A Comparison of Four Survey Methods for Detecting Fox Squirrels in the Southeastern United States

Daniel U. Greene,* Robert A. McCleery, Lindsay M. Wagner, Elina P. Garrison

D.U. Greene, R.A. McCleery, L.M. Wagner
Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida 32611

E.P. Garrison
Florida Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, Gainesville, Florida 32601

Abstract

Fox squirrel *Sciurus niger* populations in the southeastern United States appear to have declined, and 3 (S. *n. cinereus*, S. *n. shermani*, and S. *n. avicennia*) of the 10 subspecies are currently listed with a conservation status of protection. Efforts to conserve and manage fox squirrels in the southeastern United States are constrained by difficulties in studying their populations because of low densities and low detectability. There is a need for an effective survey method to fill knowledge gaps on southeastern fox squirrel ecology. To address this need and to identify a cost-effective and reliable technique to survey and monitor southeastern fox squirrel populations, we compared four survey methods across seasons: live-trapping; camera-trapping; point counts; and line-transect surveys, in regard to whether a detection occurred at a survey point, the total number of detections at a survey point, and the total cost for each method. We assessed the effectiveness of capture and detection methods and the influence of seasonality using generalized linear mixed models. We found camera-trapping to be the most effective survey method for assessing the presence and distribution of southeastern fox squirrels. In total, camera-traps produced significantly more detections (*n* = 223) of fox squirrels than all other methods combined (*n* = 84), with most detections occurring in spring (*n* = 97) and the fewest in the autumn (*n* = 60). Furthermore, we detected fox squirrels at more survey points with camera-traps (73%) than all other methods (63%), and we identified 16% more individuals from camera-trap photographs than live-trapped. We recommend future monitoring of southeastern fox squirrels to be conducted using camera-trapping during the spring unless handling of animals is needed for other research purposes.

Keywords: camera survey; camera-trapping; line-transect; live-trapping; point count; *Sciurus niger*; Sherman’s fox squirrel

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* Corresponding author: dgreene907@gmail.com

Introduction

Fox squirrels *Sciurus niger* are widely distributed throughout much of their native range east of the Rocky Mountains (Hall 1981; Koprowski 1994). Six of the 10 subspecies of fox squirrel (*S. n. cinereus*, *S. n. vulpinus*, *S. n. niger*, *S. n. shermani*, *S. n. avicennia*, and *S. n. bachmani*) that range through Virginia, southern Florida, and Mississippi are collectively known as southeastern fox squirrels (Loeb and Moncrief 1993). Southeastern fox squirrels generally occur at lower densities and are more sparsely distributed across the landscape than fox
squirrels found in the Midwestern United States (Moore 1957; Weigl et al. 1989; Loeb and Moncrief 1993). The southeastern subspecies of fox squirrel also appear to be declining, primarily because of an on-going loss of habitat (Weigl et al. 1989; Loeb and Moncrief 1993), while populations of the Midwestern subspecies (S. n. limitis, S. n. ludovicianus, S. n. rufiventris, and S. n. subauratus) have remained stable (Swihart and Nupp 1998). Three southeastern fox squirrel subspecies are listed with a conservation status of protection because of habitat loss and low densities: the state of Florida considers the Sherman’s fox squirrel S. n. shermani as a species of special concern and the Big Cypress fox squirrel S. n. avicennia as threatened (Humphrey and Jodice 1992; Kantola 1992; Loeb and Moncrief 1993); and the Delmarva fox squirrel S. n. cinereus, recently (16 November 2015) delisted as federally endangered under the U.S. Endangered Species Act (ESA 1973 [as amended]; U.S. Fish and Wildlife Service 1993), is considered a state-listed endangered species in Delaware, is expected to be reclassified as a species in need of conservation in Maryland, and is anticipated to remain state-listed as endangered in Virginia (U.S. Fish and Wildlife Service 2015).

