter[b]	6.6 (8.5)	0–27	0.1718	0.5098
Woody vegetation[a]	5.8 (3.9)	0–13	0.2820	0.2728
Forbs/vines[a]	19.9 (11.6)	6–43	−0.0525	0.8413
Wiregrass[b]	12.1 (20.1)	0–64	0.3622	0.1531
Other grass[a]	27.8 (18.3)	4–59	−0.4247	0.0893
Sand at 10 cm[b]	86.8 (7.8)	57.2–89.6	−0.0166	0.9495
Sand at 25 cm[b]	86.8 (6.4)	68.8–93.6	−0.5948	0.0118
Sand at 50 cm[b]	87.4 (7.0)	72.8–93.2	0.2868	0.2643
Sand at 75 cm[b]	81.2 (10.2)	60.8–91.6	0.0550	0.8339
Sand at 100 cm[a]	79.7 (13.0)	56.4–93.2	−0.0174	0.9473
Silt at 10 cm[b]	8.6 (3.9)	6.4–22.4	0.1350	0.6055
Silt at 25 cm[b]	8.8 (4.6)	4.4–20.8	0.5539	0.0211
Silt at 50 cm[b]	6.4 (3.6)	4.8–18.8	0.0835	0.7502
Silt at 75 cm[b]	7.6 (4.2)	4.4–20.8	0.2469	0.3395
Silt at 100 cm[b]	6.0 (2.2)	4.4–13.2	−0.0078	0.9762
Clay at 10 cm[b]	4.6 (4.2)	0.8–20.4	−0.0654	0.8032
Clay at 25 cm[b]	4.4 (2.8)	0.4–14.4	0.3245	0.2038
Clay at 50 cm[b]	6.1 (6.2)	0.4–16.4	−0.5283	0.0293
Clay at 75 cm[b]	11.2 (10.4)	2.0–30.4	−0.1266	0.6282
Clay at 100 cm[b]	14.3 (11.5)	2.0–30.4	0.1190	0.6491
Nitrogen at 10 cm[b]	0.058 (0.020)	0.030–0.123	0.1165	0.6561
Nitrogen at 25 cm[b]	0.031 (0.010)	0.000–0.043	−0.0504	0.8476
Nitrogen at 50 cm[b]	0.022 (0.011)	0.000–0.036	−0.1950	0.4534
Nitrogen at 75 cm[b]	0.021 (0.011)	0.000–0.033	0.2572	0.3189
Nitrogen at 100 cm[b]	0.022 (0.009)	0.000–0.033	0.0308	0.9067
Carbon at 10 cm[a]	1.173 (0.591)	0.257–2.615	0.2182	0.4002
Carbon at 25 cm[a]	0.435 (0.193)	0.095–0.826	0.0526	0.8412
Carbon at 50 cm[a]	0.199 (0.060)	0.116–0.307	−0.4019	0.1098
Carbon at 75 cm[b]	0.143(0.109)	0.000–0.504	0.4574	0.0649
Carbon at 100 cm[a]	0.095(0.047)	0.000–0.205	0.2962	0.2484
pH at 10 cm[b]	5.59 (0.60)	5.06–7.29	0.2230	0.3895
pH at 25 cm[a]	5.56 (0.58)	4.95–7.35	0.3236	0.2052
pH at 50 cm[a]	5.51 (0.54)	4.90–7.32	0.3252	0.2027
pH at 75 cm[a]	5.53 (0.38)	5.04–6.57	−0.2148	0.4078
pH at 100 cm[a]	5.26 (0.54)	4.52–6.69	−0.3606	0.1551

[a] Relationship determined using Pearson's product moment correlation.
[b] Relationship determined using Spearman's rank correlation.

required number of locations by using the Hawth's tools extension in ArcMAP 9.3.1. For individuals that dispersed, we created the minimum convex polygon for the area with the greatest number of locations.

We conducted correlation analyses using the CORR procedure in SAS 9.3 (SAS Institute, Inc., Cary, NC) to determine relationships of home range size with body mass and habitat variables. We used Pearson's product moment correlation for normally distributed variables and Spearman's rank correlation for non-normal variables. We created a survivorship curve by using the Kaplan–Meier Staggered Entry method (Pollock et al. 1989) based on weekly counts of individuals added to the study, lost to mortality, or censored (i.e., removed because of transmitter failure or because fate of the individual was unknown). We described instances of mortality and dispersal anecdotally due to a low number of occurrences.

