Survival and Home-Range Size of Southeastern Fox Squirrels in North Carolina

Annemarie Prince[1,2,*], Christopher S. DePerno[1], Beth Gardner[1], and Christopher E. Moorman[1]

Abstract - Studies of *Sciurus niger* (Fox Squirrel) in the Southeast have focused on habitat relationships with limited emphasis on other life-history characteristics. We estimated survival rates for 51 radio-collared *Sciurus n. niger* (Southeastern Fox Squirrel) on Fort Bragg, NC, during March 2011–June 2012 using the Kaplan-Meier staggered-entry design. Also, we calculated composite and seasonal 99% kernel-density home-range estimates for male and female Fox Squirrels. During our study, 22 radio-collared Fox Squirrels died: 8 were depredated, 2 were hunter harvested, and 12 died of unknown causes. Survival rates differed among the seasons when the sexes were combined; survival was greatest in the winter and lowest in the fall. Male annual survival (0.35) was lower than female annual survival (0.66) at the $\alpha = 0.10$ level. Male home ranges were larger than female home ranges, potentially exposing them to greater predation risk. High mortality of male Fox Squirrels may warrant reevaluation of harvest regulations for declining, hunted Fox Squirrel populations. Additionally, large space requirements for Fox Squirrels may be indicative of low availability of forage on the landscape, a condition that should prompt land managers to adjust management actions to improve habitat conditions for Fox Squirrels.

Introduction

In the Southeast, most studies of *Sciurus niger* L. (Fox Squirrel) have focused on habitat relationships, and few have focused on demographic processes, including survival (Conner 2001, Lee et al. 2008, McCleery et al. 2008, Weigl et al. 1989). Yet, survival estimates are critical for setting appropriate hunting seasons and harvest limits where Fox Squirrels are hunted (Bailey 1984, Dasmann 1981).

In some southeastern states, Fox Squirrel and *Sciurus carolinensis* Gmelin (Eastern Gray Squirrel) harvest regulations and bag limits are combined to form a general squirrel season (Loeb and Moncrief 1993, Tappe and Guynn 1998). Recently, researchers have questioned managing these species together because Fox and Gray Squirrels have different survival strategies (Conner 2001, Edwards et al. 2003, Lee et al. 2008, Tappe and Guynn 1998). In the Southeast, Fox Squirrels tend to be long-lived, have smaller and fewer litters, and exhibit high adult survival rates. Therefore, Tappe and Guynn (1998), and others (see Conner 2001, Lee et al. 2008) suggested Fox Squirrels are closer to a K-selected species (Pianka 1970) than Eastern Gray Squirrels and should be managed separately with respect to hunting seasons and harvest regulations.

[1]Department of Forestry and Environmental Resources, Fisheries, Wildlife, and Conservation Biology Program, North Carolina State University, Raleigh, NC 27607. [2]Current address - Washington Department of Fish and Wildlife, Colville, WA 99114. [*]Corresponding author - annemarie.prince@dfw.wa.gov.

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Although mid-western Fox Squirrels have been more thoroughly studied, extrapolation of survival rates from these studies is not appropriate because of ecological differences between regional populations (e.g., diet, home-range size, morphology, habitat use; Conner 2001, Edwards et al. 1989, Nixon et al. 1968, Weigl et al. 1989). Therefore, we estimated survival rates for a population of *Sciurus n. niger* (Southeastern Fox Squirrel, hereafter Fox Squirrel). Also, to relate space use to survival, we determined seasonal home-range size of male and female Fox Squirrels.