At present, we believe there are no reliable methods to survey or monitor southeast fox squirrel populations. Live-trapping has been the most common method used to study fox squirrels throughout their range. However, southeastern fox squirrels are difficult to capture (Weigl et al. 1989; Kantola and Humphrey 1990), with capture success <1% (Steele and Koprowski 1990; Moore 1957; Weigl et al. 1993). In the Southeast, traps are typically placed on the ground for fox squirrels (e.g., Tappe et al. 1993; Conner and Godbois 2003), but in other parts of their range capture success has been improved by elevating a trap on a branch or platform (Huggins and Gee 1995).

Common problems that can occur when live-trapping wildlife include a behavioral response where animals may become trap-shy or trap-happy (Morris 1955) and the risk of stress and injury when captured (Romero 2004). These problems can often be minimized or eliminated with passive survey methods. Several passive methods have been used with varying degrees of success to detect fox squirrels: line-transect surveys (Humphrey et al. 1985; Hein 1997; Eisenberg et al. 2011), time area counts (Chamberlain et al. 1999), point counts (McCleery 2009; McCleery and Parker 2011), leaf-nest counts (Moore 1957; Kantola and Humphrey 1990), and nest box monitoring (Weigl et al. 1989; Larson 1990). However, none have proven effective for surveying southeastern fox squirrel populations. The use of camera-traps has become increasingly popular as another passive survey method for elusive wildlife (Foster and Harmsen 2012), but such traps have not been examined as to their effectiveness as a survey method for fox squirrels compared with survey methods traditionally used.

The overall difficulty of studying southeastern fox squirrel populations likely stems from their low densities (0.08–0.75/ha) and low capture success (Moore 1957; Weigl et al. 1989; Tappe et al. 1993; Lee et al. 2009). Their scarcity and difficulty in being detected on the landscape contribute to the need for a reliable, cost-effective method for surveying and monitoring their populations. An effective standardized survey method for southeastern fox squirrels is needed to fill knowledge gaps on their distribution, population dynamics, habitat association, and to provide managers with a means to evaluate the effectiveness of management practices. Additionally, it is important to know the best time to survey southeastern fox squirrels because their activity patterns can vary seasonally depending on extreme temperatures and the availability of food (Moore 1957; Weigl et al. 1989).

Our objective was to compare four methods for surveying southeastern fox squirrels: passive infrared digital cameras (hereafter, camera-traps); live-capture using wooden traps on the ground and wire traps elevated in trees; point counts; and line-transect surveys. We evaluated these methods by comparing their ability to detect a fox squirrel at a survey point, the total number of detections at a survey point, and the number of individuals detected. Additionally, we assessed seasonal variation in fox squirrel detections and compared the total cost and cost per detection for each survey method.

### Study site

We conducted the study at Camp Blanding Wildlife Management Area in Clay County, Florida, and Ordway–Swisher Biological Station in Putnam County, Florida. The vegetation communities at Camp Blanding were classified as a mixture of sandhill and mesic flatwoods, and Ordway was classified as sandhill (Florida Natural Areas Inventory 2010), both typical of southeastern fox squirrel habitat (described by Moore 1957; Kantola and Humphrey 1990; Conner et al. 1999). At Camp Blanding, longleaf pine Pinus palustris, slash pine P. elliottii, and turkey oak Quercus laevis were the most common tree species. The understory was primarily saw-palmetto Serenoa repens, gallberry Ilex glabra, and swamp bay Persea palustris. At Ordway, longleaf pine, turkey oak, and live oak Q. virginiana were the most common tree species. The understory was open, and the ground cover was primarily wiregrass Aristida stricta.