We separated daily activity data into six 4-h segments and treated the proportional distances traveled and proportional distances from the nest within each 4-h segment as subsamples for each individual. Four-hour time segments represent reasonable time periods during which to conduct trapping efforts that coincide with times of greatest activity away from the burrow. We determined differences in distance traveled and distance from the nest among the 4-h time segments by using the GLM procedure in SAS 9.3. We used Fisher's protected least significant difference for mean separation. Due to difficulty trapping and retaining pocket gophers during our study, sample size of radio-tagged individuals was lower than anticipated. Therefore, given the low sample size, we considered results significant at $P < 0.10$ for all analyses.

Results

We captured 27 southeastern pocket gophers between 26 September 2012 and 30 April 2013. One individual was too small (<100 g) for transmitter implantation and one adult female (180 g) was in late-stage gestation. Thus, we implanted transmitters into 25 individuals (mean body mass = 194 g, SD = 65, range = 122–338). The first 12 individuals captured received subcutaneously implanted transmitters, four of which lost transmitters 12–20 d postsurgery. Therefore, we implanted transmitters in the peritoneal cavity of the remaining 13 individuals. None of the 13 pocket gophers with peritoneal implants lost transmitters during the study, but one died before release due to complications from surgery. We tracked radio-tagged individuals from 4 October 2012 through 18 September 2013.

Home range

Based on the area-observation curve, a minimum of 17 locations was required to estimate home range. We recorded the minimum number of locations for 17 individuals. Mean home range size for all pocket gophers included in the analysis was 921.9 m^2 (SD = 805.3, range = 43.4–2246.8; Table S1, *Supplemental Material*). Home range size was positively associated with body mass ($r = 0.460$, $P = 0.063$), percent silt at 25 cm ($r = 0.554$, $P = 0.021$), and carbon content at 75 cm ($r = 0.457$, $P = 0.065$) and negatively associated with percent sand at 25 cm ($r = -0.595$, $P = 0.012$), percent clay at 50 cm ($r = -0.528$, $P = 0.029$), and ground cover of grasses other than wiregrass ($r = -0.424$, $P = 0.089$; Table 2; Tables S2–S6, *Supplemental Material*).

Survival and cause-specific mortality

All radio-tagged individuals ($n = 24$; excluding one that died from surgery complications and was never released) were used to estimate survival until they were censored