Study Area

We conducted the study on Fort Bragg Military Installation, a 64,280-ha active army base in the Sandhills physiographic region of North Carolina. Dominated by an overstory of *Pinus palustris* Mill. (Longleaf Pine) and an understory of *Aristida stricta* Michx. (Wiregrass), Fort Bragg and adjacent areas make up the largest contiguous tract of Longleaf Pine-Wiregrass ecosystem remaining in North Carolina (Sorrie et al. 2006). Large hardwood trees, including *Quercus laevis* Walter (Turkey Oak), *Q. stellata* Ashe (Sand Post Oak), *Q. marilandica* Münchh. (Blackjack Oak), *Q. falcata* Michx. (Southern Red Oak), and *Carya* spp. (hickories), were scattered across the base and located in small patches in the uplands, along drainages, and bordering the military drop zones. Fort Bragg has relied heavily on the use of prescribed fire to maintain an open midstory for the federally endangered *Picoides borealis* Vieillot (Red-cockaded Woodpecker). Beginning in the late 1980s, prescribed fires were conducted primarily in the growing-season (April–June) every 3 years to prevent hardwood encroachment in the uplands; however, dormant-season burns were conducted yearly on the parachute-drop zones and throughout the base on forest acreage not burned due to weather or lack of personnel the previous year (J. Jones, Fort Bragg Wildlife Branch, Fort Bragg, NC, pers. comm.). On Fort Bragg, hunters were allowed to harvest 1 Fox Squirrel per day, with a season limit of 10 during October–December. The Eastern Gray Squirrel hunting season extended October–February and had a daily limit of 8 with no season limit. Hunting Eastern Gray Squirrels and Fox Squirrels with dogs was permitted on Fort Bragg. Since 1982, squirrel hunter effort has declined on Fort Bragg, and Fox Squirrel harvest has remained relatively constant over this period (J. Jones, pers. comm.).

Methods

Animal capture and monitoring

We trapped Fox Squirrels using wooden-box traps (Baumgartner 1940) and wire-cage traps (Tomahawk Live Trap Company, Tomahawk, WI) baited with dried whole-kernel corn. After capture, Fox Squirrels were transferred into a modified capture cone (Koprowski 2002) and weighed, sexed, aged (juvenile or adult; Weigl et al. 1989), assessed for reproductive condition, and individually ear-tagged (Monel 1005-1/1005-3, National Band and Tag Company, Newport, KY). We radio collared adult Fox Squirrels weighing ≥750 g (collar weight = 19 g, <3% body weight; Model SI-2C, Holohil Sys. Ltd., Carp, ON, Canada) and released them at the capture

location. During the study, we had 33 radio collars available for deployment, and we trapped periodically during February 2011–May 2012 to maintain 33 radio-collared Fox Squirrels throughout the study. All capture and processing methods met the specifications set forth by the Institutional Animal Care and Use Committee at North Carolina State University (IAUCUC # 10-153-O) and followed guidelines of the American Society of Mammalogists (Gannon et al. 2007).

We located radio-collared Fox Squirrels once per day and ≥3 times per week using the homing technique (White and Garrott 1990) at random times between 0.5 hours after sunrise and 0.5 hours before sunset during February 2011–June 2012. We continually monitored radio-collared Fox Squirrels until death, radio failure, or they became inaccessible to tracking (i.e., moved into artillery impact area).

We confirmed mortalities by the presence of Fox Squirrel remains near the radio collar or by signs of a struggle (i.e., ground disturbance, blood and/or bite marks on the radio collar). If Fox Squirrel remains were absent or we could not distinguish predation from scavenging, we classified mortalities as unknown. We determined cause of death by examining squirrel remains, looking for signs of a struggle, and swabbing the radio collar for potential predator DNA. We obtained DNA swabs by vigorously rubbing a double-sided Q-tip on the radio transmitter and the collar casing. We individually labeled the swabs, placed them in envelopes, and sent them to Wildlife Genetics International (Nelson, BC, Canada) for genetic analysis. The species-identification test was a sequence-style analysis of the 16S rRNA mitochondrial gene (Johnson and O'Brien 1997). Using evidence from the field and from the laboratory DNA results, we categorized mortalities as predation (mammalian carnivores and raptors), hunting, and unknown.

Data analysis

We excluded radio-collared Fox Squirrels that died within 7 days of capture to avoid using capture-related mortalities in our analysis (Conner 2001). Also, we censored Fox Squirrels when the radio collar stopped transmitting, an individual moved into the artillery impact area (inaccessible to tracking), or when we found the collar with no clear sign of mortality.

We calculated annual and seasonal survival rates using the staggered-entry modification (Pollock et al. 1989) of the Kaplan-Meier product-limit survival estimator (Kaplan and Meier 1958). We estimated annual survival using 52 weeks of data collection. We defined seasons based on plant phenology and according to Weigl et al. (1989) (winter: 16 January to 15 March, spring: 16 March to 1 June, summer: 2 June to 30 September, and fall: 1 October to 15 January). We used a chi-square test within Program CONTRAST (Patuxent Wildlife Research Center, United State Geological Survey, Laurel, MD) to compare among seasonal survival rates for males, females, and the sexes combined, and annual survival rates between males and females (Sauer and Hines 1989); alpha was set at 0.05.

