National Park Service
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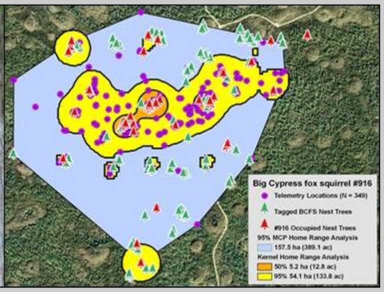
Big Cypress
National Preserve

Big Cypress Fox Squirrel Home Range and Habitat Use in Cypress Dome Swamp and Pine Forest Mosaic Habitats



Final Report

ON THE COVER (counterclockwise from top image): (1) Adult radio-collared black phase Big Cypress fox squirrel (BCFS); (2) Biologists John Kellam and Deborah Jansen releasing an adult radio-collared orange phase BCFS; (3) Adult radio-collared orange phase BCFS; (4) BCFS bromeliad (*T. fasciculata* Sw.) nest enhanced with fresh stripped cypress bark; and (5) Adult male BCFS telemetry/nest tree locations and minimum convex polygon/kernel home range estimates. Cover photos © Ralph Arwood. Cover home range image © John Kellam BICY RM 2013.

Big Cypress Fox Squirrel Home Range and Habitat Use in Cypress Dome Swamp and Pine Forest Mosaic Habitats

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Final Report

Resource Management
Big Cypress National Preserve
Ochopee, Florida

National Park Service
U.S. Department of the Interior

This report received peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Further, data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Cover; Fig. 2A, C; Fig. 3A, B; Fig. 4A, B; and Fig. 5A, B, C. photos © Ralph Arwood. Figure 2B photo © Dennis Giardina. Cover home range image and all in-text figures © John Kellam BICY RM 2013.

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A note on the revisions:
This report, as originally published, contained errors (i.e., punctuation, grammar, formatting, and citation) that have been corrected in this revision. In addition, the discussion on diet (p. 20) was expanded to clarify the timing of peak *Tillandsia fasciculata* Sw. flowering.

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FOREWORD

Until recently, knowledge of Sciurus niger avicennia (Big Cypress fox squirrel; BCFS) ecology was based on studies conducted on urban BCFS populations, urban radio-collared BCFS translocated to natural habitats, or on studies of other Sciurus niger (Eastern fox squirrel) subspecies. From May 2007–April 2011, Big Cypress National Preserve (BICY) biologists and project staff used radio-telemetry to examine home range and habitat use of 10 male and 10 female BCFS in BICY. The BICY BCFS study has yielded new information on BCFS ecology, new effective survey and trapping techniques, and represents the first successful home range and habitat use study of BCFS in natural habitats.

This report, "Big Cypress Fox Squirrel Home Range and Habitat Use in Cypress Dome Swamp and Pine Forest Mosaic Habitats," provides a summary of the core findings and techniques of the BICY BCFS study in a format that benefits agency, interagency, and public BCFS stake-holders.

The authors hope that the information and techniques presented herein will encourage and facilitate research efforts and management practices that are necessary for the conservation of the BCFS.

John Kellam
Resource Management
Big Cypress National Preserve

July 2013

INTRODUCTION

Sciurus niger avicennia Howell (Big Cypress fox squirrel) is a subspecies of *Sciurus niger* L. (Eastern fox squirrel) that occurs in southwest Florida and is disjunct from other subspecies (Eisenberg et al. 2011, Howell 1919, Moore 1956, Turner and Laerm 1993, Williams and Humphrey 1979). Howell (1919) described *S. n. avicennia* from a type specimen collected within a coastal *Avicennia germinans* L. (Black mangrove) dominant swamp habitat to which he believed the subspecies was restricted. Subsequent taxonomy and distribution studies redefined the range of the Big Cypress fox squirrel (BCFS) to include the coastal and interior forested habitats found south of the Caloosahatchee River and west of the Everglades region of Florida (Eisenberg et al. 2011, Moore 1956, Williams and Humphrey 1979) (Fig. 1).

Big Cypress fox squirrels inhabit *Pinus elliottii* var. *densa* Little and Dorman (South Florida slash pine) forests, *Taxodium distichum* var. *imbricarium* (Nuttall) Croom (Pondcypress) and *Taxodium distichum* (L.) Rich. var. *distichum* (Baldcypress) swamp forests, *Quercus virginiana* Mill (Live oak) woods, tropical hardwood forests, coastal broadleaf evergreen hammocks, mangrove swamps, agricultural fields, and urban habitats including golf courses, city parks, and residential areas (Ditgen et al. 2007, Duever et al. 1986, Eisenberg et al. 2011, Howell 1919, Jodice and Humphrey 1992, Moore 1956, Williams and Humphrey 1979). Moore (1956) and subsequent studies have concluded that interior pine and cypress forested habitats within the Big Cypress watershed are primary BCFS natural habitats (Ditgen et al. 2007, Duever et al. 1986, Eisenberg et al. 2011, Humphrey and Jodice 1992, Jodice and Humphrey 1992, Williams and Humphrey 1979).

The BCFS was once a game species in Florida (Duever et al. 1986, FWC 1958). However, from the mid-1950s through the 1970s, populations declined noticeably throughout their range, which led the Florida Fish and Wildlife Conservation Commission (FWC) to ban BCFS hunting in 1972, declare the subspecies Endangered in 1973, then reclassify it as Threatened in 1979 (Duever et al. 1986, USFWS 2002, Williams and Humphrey 1979). Historic and present declines in BCFS populations have been attributed to habitat fragmentation and loss, habitat modification – including exclusion of fire and changes in hydrological conditions, hunting, poaching, wildlife diseases, predation, road mortality, and hurricanes (Brown 1978, Ditgen et al. 2007, Duever et al. 1986, Eisenberg et al. 2011, Humphrey and Jodice 1992, Kellam 2010, Moore 1956, USFWS 2002, Williams and Humphrey 1979).

Due to the scarcity of BCFS in natural habitats and known difficulties in capturing the species (Eisenberg-Munim et al. 2007, Jodice 1990, Weigl et al. 1989), past studies designed to elucidate BCFS ecology were either conducted on urban BCFS populations found on golf courses (Ditgen et al. 2007, Jodice and Humphrey 1992), or on urban BCFS that were radio-collared and translocated to Big Cypress National Preserve (BICY) (Dusek et al. 1998, Jodice 1993). Translocated BCFS exhibited dispersal behavior (≤ 32 km movements; Jodice 1993) and habituation to humans (Dusek et al. 1998). A lack of information on BCFS demographic parameters and trends in natural habitats and a growing list of threats to the species led to a petition in 1998 being filed with the U.S. Fish and Wildlife Service (USFWS) to list the BCFS as a federally protected species and designate critical habitat (USFWS 2002). The USFWS denied the federal listing petition in 2002, in part due to a lack of data on BCFS ecology and the large area of potential BCFS habitat found on state and federal conservation lands (Ditgen et al. 2007, USFWS 2002).

In 2007, we initiated a study of BCFS within the Raccoon Point region of BICY (Fig. 1). Our study was designed as a descriptive natural history study with the goal of developing BCFS survey, capture, and radio-collaring techniques and if successful, provide new information on BCFS home range, movements, habitat use, nest use, and diet within natural habitats.