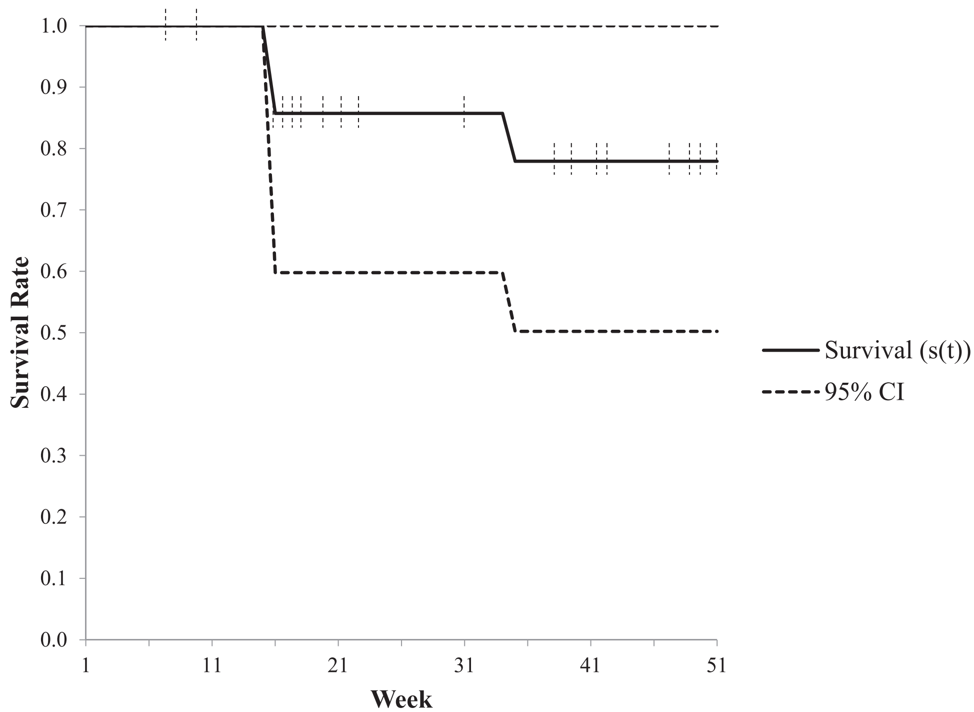

Figure 2. Estimated survival rate of 24 radio-tagged southeastern pocket gophers *Geomys pinetis* over a 51-wk study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013. Vertical hash marks indicate censorship events.

due to transmitter loss/failure ($n = 17$) or unknown fate ($n = 5$; Table S1, *Supplemental Material*). We documented two mortality events during the study that are reflected in the weekly estimates of survival. Survival rate dropped from 1.000 to 0.857 with a mortality event at week 16 and then dropped to 0.779 with a second mortality event at week 35, where it remained until the end of the 51-wk study (Figure 2; Table S7, *Supplemental Material*). Avian predation was likely the cause of both mortalities.

Dispersal

Three of the 20 radio-tagged individuals tracked for >20 days dispersed during the study. All were smaller (137, 131, and 155 g) than mean body mass of all individuals (194 g). The first individual dispersed on 25 October 2012 after 22 d of tracking, traveled 264.9 m over 3 d, and settled at a new location for the remaining 75 d of the tracking period. On 12 November 2012, this individual made a 305.7-m excursion over 3 d to a third location, but returned to the second location 3 d later. The second individual dispersed on 4 November 2012 after 32 d of tracking, traveled 319.1 m over 9 d, and settled at a new location for the remaining 70 d of the tracking period. The third individual dispersed on 15 June 2013 after 77 d of tracking, traveled 143.2 m over 10 d, and settled at a second location for the remaining 84 d of the tracking period.

Daily activity patterns

Mean maximum distance individuals were recorded from nests during 24 h of focal telemetry was 17.0 m (SD = 14.1, range = 3.8–41.9). Mean maximum distance traveled during 20-min intervals of focal telemetry was 20.5 m (SD = 18.4, range = 4.0–51.0). There was no difference in proportional distance from the nest among the six 4-h segments ($P = 0.139$; Figure 3; Table S8, *Supplemental Material*). However, proportional distance traveled differed ($P = 0.085$) among segments. The mean separation test indicated that proportional distance traveled from 1600 to 2000 hours was greater than proportional distance traveled from 0800 to 1200 hours, from 1200 to 1600 hours, and from 2000 to 2400 hours, and proportional distance traveled from 0000 to 0400 hours was greater than proportional distance traveled from 1200 to 1600 hours and from 2000 to 2400 hours (Figure 4; Table S9, *Supplemental Material*).

Discussion

Home range

To our knowledge, this is the first study to report southeastern pocket gopher home range estimated using radiotelemetry. Hickman and Brown (1973a) estimated mean home range size of eight southeastern pocket gophers in Hillsborough County, Florida, based on the area in which new mounds were produced. Their mean estimate ($\bar{x} = 2{,}666.5$ m^2, SD = 2308.5; calculated using the rectangular dimensions reported) is almost 3 times larger than our estimate ($\bar{x} = 921.9$ m^2, SD = 805.3). Hickman and Brown (1973a) delineated "maximum dimensions of mound pattern size" that likely included considerable unused area. In addition, they could not