We calculated seasonal home ranges for Fox Squirrels (mean ± SE = 36.7 ± 1.3 locations, n = 152) within a season using the same seasons defined above. We calculated composite (i.e., entire study period, all seasons combined) home

ranges for Fox Squirrels with ≥30 locations during the study period. We imported coordinates of squirrel locations into a geographic information system (ArcView10; Environmental Systems Research Institute, Redlands, CA) and calculated 99% kernel-density home ranges using the kde function (bandwidth = PLUGIN, cell size = 30) within the Geospatial Modeling Environment (Version 0.7.1.0; Hawthorne L. Beyer 2009–2012). We used 2-way analysis of variance (ANOVA) and Tukey's HSD post hoc comparison tests to compare home-range sizes between the sexes and among the seasons.

Results

We radio collared 52 Fox Squirrels (27 male, 24 female, 1 unknown). The mean body weight at capture was 922 ± SE 22 g for males and 963 ± SE 24 g for females. One male Fox Squirrel was removed from the survival analysis because it died within 7 days of capture. We detected 22 mortalities (15 male, 7 female): 2 squirrels were harvested by hunters, 8 were killed by predators, and 12 squirrels lacked sufficient remains and/or signs of a struggle to determine cause of death and were classified as unknown. Of the 8 predator mortalities, *Lynx rufus* Schreber (Bobcat) and *Urocyon cinereoargenteus* Schreber (Gray Fox) DNA were extracted from 1 collar each, we suspected a *Buteo jamaicensis* Gmelin (Red-tailed Hawk) killed 1 squirrel, and the remaining 4 deaths were not attributable to a specific predator. However, because of the presence of the tail and fur at the recovered collar location, we suspect predation in 6 of the 12 deaths classified as unknown.

Survival rates differed among the seasons when the sexes were combined (χ^2 = 11.61, P = 0.03, df = 4); survival was greatest in the winter and lowest in the fall (Table 1). Male annual survival was about half of female annual survival, but the statistical difference was weak (χ^2 = 2.64, P = 0.10, df = 1).

Composite home ranges were calculated for 47 (25 male, 22 female) Fox Squirrels. Male composite home range size (mean ± SE = 81.26 ± 14.12 ha [range = 6.85–312.67 ha]) was about 4 times larger on average ($F_{1, 143}$ = 42.70, P < 0.001) than that

Table 1. Kaplan-Meier seasonal survival rates (Ŝ) and 95% confidence intervals for male, female, and combined sexes of radio-collared Southeastern Fox Squirrels on Fort Bragg, NC, 1 May 2011–2 June 2012.

	Males			Females			Sexes combined		
		95% CI			95% CI			95% CI	
Time period[A]	Ŝ	Lower	Upper	Ŝ	Lower	Upper	Ŝ	Lower	Upper
Spring 2011	0.87	0.71	1.00	0.93	0.81	1.00	0.88	0.77	0.88
Summer 2011	0.87	0.71	1.00	0.82	0.64	1.00	0.85	0.72	0.85
Fall 2011	0.66	0.45	0.87	0.80	0.61	0.99	0.72	0.57	0.72
Winter 2011	0.94	0.82	1.00	1.00	1.00	1.00	0.97	0.90	0.97
Spring 2012	0.65	0.27	1.00	1.00	1.00	1.00	0.84	0.66	0.84
Annual[B]	0.35	0.07	0.63	0.66	0.41	0.91	0.49	0.30	0.68

[A]Spring: 16 March to 1 June, summer: 2 June to 30 September, fall: 1 October to 15 January, and winter: 16 January to 15 March.
[B]2 June 2011–2 June 2012.

of females (mean ± SE = 19.83 ± 3.01 ha [range = 5.40–72.07 ha]) (Table 2). We observed an effect of season on home-range size ($F_{3, 143} = 5.78$, $P = 0.001$); on average, home ranges were about 3 times larger in spring than in winter.