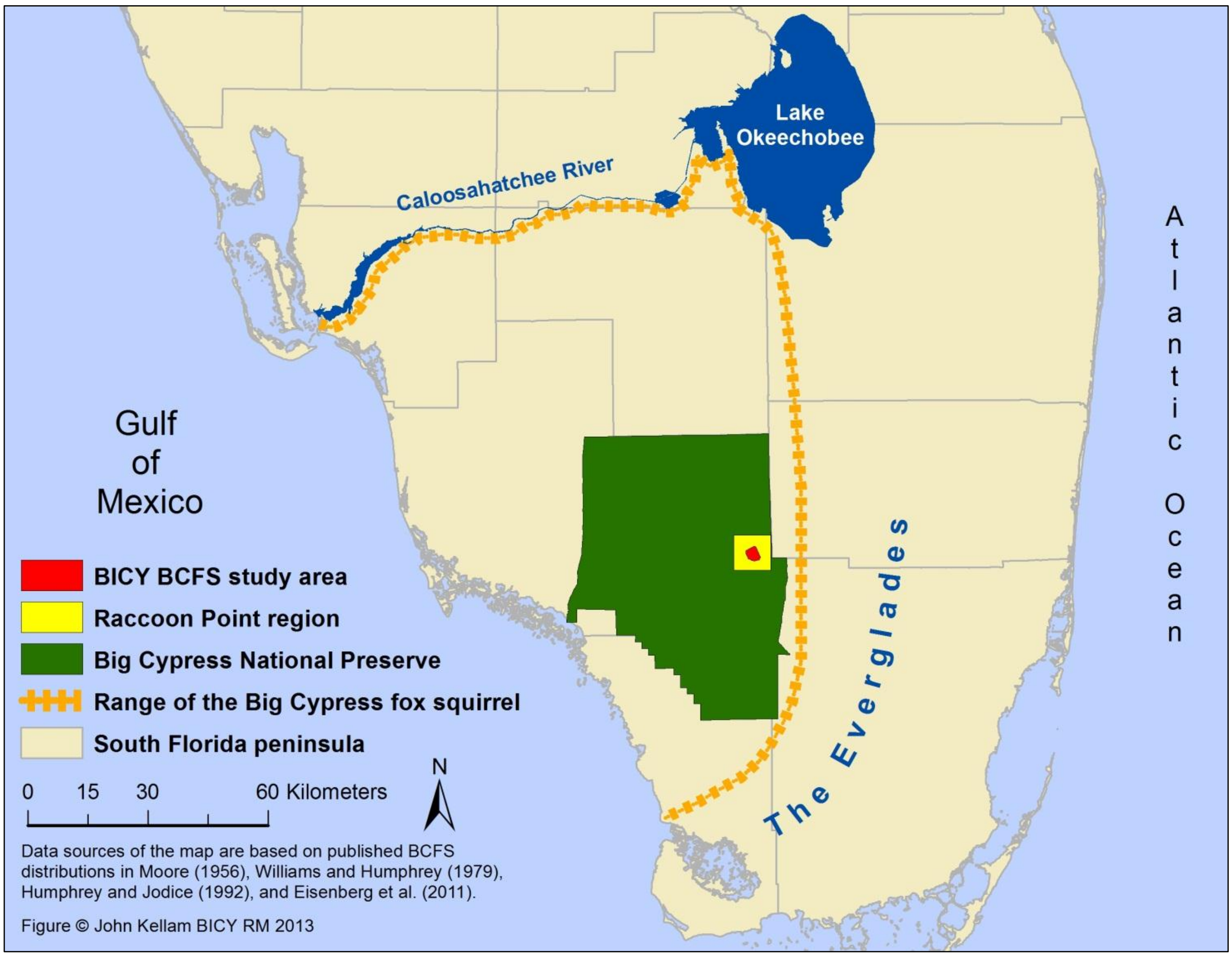

Figure 1. Map of the South Florida peninsula showing the location of the BICY BCFS study area within the Raccoon Point region of BICY and the range of the BCFS.

FIELD SITE DESCRIPTION

The decision to locate the study area in Raccoon Point (UTM 507148/2874313) was based on a review of BICY BCFS sighting records (late 1970s–2006) and an analysis of BICY habitat compositions, land management practices, and accessibility factors. Big Cypress National Preserve, covering 295,245 ha of Collier, Monroe and west Miami-Dade counties in southwest Florida, represents the core range of the BCFS (Humphrey and Jodice 1992, Williams and Humphrey 1979). Raccoon Point contains the largest remaining unlogged stands of South Florida slash pine (pine) (Patterson and Robertson 1981). The upland pine forest exists within a codominant mosaic of unlogged lower elevation Pondcypress (cypress) dome swamps that are in the headwaters of a largely intact surface rainfall driven hydrological system (Duever et al. 1986, Gunderson and Loope 1982, McPherson 1973). The U.S. Geological Survey (USGS), in cooperation with the National Park Service (NPS), initiated a long-term fire ecology study in Raccoon Point in 1996 that uses prescribed fire to treat individual burn units during 3 seasons (spring, summer, and winter) and at 2 intervals (every 3 years and every 6 years) (Snyder and Belles 2000). This frequent and varied fire regime has resulted in the old-growth pine forests having open canopy and low understory habitat characteristics that BCFS prefer (Ditgen et al. 2007, Duever et al. 1986, Eisenberg et al. 2011, Jodice and Humphrey 1992, Koprowski 1994a, Williams and Humphrey 1979).

In 2007, a 2500 ha BCFS survey and trapping focus area boundary was created by drawing a geographic information system (GIS) polygon rectangle around the pine forest and cypress dome swamp mosaic habitats within ≈ 2.5 km of the dirt road system in Raccoon Point. From April 2007–April 2011, all survey, trapping, radio-collaring, and monitoring efforts took place within the focus area. Upon completion of the study in April 2011, a formal GIS polygon study area boundary was created in order to analyze and describe the habitats within and immediately adjacent to individual BCFS home ranges. The formal study area boundary was delineated by first conducting a 100% minimum convex polygon (MCP; Mohr 1947) home range analysis of the total telemetry locations for the male and female study BCFS; the resulting 100% MCP area was then GIS buffered by 150 m, thereby creating the formal 923-ha study area boundary. From 1995–1999, the Center for Remote Mapping Science at the University of Georgia (UGA) used color-infrared aerial photography interpretation/analysis techniques to create vegetation classification maps of BICY, Everglades National Park, and Biscayne National Park (Madden et al. 1999, Welch et al. 1999). An analysis of the UGA vegetation map GIS layer and the study area GIS shapefile identified 14 available habitat types which were re-classified into 7 general habitat types to conform with existing standardized BICY habitat definitions. The area (ha) for each of the 7 habitat types found within the 923-ha study area and their corresponding Raccoon Point specific habitat descriptions based on Burch (2011), Duever et al. (1986), and Gunderson and Loope (1982), are listed here: (1) Cypress Dome (294.0 ha): a cypress dominant circular/hemispherical profiled swamp with shorter trees on the periphery and taller trees in the center, contains cypress density of ≈ 2,000 trees/ha and tree heights ≈ 4 m at the edges to ≈ 20 m in the center; epiphytic bromeliads, especially *Tillandsia fasciculata* Sw. (Stiff-leaved wild pine) and