### Materials and Methods

#### Field surveys

At each study site, we established two 75-ha grids in areas known to be occupied by Sherman’s fox squirrels. Each grid had 20 survey points placed in a 4 × 5 arrangement, with 250-m spacing between survey points (Figure 1). We conducted surveys for fox squirrels using camera-traps, live-capture, point counts, and line-transect surveys on all grids and points each season. We surveyed for 2 mo each season, and defined seasons as autumn (October–November 2011), winter (February–March 2012), spring (April–May 2012), and summer (August–September 2012).
For the camera surveys, we placed one camera (Bushnell Trophy Cam model 119436c; Bushnell Outdoor Products, Overland Park, KS) at each survey point on a grid for 4 consecutive d. Cameras were equipped with a 2-GB SanDisk memory card (SanDisk Corporation, Milpitas, CA) and set to take three photographs every 10 s at a normal sensitivity level when triggered. We set the cameras 70 cm above the ground and angled them toward a bait pile of pecans and cracked corn (Baumgartner 1940; McCleery and Parker 2011) placed at the base of a tree 1.5 m from the camera. We baited survey points twice during each 4-d sampling period. We identified individual fox squirrels from camera-trap photographs using their unique pelage features (Tye et al. 2015) and calculated the time difference between camera-trap photographs for each individual at a survey point to determine how to define an independent detection.

For live-trapping, we placed a wooden box trap (23 × 18.5 × 61 cm; Baumgartner 1940) on the ground at the base of a tree at the survey point, and strapped a Tomahawk wire cage trap (No. 103; Tomahawk Live Trap Company, Tomahawk, WI) on a wooden platform attached to the trunk of the same tree 1.5 m above the ground. We prebaited both trap types every other day for 6 d with pecans and cracked corn to account for the

Figure 1. Distribution of the four grids used in a study of Sherman’s fox squirrels *Sciurus niger shermani* to identify the most effective survey method for detecting individuals. Grids were located at Camp Blanding Wildlife Management Area in Starke, Florida, and the Ordway–Swisher Biological Station in Melrose, Florida, from 2011 to 2012.
expected low capture success (Weigl et al. 1989; Steele and Korprowski 2001), and live-trapping began on the seventh day. Traps were open from sunrise to sunset for 4 consecutive d, ranging from 10 to 14 h each day, varying by the number of daylight hours during each season. We checked our traps every 2–3 h to minimize stress and to avoid heat-related trap mortality. We marked all squirrels with a monel #3 ear tag (National Band and Tag Company, Newport, KY) to quantify the number of individuals captured, and defined a capture as a detection. Live-trapping and handling were conducted under the Florida Fish and Wildlife Conservation Commission’s Scientific Collecting Permit (Permit no. LSSC-11-00026), was approved by the University of Florida’s Non-Regulatory Animal Research Committee (021-10WEC), and followed the guidelines approved by the American Society of Mammalogists (Sikes et al. 2011).

We conducted point counts and line-transect distance sampling (Buckland et al. 1993) using the same grids during the live-trapping sessions. We first assessed the feasibility of point counts in a pilot study; with no detections either in the pilot study or in the first season, we limited our effort of this method to only one point-count survey per season at each survey point. We conducted all point counts during the peak activity periods 1–2 h before sunset, which ranged from 1400 hours to 1800 hours Eastern Standard Time depending on the season (Weigl et al. 1989). We used a snapshot method (Buckland 2006), where surveyors had a rest period for 20 min to allow squirrels to acclimate to their presence in the area. Surveyors visually searched for fox squirrels during the rest period and recorded the distance and direction of all visible fox squirrels. Each visible squirrel counted as a detection.

We conducted line-transect surveys between all survey points along a continuous transect on a grid (4.75 km) while checking traps. Surveyors walked at a constant speed with minimal disturbance to record the perpendicular distance from the line to an observed squirrel (hereafter, a detection) using a rangefinder. Each grid was checked 3–4 times/d throughout the trapping period, yielding 14–19 total km surveyed daily for each grid. Individual fox squirrels could not be identified from point counts and line-transect surveys.