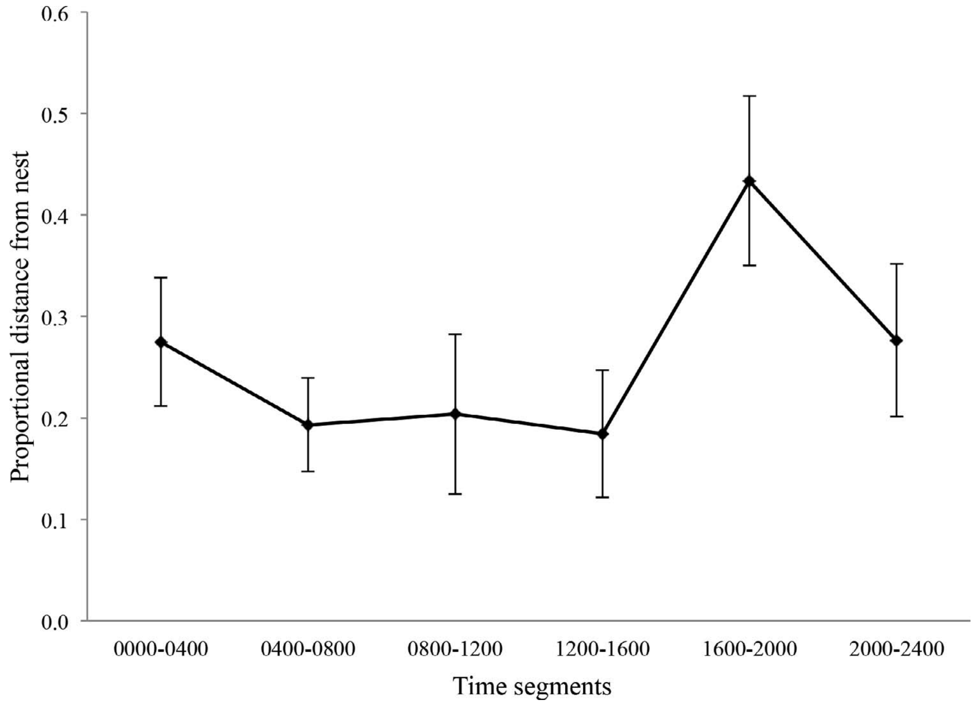

Figure 3. Proportional distance of nine radio-tagged southeastern pocket gophers *Geomys pinetis* from the nest during 4-h time segments throughout the diel period recorded as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2013. Bars show standard error.

ensure that mounding was by a single individual rather than two or more in close proximity. In comparison to other members of Geomyidae, home range of southeastern pocket gophers we report is larger than those reported for the Ozark pocket gopher ($\bar{x} = 291.8$ m^2, SD = 162.2; Connior and Risch 2010), Botta's pocket gopher ($\bar{x} = 474.4$ m^2, SD = 148.2; Bandoli 1987), and the Mazama pocket gopher *Thomomys mazama* ($\bar{x} = 108$ m^2, SD =

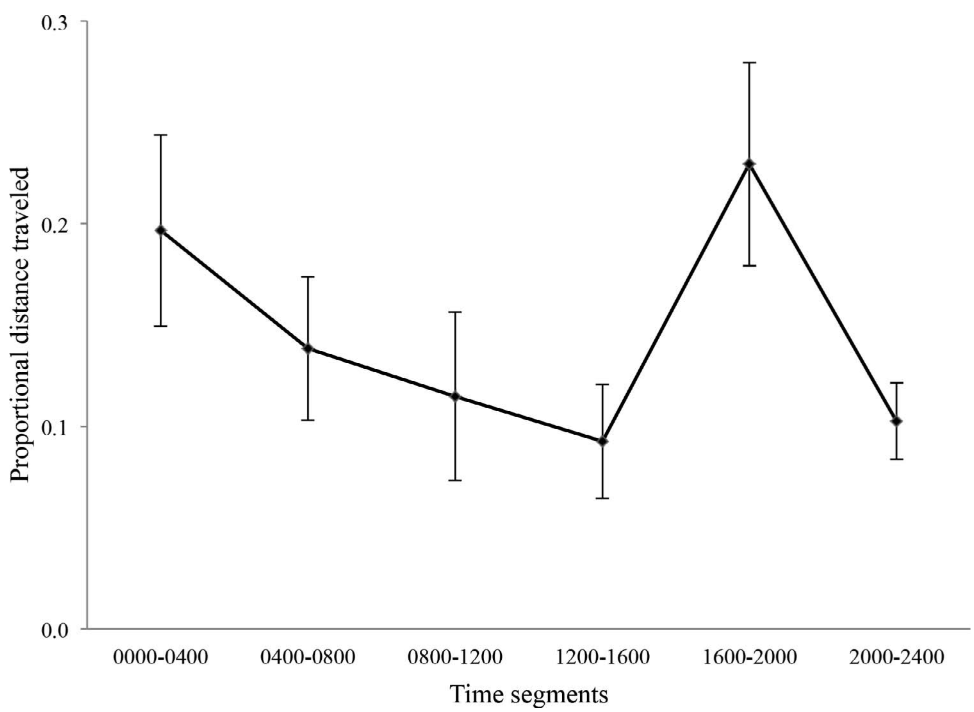

Figure 4. Proportional distance of nine radio-tagged southeastern pocket gophers *Geomys pinetis* traveled during 4-h time segments throughout the diel period recorded as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2013. Bars show standard error.