Tillandsia balbisiana Schult. & Schult. f. (Northern needleleaf) are common; open canopy dome edges are ecotonal with Cypress Prairie plant communities containing *Rhynchospora microcarpa* Baldw. ex A. Gray (Southern beaksedge), *Schizachyrium rhizomatum* (Swallen) Gould (Florida little bluestem), *Muhlenbergia filipes* M.A. Curtis (Gulfhairawn muhly), and *Rhynchospora tracyi* Britton (Tracy's beaksedge); variable canopy cover dome interiors create a patchy plant community containing *Panicum hemitomon* Schult. (Maidencane) and *Eupatorium leptophyllum* DC. (False fennel); longer hydroperiod dome interiors contain *Cladium jamaicense* Crantz (Sawgrass); deep water dome centers with sparse or absent canopy cover support *Thalia geniculata* L. (Alligatorflag); (2) Cypress Prairie (127.0 ha): an open canopy dwarf cypress dominant forest with cypress density of ≈ 1,000 trees/ha and tree heights ≈ 2–7 m; sparse understory species include Sawgrass, Southern beaksedge, Florida little bluestem, Gulfhairawn muhly, and Tracy's beaksedge; (3) Pine Forest (394.9 ha): a pine dominant forest with pine density of 100–600 trees/ha and tree heights generally < 24 m; *Sabal palmetto* (Walter) Lodd. ex Schult. & Schult. f. (Cabbage palm) is the principal midstory species when subcanopy heights are attained; understory vegetation includes Cabbage palm, *Serenoa repens* (W. Bartram) Small (Saw palmetto), and *Myrica cerifera* L. (Wax myrtle); groundcover species include Florida little bluestem, Gulfhairawn muhly, and *Rhynchospora divergens* Chapm. ex M.A. Curtis (Spreading beaksedge); (4) Pine Forest with Cypress Associates (69.9 ha): a pine forest and cypress swamp ecotonal forest plant community in which pine and cypress trees are both resident with Cypress Prairie dominant understory vegetation; (5) Hardwood Hammock (12.3 ha): an upland closed canopy hardwood dominant habitat typically < 1 ha in size and with tree heights ≤ 20 m; codominant overstory species include Live oak, *Quercus laurifolia* Michx. (Laurel oak), and Cabbage palm; epiphytic bromeliads, especially Stiff-leaved wild pine and Northern needleleaf are common; midstory species include *Chrysobalanus icaco* L. (Cocoplum), *Myrsine cubana* A. DC. (Myrsine), *Ardisia escallonioides* Schltdl. & Cham. (Marlberry), and *Ilex cassine* L. (Dahoon); understory species include Saw palmetto, *Chiococca alba* (L.) Hitchc. (Snowberry), *Callicarpa americana* L. (American beautyberry), and *Psychotria nervosa* Sw. (Wild coffee); sparse groundcover species include *Andropogon virginicus* L. (Broomsedge bluestem); (6) Marsh (7.3 ha): this category contains graminoid marsh species including Gulfhairawn muhly, Maidencane, Southern beaksedge, and Sawgrass; non-graminoid emergent marsh species include *Pontederia cordata* L. (Pickerelweed), *Typha domingensis* Pers. (Southern cattail), and *Sagittaria* spp. (Duck potato); and (7) Disturbed (17.6 ha): areas that have undergone an alteration that has caused a change in plant community succession are termed Disturbed; soil disturbance (i.e., dirt road and oil exploration pad development/use) is the singular type in this category.

Big Cypress National Preserve has a tropical savannah climate characterized by spring droughts, heavy summer rains, and mild, dry winters (Hela 1952), with an annual average rainfall of 1,360 mm (Deuver et al. 1986). The BICY wet season is defined as May 1–October 31 and the dry season November 1–April 30. The mean annual temperature for BICY is 23 °C, with a mean low of 14 °C in January and a mean high of 28 °C in August (Deuver et al. 1986).

METHODS

In 2005, a BCFS feasibility study was initiated in BICY using random sample trapping grid techniques. Although 1 BCFS was captured and radio-collared (a first for the subspecies in natural habitats), the radio-collar fell off within 8 days of capture and subsequent trapping efforts failed (I. Lundgren, NPS Biologist, pers. comm.). Due to the poor results of randomly selecting BCFS trapping sites, in 2007 we began a BCFS home range and habitat use study by initiating surveys that identified trapping sites by locating physical sign of BCFS occupancy within habitats.

Occupancy surveys

Study surveyors conducted ground searches for 3 primary BCFS habitat use indicators within cypress dome swamp-pine forest mosaic habitats: (1) Presence of BCFS nest structures (Fig. 2B, C); (2) Presence of stripped cypress bark on the trunk and limbs of cypress trees (Fig. 2A); and (3) Presence of partially consumed BCFS food items (e.g., pine and cypress seed cones).

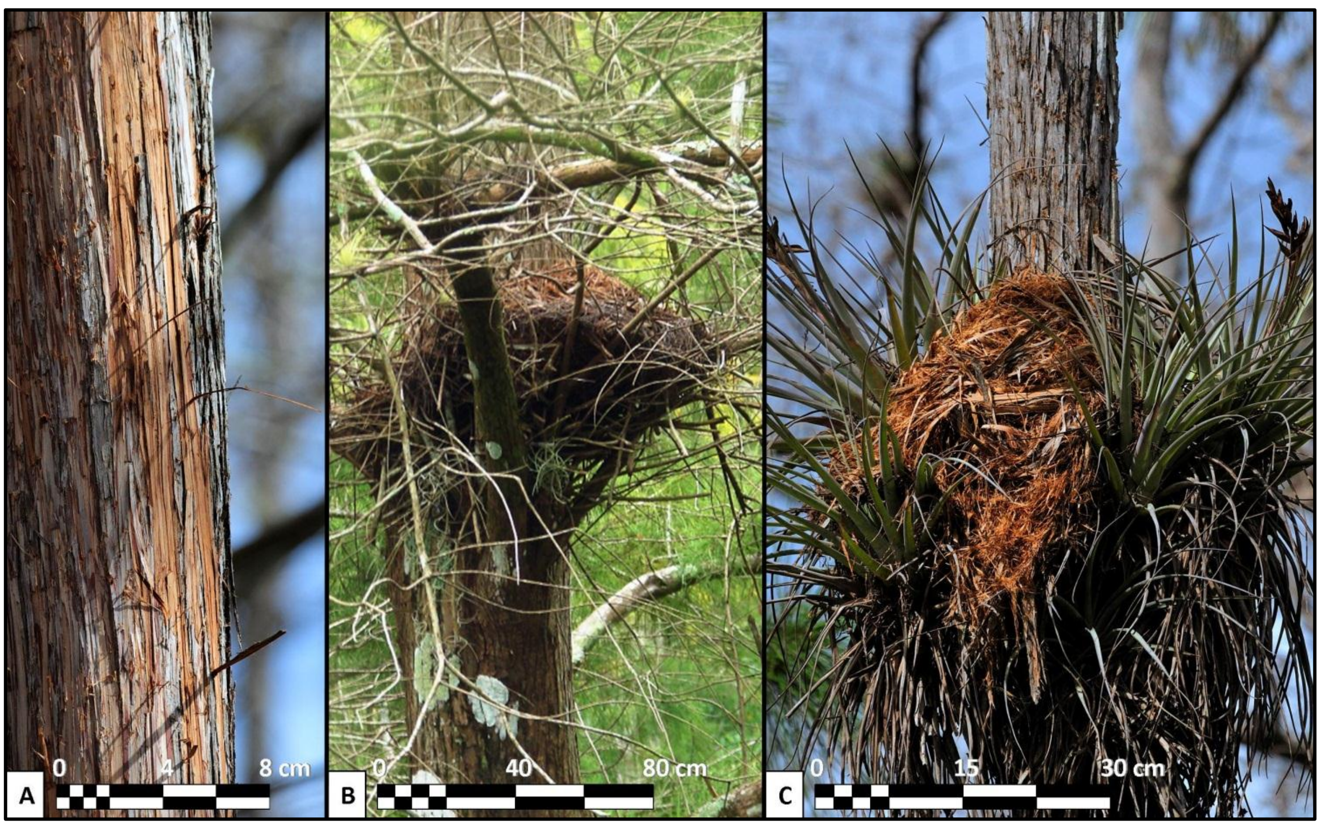

Figure 2. A. Cypress bark freshly stripped by BCFS; B. BCFS cypress stick platform nest enhanced with fresh stripped cypress bark; C. BCFS bromeliad (*T. fasciculata* Sw.) nest enhanced with fresh stripped cypress bark. Fig. 2A, C. photos © Ralph Arwood. Fig. 2B photo © Dennis Giardina.