For a cost comparison, we estimated the total cost to conduct each survey method for all seasons and the cost per detection. Although we combined the distance-based methods with live-trapping in our study and had a large group of volunteers, we estimated the costs to only include the minimum number of people needed to independently conduct each survey method. Costs included the materials, bait, traps, cameras, memory cards, and labor. Labor included time to construct the equipment, commute time, and time in the field and office at a rate of U.S. $16/h.

Data analysis

We analyzed detections at each survey point three ways to compare the effectiveness of capture or detection methods and influence of seasonality. First, we modeled the binary response of detecting a squirrel for each capture or detection method (camera-trap, wooden trap on the ground, wire trap in a tree, point count, and line-transect) at each survey point. We used the location of a detection (i.e., the survey point) as the random effect in our models to account for the lack of independence among methods. We also compared the probability of detecting a squirrel at a survey point during each season from all capture methods. Second, we compared the number of detections at a survey point for each capture method and season. Third, we combined wooden and wire traps and compared the probability of a detection and the number of detections at each survey point for cameras and live-trapping. For all analyses, we used cameras and autumn as our reference categories. We conducted our analyses using a generalized linear mixed model with a zero-inflated negative binomial distribution to account for the low number of detections and overdispersion. We used the packages lme4 version 1.1–7 (Bates et al. 2012), R2admb (Bolker et al. 2013), and glmmADMB version 0.8.0 (Fournier et al. 2012; Skaug et al. 2013) for R (R Development Core Team 2012). We compared the direction of the effect using the beta estimates and their standard errors, and assessed significance at $\alpha = 0.05$.

Results

Combining all survey methods, we detected fox squirrels at 65 of 80 survey points over all seasons (Tables S1–S2, Supplemental Material). For the camera-trap surveys, we recorded 3,614 photographs of fox squirrels at 58 survey points, which we identified to be 50 individuals. After plotting the time difference between successive photographs ($n = 2,940$) for each individual at a survey point, we found that $<6\%$ ($n = 163$) of the encounters included an individual who returned to a survey point after a 20-min interval. Therefore, we defined a detection of an individual to be independent if $\geq 20$ min elapsed since its last observation at a survey point.

In total, we had 223 detections of fox squirrels from the camera-traps. For live-trapping, we captured fox squirrels at 43 survey points, and totaled 82 captures of 42 individuals. We captured fox squirrels more often in a wooden trap on the ground ($n = 60$) than in a wire trap elevated in a tree ($n = 22$). We detected two fox squirrels at two survey points during point counts at 12 and 40 m from the surveyor, both during the summer. Two additional squirrels were seen during the rest period but not at the 20-min mark—one 27 m from a surveyor in the summer and one 30 m from a surveyor in the winter. We did not detect fox squirrels during the line-transect surveys. As a result of few detections based on
Table 1. Estimated betas, standard errors (SE), z-values, and corresponding P-values from our analyses of the survey methods to detect Sherman’s fox squirrels Sciurus niger shermani at Camp Blanding Wildlife Management Area in Starke, Florida, and the Ordway-Swisher Biological Station in Melrose, Florida, from 2011 to 2012. Results are based on whether a detection occurred at a survey point, and the total number of detections at a survey point. Analyses included a comparison of capture or detection by each method, and with live-trapping methods combined. Camera-traps were the reference category.

<table>
<thead>
<tr>
<th>Analysis type</th>
<th>Variable</th>
<th>Beta</th>
<th>SE</th>
<th>z-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection at a survey point</td>
<td>Intercept</td>
<td>−1.086</td>
<td>0.113</td>
<td>−9.600</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Wooden</td>
<td>−0.859</td>
<td>0.169</td>
<td>−5.090</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Wire</td>
<td>−1.775</td>
<td>0.242</td>
<td>−7.340</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Combined</td>
<td>Intercept</td>
<td>−1.052</td>
<td>0.108</td>
<td>−9.7</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Wood + Wire</td>
<td>−0.644</td>
<td>0.157</td>
<td>−4.1</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Total detections at a survey point</td>
<td>Intercept</td>
<td>−0.607</td>
<td>0.132</td>
<td>−4.600</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Wooden</td>
<td>−1.347</td>
<td>0.170</td>
<td>−7.920</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Wire</td>
<td>−2.388</td>
<td>0.244</td>
<td>−9.780</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Combined</td>
<td>Intercept</td>
<td>−0.601</td>
<td>0.132</td>
<td>−4.55</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Wood + Wire</td>
<td>−1.040</td>
<td>0.157</td>
<td>−6.63</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