37.9; Witmer et al. 1996). Pocket gopher home ranges likely shift as individuals excavate new foraging tunnels, which could result in an overestimation of home range size. However, given the time frame in which we tracked pocket gophers in our study ($\bar{x} = 103$ d), we are confident that any error in home range estimates is negligible.

Similar to the Ozark pocket gopher (Connior and Risch 2010), we found that home range size for the southeastern pocket gopher was associated with body mass. 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 needed to procure sufficient resources and sustain metabolic requirements also increases.

Home range size also may be influenced by the ability to expand and maintain tunnels, which likely explains the observed relationship between home range and soil texture. Because southeastern pocket gophers select sandy soils (McNab 1966; Wilkins 1985, 1987; Simkin and Michener 2005), 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 compacts poorly (Plaster 2013), making voids in the soil less stable. Thus, an increasing silt to sand ratio at 25 cm likely increases stability of tunnels, reducing collapse and allowing pocket gophers to maintain larger tunnel systems. However, too much clay in the soil can limit home range size by increasing the energetic cost of tunnel expansion, explaining the observed decrease in home range size with increasing percent clay (Romañach et al. 2005). Our results support those of Warren et al. (in press) who found that southeastern pocket gophers were more likely to be present in areas with sandy, loamy sand or sandy-loam textures throughout the profile relative to areas with higher clay content and sandy clay loam, loam or clay loam textures at deeper horizons.

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). Because southeastern pocket gophers feed on above- and belowground parts of plants (Golley 1962), percent vegetative ground cover estimated within home ranges should represent available food resources. Therefore, the observed negative association between home range size and ground cover of grasses (other than wiregrass) is likely due to the ability of pocket gophers to procure sufficient food in smaller areas when food resource availability is higher. Southeastern pocket gophers feed on a variety of herbaceous plants, and grasses are consumed extensively (Ross 1976). Because foraging pocket gophers must balance procuring food and expanding tunnels (Vleck 1981), it would be inefficient to expand tunnels larger than necessary to gather sufficient food.

The cause for the positive association between home range size and soil carbon content at 75 cm is unknown. Based on our field observations, tunneling was limited at that depth, and organic matter should not have an impact on the ability to procure food. Thus, this observed relationship may be an artifact of a shared relationship with an unquantified variable.

Survival and cause-specific mortality

The survival rate we observed is similar to the only comparable study to examine survival in pocket gophers (Connior and Risch 2010). It is likely that, like most geomyids, the southeastern pocket gopher has high survival because its fossorial lifestyle reduces predation risk. However, predation risk in geomyids is likely higher during dispersal, which typically occurs above ground (Vaughn 1963; Williams and Cameron 1984; Daly and Patton 1990). Although we were unable to document fate of five individuals, only one of those individuals was known to disperse. Our observations suggest that southeastern pocket gophers likely disperse before reaching 100 g, the minimum weight of individuals radio-tagged in our study. Therefore, it is unlikely that the individuals of unknown fate had a significant effect on our survival estimate. The survival rate observed in our study supports the contention that longevity in southeastern pocket gophers is likely more than 2 y (Brown 1971).