The best indicator of current BCFS occupancy (confirmed by trapping results) is the presence of fresh stripped cypress bark (as determined by color) incorporated into BCFS nest structures and adjacent sign of fresh partially consumed BCFS food items. The BICY BCFS study photo documented the general oxidation rate of fresh stripped cypress bark, which is typically a bright orange/red color when fresh (Fig. 3A) and a dull reddish brown/grey color when exposed to the elements > 1 month (Fig. 3B).

Figure 3. A. BCFS bromeliad (*T. fasciculata* Sw.) nest enhanced with fresh stripped cypress bark that was photographed on 23 January 2008; B. Fig. 3A nest re-photographed on 26 February 2008. Fig. 3A, B. photos © Ralph Arwood.

An important BCFS food item sign of fresh use within cypress domes during the wet season is the concentrated presence of resinous oil droplets (typically .25–3 cm in diameter) and cypress cone scale/resin-coated seed particles floating directly above and adjacent to submerged partially-eaten fresh cypress seed cones. Optimal trapping sites contained multiple fresh stripped cypress bark incorporated BCFS nests, with adjacent fresh stripped cypress bark trees, and an abundance of fresh partially consumed BCFS food items.

Live trapping

Once suitable trapping sites were identified, 61 cm x 18 cm x 18 cm box traps constructed of 1.3 cm x 2.5 cm wire mesh (model No. 605; Tomahawk Live Trap Co., Tomahawk, Wisconsin, USA) were baited behind the trip plate with a dried halved corncob and peanut butter, in conjunction with loose dried corn and peanut butter on the trip plate and near the trap entrance. Peanut butter was also applied to tree trunks and vegetation directly above and adjacent to each trap to provide additional scent. Baited traps were either placed on the ground in shaded conditions (Fig. 4B) or on 200 cm x 90 cm freestanding wood trapping platforms constructed over water (≈ 95 cm above ground level) and adjoined to the base of fresh stripped cypress bark incorporated BCFS nest trees (Fig. 4A). Note: wood hollow core doors proved to be lighter and easier to attach wood legs to than cut plywood of suitable dimension. The top surface of each trapping platform was covered with a layer of cypress needle duff (≈ 2.5 cm thick) upon which a baited trap was secured with bungee/shock cords and screw-eye hooks (Fig. 4A). Cabbage palm fronds were affixed over traps with the frond leaf tips oriented to nearly cover the armed trap door entrance, to provide shade and assist in deterring *Corvus brachyrhynchos* Brehm. (American crow) and *Corvus ossifragus* Wilson. (Fish crow) bait consumption and bycatch (Fig. 4A, B). During the wet season when trapping sites contained multiple BCFS nests separated by wide tree/canopy spacing, fallen cypress limbs (≈ 5 m in length) were lashed horizontally to tree trunks (≈ 95 cm above ground level) to provide a continuous pathway (above water) from nest trees to trapping platforms; these lashed cypress limbs were also lightly scented with peanut butter and baited with loose dried corn.

Figure 4. A. Freestanding wood trapping platform constructed over water and adjoined to the base of a fresh stripped cypress bark incorporated BCFS nest tree; B. Ground-based trap. Fig. 4A, B. photos © Ralph Arwood.

The 3 most effective trap placement strategies developed by the study are: (1) Set 1–2 ground-based traps adjacent to each priority nest tree during the dry season or 1 platform-based trap adjoined to each priority nest tree during the wet season, and then set ≈ 10 traps in the adjacent pine forest edges where fresh (or recent) partially consumed BCFS food items (typically pine seed cones) have been located; (2) Set a series of traps 10–20 m apart along the entire pine forest edge boundary surrounding a discrete cypress dome containing priority nest trees; and (3) Set traps within the pine forest edge that is perpendicular to the most probable BCFS travel route between the pine forest edge and the BCFS nest locations within a cypress dome (as determined by tree spacing and canopy characteristics).

Traps were wired open and pre-baited 3–7 days prior to arming. Trapping sessions were 2–5 days in length. Traps were armed at dawn and checked every 2 hours until dusk or as trapping success dictated. At the end of each trapping day, the traps were closed and wired shut.

Handling

Captured BCFS were transferred from wire box traps to a cloth handling cone bag (Koprowski 2002) to assess sex and age class, reproductive condition, body mass, and assist with PIT-tag (Trovan ID100 passive-integrated transponder; 2.6 mm x 0.15 mm x 40 mm; < 0.1 g; Trovan, Ltd., Douglas, UK) insertion and the collection of hair follicle samples. A cloth hood was used in conjunction with the handling bag to aid in further reducing animal stress during radio-collaring efforts (J.L. Koprowski, University of Arizona, pers. comm.). Adult and subadult BCFS ≥ 490 g were fitted with Holohil RI-2D VHF radio-transmitter collars (Holohil Systems Ltd., Carp, Ontario, Canada), that were ≤ 2.4% of body mass. Collars were made of multi-strand wire contained within plastic Tygon tubing (Saint-Gobain, Valley Forge, PA, USA) and attached with a brass crimp. Study BCFS were trapped and handled following American Society of Mammalogists (ASM) guidelines (Sikes et al. 2011) and in accordance with a State of Florida FWC special purpose permit (Permit No. WX05260).

Monitoring

Radio-collared BCFS were located once per day and approximately 3 days/week. To reduce data collection bias, monitoring efforts were rotated within 4 primary 3-hour time periods (0700–1000, 1001–1300, 1301–1600, and 1601–1900). Digital R-1000 Telemetry Receivers (Communications Specialists, Inc., Orange, CA, USA) in conjunction with RA-2AK VHF directional "H" antenna (Telonics, Inc., Mesa, AZ, USA) were used to locate study BCFS using radio-tracking homing techniques (White and Garrott 1990). Consumer-grade Garmin GPSmap 76Cx (or type) GPS units (Garmin International, Inc., Olathe, KS, USA) were used to record project location data. The GPSmap 76Cx Owner's Manual (Garmin 2005) specified a positional accuracy of < 10 m (95% of the time). Wing (2008) reported the positional accuracy (mean ± 1 SD) of 60 waypoints recorded with a GPSmap 76Cx on 2 days and in 3 condition settings: (1) Unobstructed Open Sky: ≤ 4.6 ± 3.5 m; (2) Young Forest: ≤ 3.5 ± 2.5 m; and (3) Closed Canopy Forest: ≤ 12.3 ± 8.5 m, for a 3 condition setting combined error of 6.1 ± 6.0 m.

The following primary information was recorded at each BCFS telemetry location during monitoring efforts: BCFS identification #, date, time, weather, hydrologic conditions, BCFS location/tree species/DBH, habitat type, nest tree location/species/DBH/nest substrate type, observation/evidence of BCFS food item use, stripped cypress bark presence/quantity, predator presence, predator-BCFS interactions, and BCFS behavioral observations.