Discussion

Our estimate of male annual survival was low compared to other studies in the Southeast and may be explained by the large home ranges of male Fox Squirrels on Fort Bragg and the resulting increase in predation risk. The Kaplan-Meier estimate of male annual survival on Fort Bragg was 0.35 (95% CI = 0.07–0.63) compared with 0.73 (95% CI = 0.59–0.87) and 0.62 (95% CI = 0.46–0.78) calculated for Fox Squirrel populations in Georgia (Conner 2001) and South Carolina (Lee et al. 2008), respectively. Discrepancies in predation rates among studies of Fox Squirrel survival could be due to differing forest structure on study sites or varying predator densities across the Southeast. Weigl et al. (1989) suggested that Fox Squirrel predation would only reach appreciable levels when Fox Squirrel habitat was in close proximity to large closed-canopy hardwood stands that support high populations of alternate prey, like Eastern Gray Squirrels. Because Fox Squirrels on Fort Bragg selected areas in close proximity to drainages with high hardwood densities, Weigl's hypothesis could explain our relatively high predation rates and low male survival rates (Prince 2013). Regardless of the mechanism, low male survival estimates on Fort Bragg suggest the need for close monitoring of the potential additive effects of hunter harvest in the future.

Seasonal changes in activity level and home-range size likely caused the variation in seasonal survival estimates for Fox Squirrels on Fort Bragg. In North Carolina, the spring and fall are typically seasons of plentiful food, and corresponding increases in foraging and caching behavior could make males and females more susceptible to predation (Edwards et al. 2003, Weigl et al. 1989). During our study, the majority of the Fox Squirrel mortalities occurred in the fall, but home-range sizes for males and females were greatest in the spring. Perhaps squirrels are more active during the fall, but their movements are more localized as they forage in areas with a greater hardwood (and acorn) component. Conversely, survival rates

Table 2. Mean home-range size (ha) based on 99% kernel-density estimates and standard error (SE) by sex and season for radio-collared Southeastern Fox Squirrels on Fort Bragg, NC, 2011–2012.

	Males			Females			Sexes combined		
Season[A]	*n*	Home range	SE	*n*	Home range	SE	*n*	Home range[C]	SE
Spring	22	108.52	20.54	20	28.18	4.32	42	71.39 A	12.43
Summer	20	76.14	13.31	18	19.24	5.65	39[B]	50.31 AB	8.70
Fall	18	68.67	13.17	16	18.12	5.32	33[B]	45.64 AB	8.75
Winter	18	34.42	9.38	16	6.62	1.33	35[B]	21.57 B	5.34
All (composite)	25	81.26	14.12	22	19.83	3.01	47	53.30	8.78

[A]Spring: 16 March to 1 June, summer: 2 June to 30 September, fall: 1 October to 15 January, and winter: 16 January to 15 March.
[B]Includes Fox Squirrel of unknown sex.
[C]Tukey's HSD post hoc comparison test; seasons with the same letter are similar at α = 0.05.

were greatest in the winter and may correlate with reduced activity during this time period; decreased winter activity similarly was observed for Eastern Gray Squirrels in Maryland (Thompson 1977).

In all studies of Fox Squirrel space use in the Southeast, males consistently had larger home ranges; however, techniques used to determine home-range size have varied (Edwards 1986, Powers 1993, Weigl et al. 1989, Wooding 1997). For example, previous studies in the Southeast used the minimum convex polygon method for determining home-range sizes and report estimates of the mean size ranging from 79.5 ha for male Fox Squirrels in Florida (Wooding 1997) to 11.6 ha for females in Alabama (Powers 1993). Home-range estimates derived from kernel-density estimators are considered more robust than minimum convex polygon methods (Borger et al. 2006), and our comparatively large estimates may more accurately represent the true space requirements of Fox Squirrels.

Management implications

For declining or isolated, hunted Fox Squirrel populations, high mortality rates for male Fox Squirrels may warrant reevaluation of harvest regulations (e.g., shorter seasons, smaller bag limits). Additionally, if large space requirements of Fox Squirrels are indicative of low availability of forage on the landscape, land managers may need to adjust management actions (e.g., hardwood retention) to improve habitat conditions for Fox Squirrels.

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