* Indicates significant at α = 0.05.

distance-based survey methods, we removed point counts and line-transects from further analyses.

Camera-traps were the most effective survey method for detecting fox squirrels. Camera-traps were more likely to record a detection at a survey point than a wooden trap on the ground, a wire trap elevated in a tree, and both live-trap types combined. Camera-traps also recorded more detections per survey point than a wooden trap on the ground, a wire trap elevated in a tree, and both live-trap types combined (Table 1). We recorded the most detections and individuals during the spring and the fewest in the autumn (Detections: autumn [n = 60], winter [n = 69], spring [n = 97], and summer [n = 87]; individuals: autumn [n = 27], winter [n = 37], spring [n = 39], and summer [n = 35]). A detection occurring at a point was significantly more likely during the spring compared with the autumn, but was not different from the other seasons. We also recorded more total detections per survey point in spring and summer compared with other seasons (Table 2).

The cost of independently implementing each method was correlated with the number of detections (Table 3). The total cost of camera-trapping surveys was the most expensive (U.S. $114,459) and point-count surveys were the cheapest (U.S. $1,528). However, when comparing the cost per detection, camera-trapping was the most economical survey method (U.S. $51) and point counts were the most expensive (U.S. $764).

Discussion

We found camera-trapping to be the most effective survey method for determining the presence of southeastern fox squirrels. Camera-traps recorded 2.65 times more detections than all other methods combined, detected fox squirrels at more survey points compared with live-trapping, and allowed us to identify 16% more individuals than we live-trapped. Although our overall number of detections from camera-traps was determined by how we defined the interval between subsequent detections of an individual at a survey point, we do not believe this influenced the effectiveness of camera-traps compared with the other survey methods. We acknowledge one important difference between camera-trapping and live-trapping that may have influenced our results—a fox squirrel detected on a camera-trap was always able to move to other points, whereas a live-trapped squirrel was not available to be captured in another trap until it was processed and released.

Our capture success for live-trapping was greater than the 1% previously described for southeastern fox squirrels (Steele and Kopolovski 2001). Combining the wooden and wire traps at survey points for all seasons, our live-capture success for the 1,280 trap-days was 6%. We believe two factors likely contributed to this

Table 2. Estimated betas, standard errors (SE), z-values, and corresponding P-values from our analyses of the seasonal influence on detections of Sherman’s fox squirrels Sciurus niger shermani at Camp Blanding Wildlife Management Area in Starke, Florida, and the Ordway-Swisher Biological Station in Melrose, Florida, from 2011 to 2012. Autumn was the reference category.

<table>
<thead>
<tr>
<th>Analysis type</th>
<th>Variable</th>
<th>Beta</th>
<th>SE</th>
<th>z-value</th>
<th>P-value</th>
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</thead>
<tbody>
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<td>Detection at a survey point</td>
<td>Intercept</td>
<td>−1.986</td>
<td>0.179</td>
<td>−11.080</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.223</td>
<td>0.224</td>
<td>1.000</td>
<td>0.318</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>0.460</td>
<td>0.213</td>
<td>2.160</td>
<td>0.031*</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.329</td>
<td>0.219</td>
<td>1.500</td>
<td>0.133</td>
</tr>
<tr>
<td>Total detections at a survey point</td>
<td>Intercept</td>
<td>−1.760</td>
<td>0.204</td>
<td>−8.620</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.274</td>
<td>0.240</td>
<td>1.140</td>
<td>0.253</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>0.638</td>
<td>0.232</td>
<td>2.750</td>
<td>0.006*</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.507</td>
<td>0.236</td>
<td>2.150</td>
<td>0.031*</td>
</tr>
</tbody>
</table>

* Indicates significant at α = 0.05.