Field observations of BCFS consuming food items were documented with photographs, the collection of physical evidence, and the recording of detailed field notes. Indirect evidence of fresh BCFS food item use (e.g., fresh partially consumed pine and cypress seed cones) in the immediate vicinity (≤ ≈ 10 m) of a BCFS or BCFS occupied tree was also documented and recorded on field data sheets. Of the 12 BCFS food item species recorded by the study, 10 species were verified by direct observation of BCFS consumption, and 2 species, *Cirsium horridulum* Michx. (Purple thistle) and *Romalea guttata* Houttuyn (Eastern lubber grasshopper) were verified by the careful analysis of collected physical evidence in conjunction with associated BCFS observations (i.e., "The BCFS was in the tree directly above the partially consumed E. Lubber grasshopper that we heard drop to the ground as the squirrel climbed up the trunk"). Confirmation of BCFS bromeliad floral bud use was primarily by direct observation only, due to the rarity of finding adequate evidence that a BCFS consumed the plant material. Confirmation of BCFS bromeliad stem use was by direct observation and the common indirect evidence of finding individual bromeliad leaf stems on the ground that showed clear sign of the leaf bases having been sheared off and the meristematic tissue consumed by BCFS (especially Mar–May). Observations of predators in the vicinity (≤ ≈ 25 m) of, or interacting with, radio-collared BCFS were recorded on field data sheets.

Individual BCFS nest trees were marked ≈ 170 cm above the ground with a 3.2 cm aluminum identification tag and brightly colored 2.9 cm flagging tape. When a potential BCFS stick platform nest could not be confirmed from the ground, a trained tree climber was used for BCFS nest confirmation. Potential BCFS tree cavity nests (determined by the presence of stripped bark near tree cavity openings or evidence of radio-collared BCFS use) were examined with a TreeTop Peeper elevated video inspection system (Sandpiper Technologies Inc., Manteca, CA, USA).

Analysis

We used ArcView 3.3 (ESRI, Redlands, CA, USA) and Animal Movement Analyst Extension (AMAE; Hooge and Eichenlaub 2000) software to calculate minimum convex polygon (MCP; Mohr 1947) and fixed kernel density estimator (KDE; Seaman and Powell 1996, Worton 1989) home range areas. Being that our BCFS home range data is the first for the subspecies in natural habitats, we report both home range estimator data in order to facilitate intraspecific comparisons. The 95% MCP estimates were calculated using a 5% harmonic mean outlier removal setting; the 95% KDE (termed 'range') and 50 % KDE (termed 'core') estimates were calculated using least squares cross validation (LSCV) to minimize smoothing (Seaman and Powell 1996, Worton 1989). Only individuals with ≥ 46 telemetry locations were used for 95% MCP and KDE analysis. We used ArcGIS 9.3, ArcGIS Spatial Analyst (ESRI, Redlands, CA, USA), XTools Pro (Data East, LLC, Moscow, Russia), and MS Excel (Microsoft, Redmond, WA, USA) software to analyze spatial data, generate summary statistics, and create tables/figures.

RESULTS

Trapping effort/success

From April 2007–April 2011, we captured 24 individuals (28 total captures) during 9 trapping sessions. Of the total BCFS captures (n = 28), 13 occurred during wet season trapping sessions (May; n = 13) and 15 occurred during dry season trapping sessions (Dec; n = 3, Jan; n = 3, Mar; n = 6, and Apr; n = 3). Traps were in the field for 1823 trap days and set for 704 trap days. The total individual BCFS captured (n = 24) catch per unit effort (CPUE) for 704 trap days was 3.4 captures/100 trap days of effort. Of the 28 BCFS captures, 10 males/10 females were radio-collared, 1 radio-collared BCFS was inadvertently recaptured 2 times, 2 radio-collared BCFS were recaptured to remove collars at the end of the study period, 2 adult males were handled then released without radio-collaring, 1 subadult BCFS (gender unknown) was not handled and released (estimated < 490 g body mass/stress mitigation), and 1 adult BCFS died during handling (< 5 minute handling time; probable stress induced cardiac arrest).

Body mass

The following are the body mass data (mean ± 1 SD) for the 23 individual BCFS whose mass was measured during handling efforts: male/female total (n = 23) was 694.7 ± 92.8 g; male total (n = 12) was 676.3 ± 104.2 g; female total (n = 11) was 714.8 ± 78.4 g; adult male (n = 10) was 713.0 ± 65.4 g; adult female (n = 10) was 733.6 ± 50.3 g; subadult male (n = 2) was 492.5 ± 3.5 g; and subadult female (n = 1) was 527.0 g.

Pelage color phase

Three distinct pelage color phases were observed in captured individual BCFS (n = 24): (1) Orange (n = 17; 7 males/9 females/1 unk. gender): orange dominant dorsal fur; black dominant head fur with white nose, lip, and ear tip fur; orange dominant ventral fur; white or orange toe fur; orange/black tail fur (Fig. 5A); (2) Black (n = 6; 4 males/2 females): black dorsal fur; black head fur with white nose, lip, and ear tip fur; black ventral fur, or black ventral fur with white or orange belly fur; white or black toe fur; black tail fur, or either black/white or black/orange tail fur (Fig. 5B); and (3) Tan (n = 1; 1 male): tan dominant dorsal fur; black dominant head fur with white nose, lip, and ear tip fur; tan dominant ventral fur; white or tan toe fur; tan/black tail fur (Fig. 5C).

Monitoring

Of the total BCFS telemetry locations (n = 2061) recorded during the study period (13 May 2007–20 Apr 2011), 51.2% (n = 1056) were of males (n = 10) and 48.8% (n = 1005) were of females (n = 10). Mean number of telemetry locations was 105.6 ± 105.3 locations for males and 100.5 ± 55.4 locations for females. Mean number of radio-collared days (minus collaring/collar failure/mortality dates) was 344.6 ± 356.4 days for males and 322.7 ± 180.2 days for females. Radio-collared BCFS were located once per day and averaged 2.2 monitoring efforts/week. Project staff/work schedule constraints, wildfires, thunderstorm activity, tropical storms, and other unplanned events would at times preclude our ability to conduct monitoring 3 times/week. Monitoring efforts (n = 2061) were recorded within 4 primary time periods: 0700–1000 (n = 565), 1001–1300 (n = 953), 1301–1600 (n = 380), 1601–1900 (n = 125), and within 2 incidental time periods: 0612–0659 (n = 22) and 1901–2000 (n = 16). Of the total telemetry locations (n = 2061), BCFS were observed in 41.8% (n = 862), concealed in a nest in 33.8% (n = 697), and 24.4 % (n = 502) were telemetry fixes only.