We could not positively identify predators responsible for the two suspected predation events, but avian predation was suspected in both cases. In the first mortality event, we recovered the individual from its burrow with a puncture wound to the left shoulder and extensive bruising to the face and muzzle. There was an opening into the burrow 3–5 m from where the carcass was recovered, which seemed to be the beginning of a mound. In the second mortality event, we retrieved the transmitter near the burrow at the base of a tree. There were no signs of the carcass. Again, there was an opening into the burrow 10–15 m from the transmitter, which seemed to be the beginning of a mound. Pocket gophers are vulnerable to predation when they emerge above ground to dispose of soil and repeated trips to the surface likely attract predator attention (Hickman and Brown 1973b). We suspect the puncture wounds to the shoulder and bruising to the muzzle found on the carcass of the first mortality to be from raptor talons. The individual apparently escaped the initial attack, but later died from the injuries. In the second mortality, we suggest the transmitter was dropped by a raptor feeding on the carcass. Although snakes in the genus *Pituophis* are the primary predators of pocket gophers in regions where they coexist (Rudolph et al. 2002; Sterner et al. 2002), snakes did not seem to be the cause of either mortality. The small number of observed mortalities that occurred during this study likely does not represent the full range of potential southeastern pocket gopher predators.

Dispersal

Interestingly, only 3 of the 20 radio-tracked individuals in our study dispersed. Because we only radio-tagged individuals weighing more than 100 g, it is possible that the individuals we tracked had already dispersed and established territories at the capture site. Daly and Patton (1990) also found that dispersal by adult Botta's pocket gophers was uncommon. Although one or two small mounds were present, there were no mound systems between the initial and final locations of the dispersing radio-tagged individuals, suggesting that dispersals occurred above ground. Furthermore, we incidentally captured four juvenile pocket gophers (89–95 g) above ground that we assumed to be dispersing. Aboveground dispersal is common in geomyids (Vaughn 1963; Williams and Cameron 1984; Daly and Patton 1990). Dispersals of three, presumably subadult ($\leq$155 g) pocket gophers during our study and the four incidentally captured juveniles that were assumed to be dispersing suggests that southeastern pocket gopher dispersal occurs prior to sexual maturity, similar to Botta's pocket gopher (Daly and Patton 1990). Juvenile female Botta's pocket gophers disperse soon after weaning and males disperse later as subadults. Unfortunately, we were unable to determine sex of the dispersing individuals.

Unlike other studies that documented no evidence of homing behavior in pocket gophers (Vaughn 1963; Hickman and Brown 1973a), our observation of a pocket gopher traveling more than 300 m from its burrow and returning within 1 wk suggests that the southeastern pocket gopher may be capable of homing. Homing is a common ability among rodents and suggests the use 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), or dead reckoning (Etienne 1992). Further research is needed to fully evaluate homing mechanisms used by the southeastern pocket gopher.

Daily activity patterns

Our study is the first to document daily activity patterns of free-ranging southeastern pocket gophers. The two metrics used to describe daily activity, distance traveled and distance from the nest, provided indices of temporal movement patterns throughout the diel period. Although we could not confirm the purpose of the movements, it is reasonable to assume that movements primarily consisted of foraging, waste disposal, and reproductive efforts (Baker et al. 2003). Our observed peak activity periods (0000–0400 and 1600–2000 hours) are in contrast to those of Ross (1980) who found that captive southeastern pocket gophers were equally active during all periods. Ross (1980) acknowledged that activity in captive animals may be misrepresentative of free-ranging individuals because of the lack of opportunities for foraging activity. However, Bandoli (1987) detected a peak in activity between 1500 and 1800 in Botta's pocket gophers, but did not observe a second peak as documented in our study.

Implications for translocation

Recognition of longleaf pine communities as floral biodiversity hot spots (Peet and Allard 1993) and critical habitat for rare fauna has promoted strong interest in longleaf restoration (Van Lear et al. 2005). As longleaf communities are restored, suitable habitat for southeastern pocket gophers will become available. Although our study indicates that southeastern pocket gophers are capable of dispersing further than previously thought, the highly fragmented nature of newly available habitats likely will remain an impediment to natural colonization. Therefore, translocation will be necessary to reestablish populations in many situations.