Table 3. The total cost (U.S.) of number of detections, and cost per detection to implement four survey methods for Sherman’s fox squirrels Sciurus niger shermani at Camp Blanding Wildlife Management Area in Starke, Florida, and the Ordway-Swisher Biological Station in Melrose, Florida, from 2011 to 2012.

<table>
<thead>
<tr>
<th>Cost source</th>
<th>Camera-trapping</th>
<th>Live-trapping</th>
<th>Point counts</th>
<th>Line-transect surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey labor</td>
<td>$4,544</td>
<td>$4,608</td>
<td>$1,408</td>
<td>$3,840</td>
</tr>
<tr>
<td>Materials</td>
<td>—</td>
<td>$574</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Labor—construction</td>
<td>—</td>
<td>$320</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Traps</td>
<td>$1,208</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Bait</td>
<td>$113</td>
<td>$338</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Camera equipment</td>
<td>$6,802</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Rangefinders–compasses</td>
<td>—</td>
<td>$150</td>
<td>—</td>
<td>$150</td>
</tr>
<tr>
<td>Total cost</td>
<td>$11,459</td>
<td>$7,047</td>
<td>$1,528</td>
<td>$3,960</td>
</tr>
</tbody>
</table>

Cost per detection: $51 $86 $764 —
difference. First, our study sites may have had higher densities of fox squirrels compared with those in other studies because of regular prescribed burning, which contributes to vegetation structure preferred by southeastern fox squirrels (described in Weigl et al. 1989; Conner and Godbois 2003) and because hunting of fox squirrels is banned in Florida. Second, we prebaited our traps to account for the low capture success common for southeastern fox squirrels, although other researchers also prebaited (e.g., Weigl et al. 1989). We are uncertain how the presence of surveyors on the grids affected the behavior of the fox squirrels during the live-trapping sessions. It is likely that the squirrels were negatively affected by the presence of surveyors, although some animals may have been attracted to the survey points if they suspected bait had been added to the traps.

Live-trapping may be preferable to camera-trapping in some circumstances, such as when physiological measurements or genetic samples are needed. When live-trapping is necessary, we recommend using wooden traps placed on the ground. Wooden traps on the ground captured more fox squirrels than wire traps elevated in trees, and the squirrels often appeared less stressed inside the enclosed wooden traps. On several occasions, fox squirrels captured in wire traps harmed themselves by pushing their heads against the wires, resulting in open wounds. We did not observe injuries when squirrels were captured in the wooden traps.

We did not alternate the placement of the trap types (i.e., elevate wooden traps on platforms and place wire traps on the ground) and as a result our trap-type results are confounded by placement, leaving uncertainty as to the degree of difference in the effectiveness of the wooden versus wire traps. Nonetheless, we recommend placing the traps on the ground so researchers can shift them into the shade throughout the day to minimize heat-related stress or mortality, which we were unable to do with the elevated traps on platforms. If wire traps are used, we recommend using trap covers to mimic the closure that wooden traps provide to reduce the stress of captured squirrels.

Distance-based survey methods that rely on direct observation of fox squirrels may have been less effective because of several factors. Fox squirrels are difficult to detect not only because they are present in low densities, but also because they exhibit several antipredator responses, such as lying flat against a limb and remaining motionless (McCleery 2009), that make them difficult to detect. Fox squirrels likely exhibited these antipredator responses to the surveyors while they conducted the line-transect surveys. Additionally, southeastern fox squirrels have cryptic color patterns (Kiltie 1989), which increases the difficulty in visual observations. For our point-count surveys, the low number of detections was certainly related to the limited total effort per season, although the number of detections was unlikely to increase substantially with increased survey effort, because <1% of our total point counts had a detection.