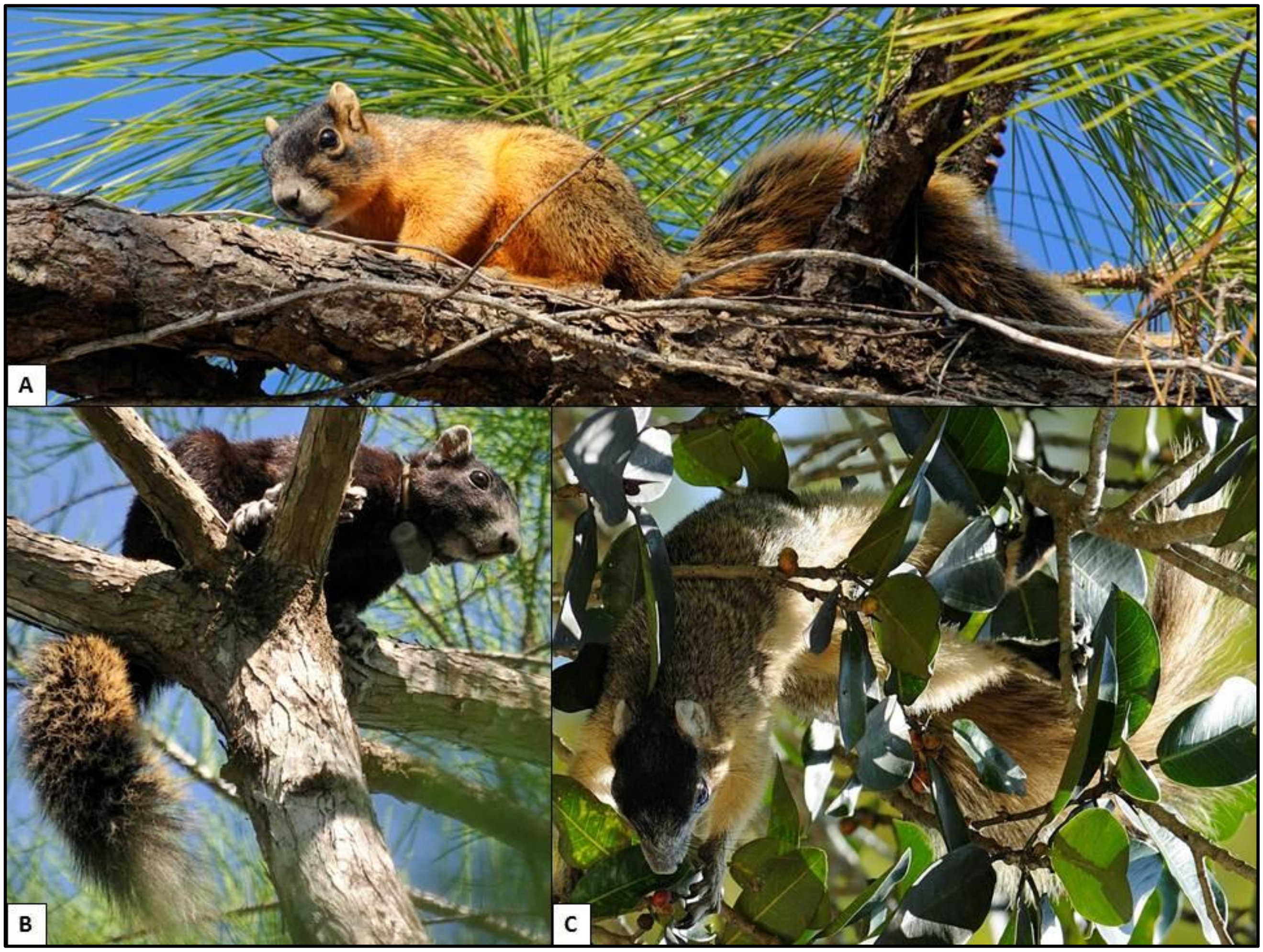

Figure 5. A. Adult orange phase BCFS; B. Adult radio-collared black phase BCFS; C. Adult tan phase BCFS. Fig. 5A, B, C. Photos © Ralph Arwood.

Home range

The 4 home range estimators used to analyze telemetry data (100% MCP, 95% MCP, 95% KDE, and 50% KDE) show a consistent trend of males having larger year-round home range areas than females (Table 1). Mean range (95% KDE) estimates for males (n = 7) were 726.9% larger in area than mean range estimates for females (n = 10). Mean core (50% KDE) estimates for males were 684.6 % larger in area than mean core estimates for females (Table 1).

Table 1. Comparison of mean (± 1 SD) 100% MCP, 95% MCP, 95% KDE, and 50% KDE home range estimates (ha), of male and female BCFS in the BICY BCFS study area, May 2007–April 2011.

		Telemetry points				Telemetry points		
Sex	n	Range	Mean	100% MCP	n	Range	Mean	95% KDE
Male	10	16-351	105.6	88.2 ± 67.2 ha	7	46-351	142.7	75.6 ± 63.0 ha
Female	10	52-221	100.5	23.7 ± 8.4 ha	10	52-221	100.5	10.4 ± 6.2 ha
				95% MCP				50% KDE
Male	7	46-351	142.7	91.3 ± 51.9 ha	7	46-351	142.7	8.9 ± 10.5 ha
Female	10	52-221	100.5	16.4 ± 5.7 ha	10	52-221	100.5	1.3 ± 1.1 ha

Home range overlap

Total male-male (n = 7) lifetime range overlap was 57.0%; total female-female (n = 10) lifetime range overlap was 7.8%. Total male-male lifetime core overlap was 5.9%; total female-female lifetime core overlap was 0.0%. Total male-female (n = 17) lifetime range overlap was 66.0%; male-female lifetime core overlap was 1.4%.

Distance moved

Maximum distance between 2 locations within a 100% MCP home range was 2320.1 m for males and 991.4 m for females. Maximum distance BCFS moved ≤ 24 hours was 1180.1 m for males and 555.7 m for females. Mean distance BCFS moved ≤ 24 hours (n = 428) was 237.8 ± 221.5 m for males (n = 219) and 138.7 ± 128.2 m for females (n = 209). Mean distance BCFS moved ≤ 24 hours during the wet season (May 1–Oct 31; n = 199) was 262.8 ± 220.5 m for males (n = 103) and 131.3 ± 122.8 m for females (n = 96). Mean distance BCFS moved ≤ 24 hours during the dry season (Nov 1–Apr 30; n = 229) was 215.6 ± 220.9 m for males (n = 116) and 145.0 ± 132.8 m for females (n = 113).

Habitat use

Big Cypress fox squirrel daytime habitat use was primarily related to the availability and location of seasonal food items within the study area's cypress dome swamp and pine forest habitats (Figs. 6, 7). Although cypress domes and pine forests represented 31.9% and 42.8% of the available habitat within the study area, respectively, cypress domes and pine forests represented 79.8% and 13.6% of the total habitats BCFS were recorded within during monitoring efforts, respectively (Fig. 8). The range and core habitat use of male (n = 7) and female (n = 10) BCFS also indicates the dominant use of cypress domes and pines forests on a year-round basis (Fig. 9).