Our results provide important baseline information on southeastern pocket gophers monitored in situ. Whether our results are representative of individuals moved to new locations is unknown. Thus, initial translocation efforts likely will involve monitoring translocated individuals via radiotelemetry to assess survival and initial movements following release. Lessons learned during our study provide guidance regarding transmitter implantation. Although subcutaneous transmitter implantation has been used and recommended for radio tracking other pocket gopher species (Cameron et al. 1988; Connior and Risch 2009b, 2010), we documented an unacceptably high rate of transmitter loss (33%) on individuals with subcutaneous implantation. In contrast, we had no transmitter loss associated with intraperitoneal implantations. The trade-off is a more invasive surgery with increased risk of complications. In our study, one of 13 individuals died (7.7%) due to apparent surgery-related complications. Zinnel and Tester (1991) experienced low occurrence of surgery-related mortalities (7.4%) with intraperitoneal implantation in Plains pocket gophers *Geomys bursarius*. The reason for the retention difference of subcutaneously implanted transmitters between our study and others is unknown, but could be related to species-specific anatomical or behavioral differences, or to specific surgical techniques. Although we recommend intraperitoneal implantation based on our results, we advise consultation with a veterinarian to determine the most appropriate implantation technique based on study species and specific surgical techniques.

Beyond improving radiotelemetry methodology, our results can be applied directly to planning and implementing pocket gopher translocations. First, southeastern pocket gopher activity peaked after dusk, suggesting that trapping to capture individuals for translocations may be most effective between 1600 and 2000 hours. Second, we found that southeastern pocket gophers disperse before they reach sexual maturity. Adults, like in other geomyids (Daly and Patton 1990), are generally sedentary. Therefore, translocating adult individuals may limit above-ground dispersal movements associated with increased predation risk (Vaughn 1963). Third, based on our estimated home range sizes, southeastern pocket gophers require approximately 1,000 m^2 per individual, but soil texture and vegetation may influence home range size. Thus, an assessment of soil and vegetation characteristics on translocation sites may be necessary to ensure adequate spacing between individuals. Finally, we documented a southeastern pocket gopher homing more than 300 m. Homing ability can lower site fidelity and affect success of translocation efforts (Van Vuren et al. 1997; Villaseñor et al. 2013) and should be considered in translocation decisions. Although southeastern pocket gopher translocation distances likely will be much greater than 300 m, individuals attempting to home may be at greater predation risk. Fencing or other barriers may be necessary to prevent above-ground homing movements during the initial period following release.

Supplemental Material

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Table S1. Number of telemetry locations, number of days tracked, home range size (m^2), body mass (g), transmitter fate, and documented dispersal for radio-tracked southeastern pocket gophers *Geomys pinetis* recorded as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S1 (32 KB DOCX).

Table S2. pH of soil samples taken in five depth (cm) increments at the center of southeastern pocket gopher *Geomys pinetis* home ranges measured as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S2 (22 KB DOCX).

Table S3. Percent nitrogen of soil samples taken in five depth (cm) increments at the center of southeastern pocket gopher *Geomys pinetis* home ranges measured as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S3 (22 KB DOCX).

Table S4. Percent carbon of soil samples taken in five depth (cm) increments at the center of southeastern pocket gopher *Geomys pinetis* home ranges measured as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S4 (23 KB DOCX).

Table S5. Percent sand, clay and silt in soil samples taken in five depth (cm) increments at the center of southeastern pocket gopher *Geomys pinetis* home ranges measured as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S5 (49 KB DOCX).

Table S6. Percent ground cover of pine litter, hardwood leaf litter, woody vegetation, forbs and vines, wiregrass, and other grass species estimated within five 1-m^2 subplots within 18 m of the center of southeastern pocket gopher *Geomys pinetis* home ranges measured as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S6 (35 KB DOCX).

Table S7. Number of at risk individuals, number of mortalities documented, number of individuals added to the radio-tagged sample, hazard rate, survival estimate, and standard error and confidence intervals of estimates for each week of southeastern pocket gopher *Geomys pinetis* survival monitoring during a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S7 (49 KB DOCX).

Table S8. Maximum, mean and mean proportional distance (m) of southeastern pocket gopher *Geomys pinetis* telemetry locations from nests recorded at 20-min intervals during 4-h time blocks across the 24-h diel period as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S8 (37 KB DOCX).

Table S9. Mean maximum distance, mean distance and mean proportional distance traveled (m) by southeastern pocket gophers *Geomys pinetis* recorded at 20-min intervals during 4-h time blocks across the 24-h diel period as part of a study examining home range, survival, and activity patterns in Baker County, Georgia, 2012–2013.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S9 (37 KB DOCX).

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Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-023.S10 (10989 KB PDF).

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