We recommend surveying fox squirrel populations in the spring, which was the season that yielded the most detections in our study. Spring has been described as a period of relatively abundant food supplies for fox squirrels (Weigl et al. 1989). However, the ideal time to survey will vary geographically. Moore (1957) described spring in Florida as a period of drought with little food supply, sparse cover, and excessive heat. However, Weigl et al. (1989) described the spring in North Carolina as a period of relatively abundant food supplies. We had the fewest detections in the autumn, which these authors described as a period of higher food availability for fox squirrels. Variability in weather patterns can alter the quantity and quality of food items available. A late-spring frost event can result in mast failures for up to 2 y, particularly for oaks, which can lead to changes in fox squirrel reproductive success, overall population size, and increased movement patterns (Weigl et al. 1989). During December 2010, Florida experienced the coldest winter on record (http://www.ncdc.noaa.gov/sotc/national/2010/12, verified 20 October 2014), with below-freezing temperatures continuing into March (http://weatherspark.com, verified 20 October 2014). Multiple below-freezing events again happened in the late winter of 2011.

Although camera-trapping was our most successful survey method, we believe this method could be improved by placing two cameras at each survey point to prevent loss of data if one camera fails to photograph the target animal (Swann et al. 2004). This would also improve the accuracy of identification if one camera poorly photographs an individual. However, two cameras would double the total equipment cost of implementing this method.

The total cost for camera surveys exceeded that of other methods, but the cost of camera have steadily decreased since we began our study, and if they continue to decrease, the cost of implementing camera surveys will become more comparable to live-trapping. In addition, 29% of total cost for our camera surveys was incurred from the time we spent identifying individuals from photographs for Tye et al. 2015. The total cost of presence-only camera surveys would decrease the price to approximately U.S. $7,196, similar to the total cost of live-trapping (U.S. $7,047). Moreover, the purchase value of camera-traps represented 59% of the cost of camera surveys. For long-term monitoring, the cost of the camera-trapping equipment will be amortized, decreasing the total cost in subsequent surveys.

Southeastern fox squirrels occur at low densities, have large home ranges, and are sparsely distribution across the landscape (Loeb and Moncrief 1993). In recent years, southeastern fox squirrels have been threatened from the degradation and loss of their habitat from land-use change and changes in the frequent fire intervals (e.g., 1–3 y) that cause the encroachment of woody vegetation in the open pine savannas where they have evolved (Weigl et al. 1989). Yet, the efforts necessary to conserve and manage southeastern fox squirrels have been hindered by the difficulty in studying their populations. We found camera-trapping to be the most effective survey method for assessing the presence of southeastern fox squirrels, especially when conducted in the spring. Camera-traps
can be utilized to estimate their populations because of the high color variation between individuals, and eliminate any risk of harm or mortality associated the traditional method of live-trapping (Tye et al. 2015). In addition to being economical, camera-traps do not require personnel to be present to capture or detect the species. Furthermore, camera-traps can be deployed for long periods of time, which reduces the probability of false absences commonly associated with survey methods traditionally used. The use of camera-traps to study and monitor fox squirrel populations will allow us to better understand population dynamics and how management can be used to improve the conservation of fox squirrels in the southeastern United States.

Supplemental Material

Please note: The Journal of Fish and Wildlife Management is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Table S1. Description file (.xls) of field headings in Table S2.
Found at: http://dx.doi.org/10.3996/082015-JFWM-080.S1 (8 KB PDF).

Table S2. Data file (.xls) used to identify an effective and reliable survey method to detect southeastern fox squirrels Sciurus niger spp. and to assess the influence of seasonality. Surveys were conducted at Camp Blanding Wildlife Management Area in Starke, Florida, and the Ordway–Swisher Biological Station in Melrose, Florida, from 2011–2012.


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References