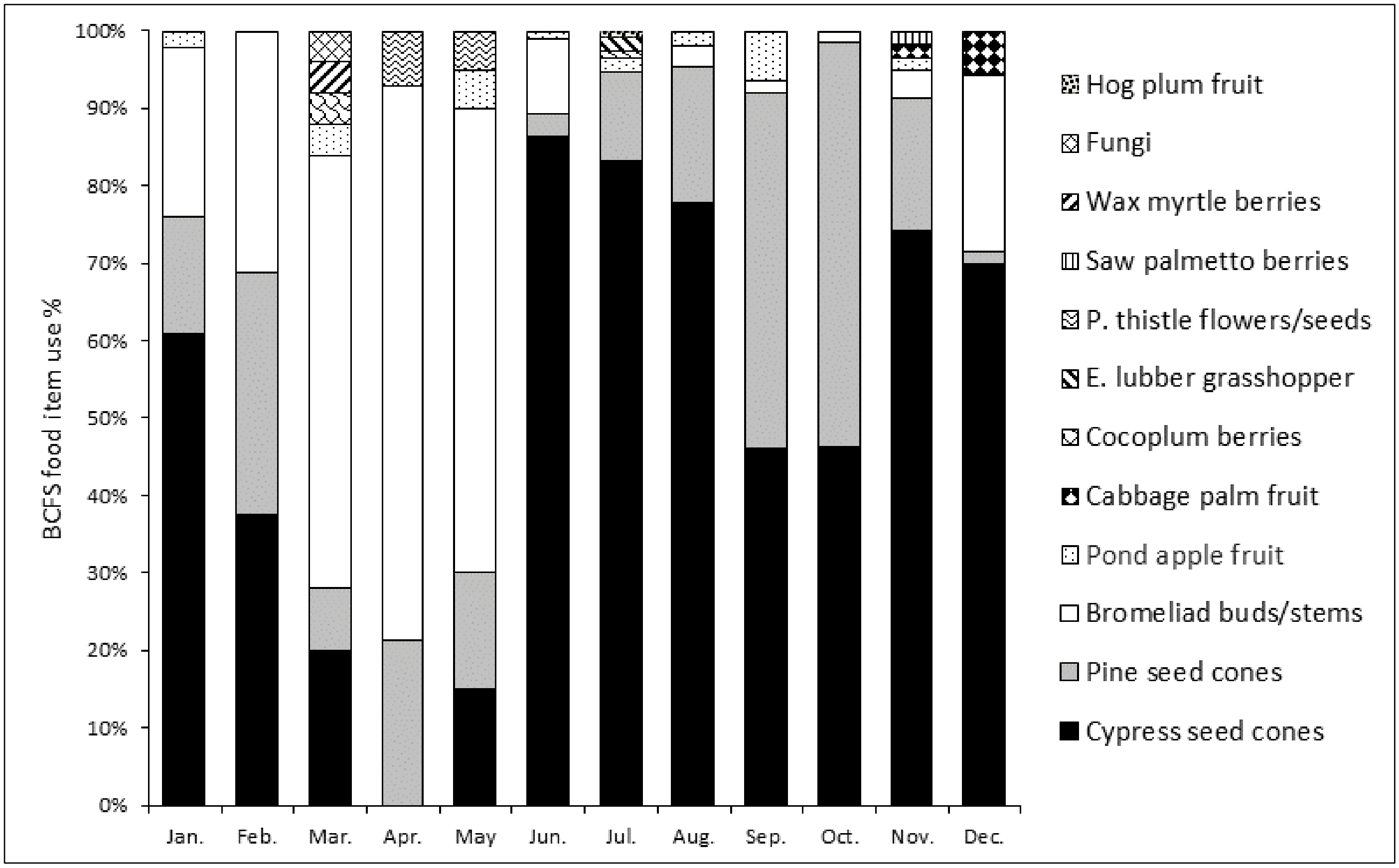

Figure 6. Total male (n = 10) and female (n = 10) BCFS food item use (n = 702) percentage per month in the BICY BCFS study area, May 2007–April 2011.

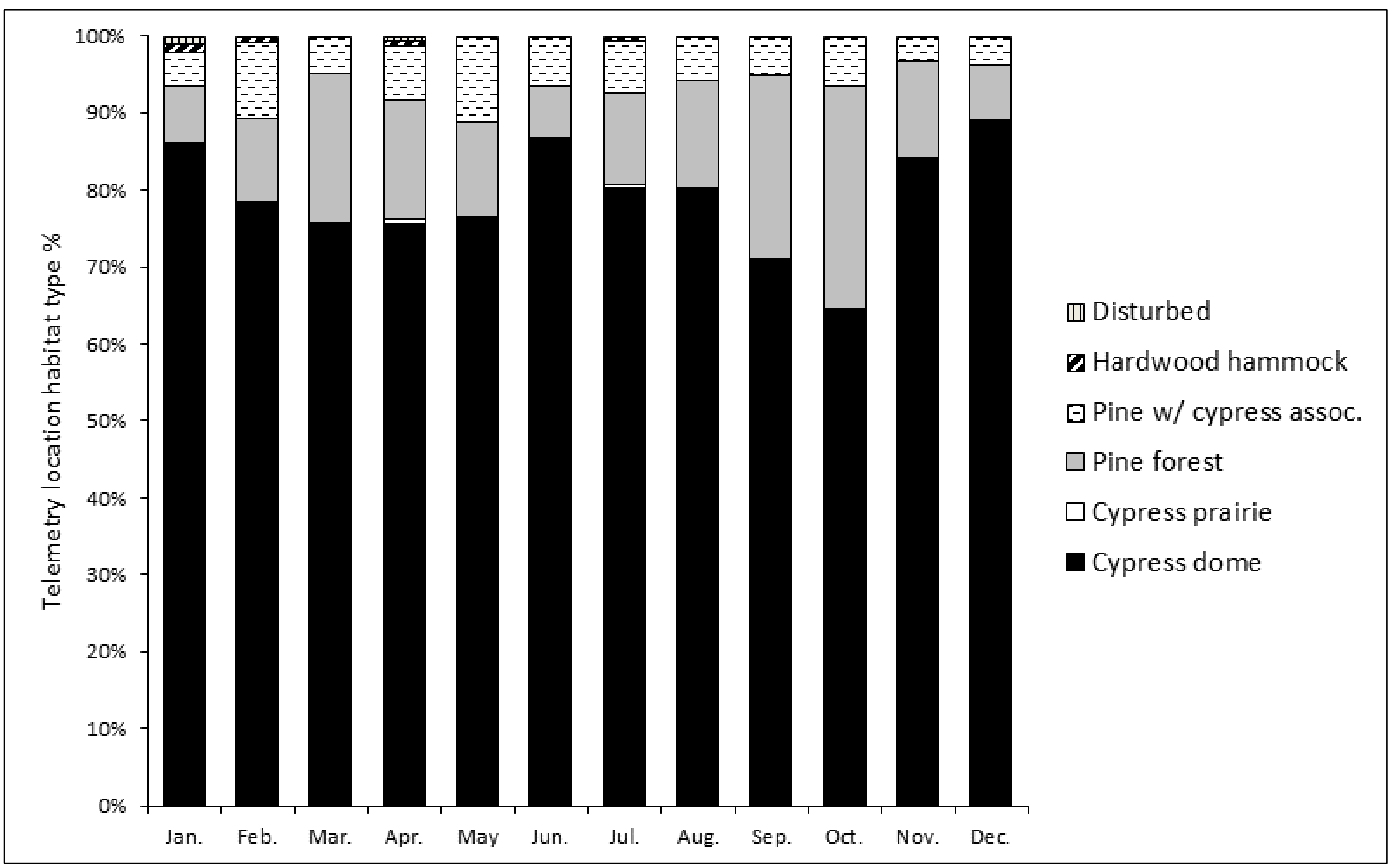

Figure 7. Total male (n = 10) and female (n = 10) BCFS telemetry location (n = 2061) habitat type percentage per month in the BICY BCFS study area, May 2007–April 2011.

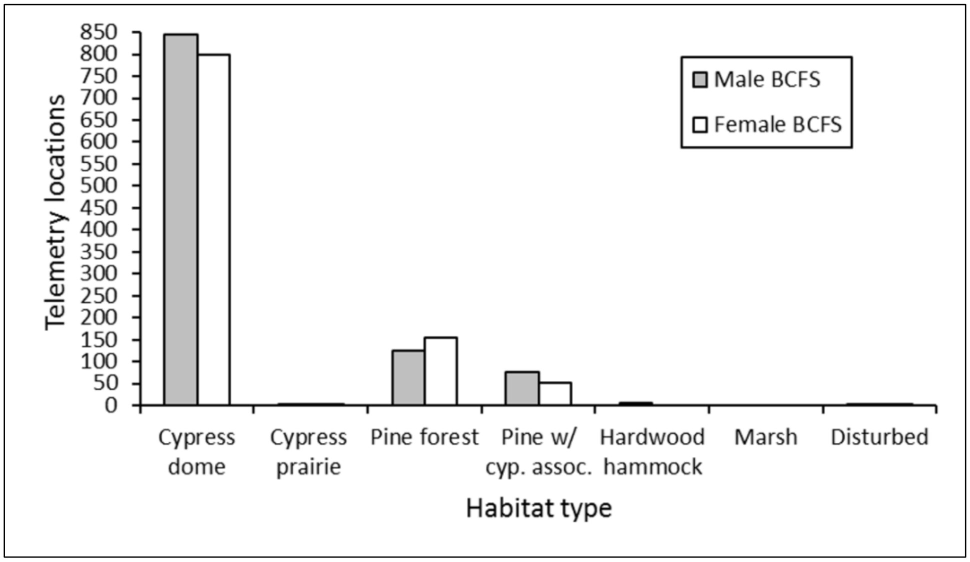

Figure 8. Total number of male (n = 10) and female (n = 10) BCFS telemetry locations (n = 2061) recorded for each habitat type within the BICY BCFS study area, May 2007–April 2011.

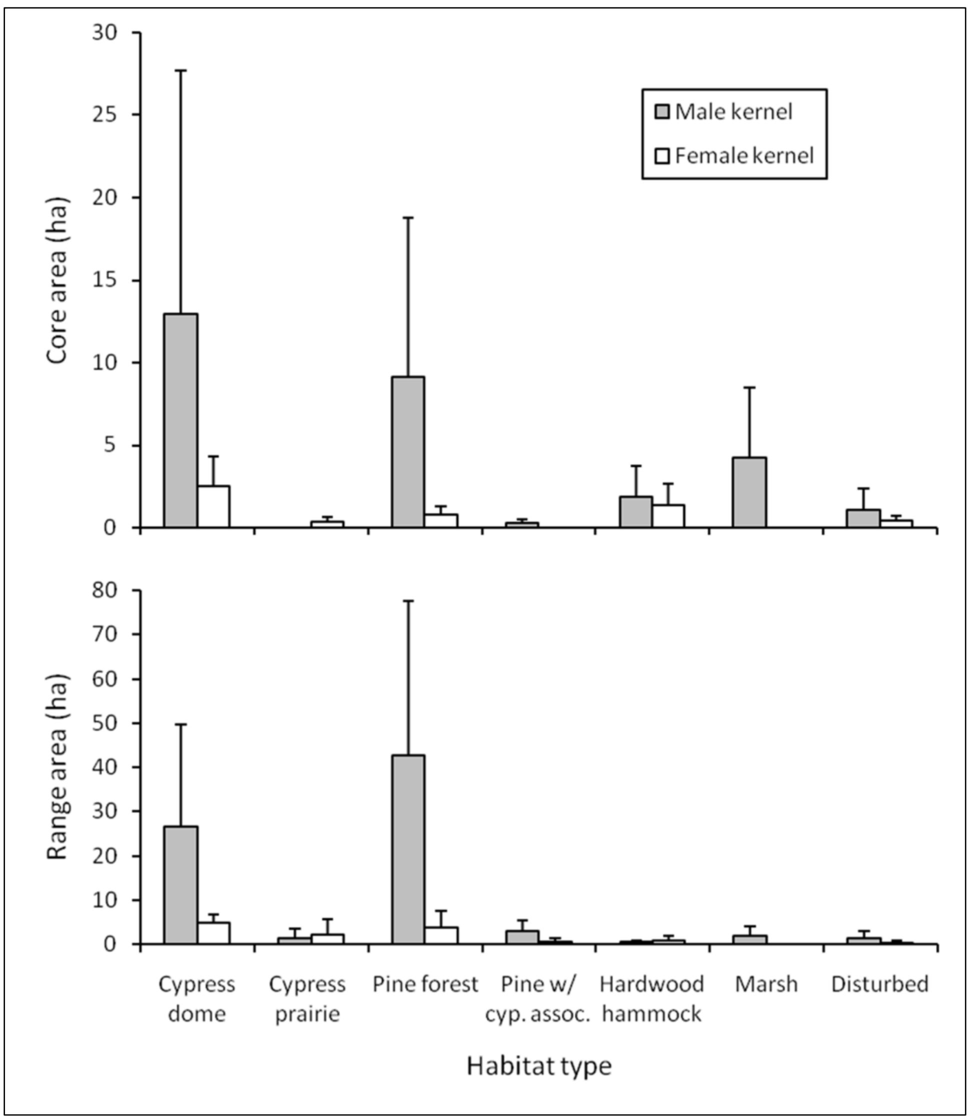

Figure 9. Difference in the mean (± 1 SD) core (50% KDE) and home range (95% KDE) habitat composition and area of male (n = 7) and female (n = 10) BCFS in the BICY BCFS study area, May 2007–April 2011.

Nest use

Within the study area, 403 BCFS nests were documented – comprised of 6 nest types: (1) Stick platform with stripped cypress bark (n = 215); (2) Bromeliad (*T. fasciculata* Sw.) with stripped cypress bark (n = 180); (3) Cabbage palm with stripped cypress bark and palm frond fibers (n = 4); (4) Cypress tree defect (splintered trunk) with stripped cypress bark (n = 2); (5) Bromeliad (*T. fasciculata* Sw.) with *Tillandsia usneoides* L. (Spanish moss) (n = 1); and (6) Stick platform with Spanish moss (n = 1). No tree cavity or leaf drey nests were found. Measured stripped cypress bark nests that had fallen to the ground (n = 3) averaged 31.0 cm in diameter. Estimated bromeliad/stripped cypress bark nest sizes (and all other non-stick platform nests) ranged from ≈ 25 cm–50 cm in diameter (Fig. 2C). Note: bromeliad quill-leaf masses create natural cavities of varying and unknown volume; therefore, bromeliad nest diameters are based on the volume of the associated stripped bark substrate. Estimated stick platform/stripped cypress bark (or Spanish moss) nest sizes ranged from ≈ 30 cm–100 cm in diameter (Fig. 2B). Nests were typically located in the upper 1/3 of the canopy and ≥ ≈ 8 m in height. Nest tree (n = 403) species (n = 3) and diameter (dbh) data were: (1) Cypress (n = 398) was 30.6 ± 10.8 cm dbh; (2) Cabbage palm (n = 4) was 27.5 ± 4.8 cm dbh; and (3) Pine (n = 1) was 23.6 cm dbh. Of the total BCFS nests (n = 403), 97.5% (n = 393) were located in cypress domes, 1.7% (n = 7) were in pine forests with cypress associates, and 0.7% (n = 3) were in pine forests. Study BCFS nest-nest (n = 403) proximity data was: 11.4% of nests (n = 46) were < 5 m apart from 1 or more nests, 27.1% (n = 109) were < 10 m apart, and 58.1% (n = 234) were < 20 m apart. Study BCFS exhibited diurnal behavior and were typically found occupying nests within ≈ 1 hour of sunset and beginning daily activity ≈ 1–2 hours after sunrise. Males (n = 10) were located in nests 34.2 ± 32.5 times and females (n = 10) were located in nests 35.5 ± 20.2 times (Fig. 10). Mean number of individual nests used was 21.2 ± 18.0 nests for males and 14.3 ± 5.1 nests for females.

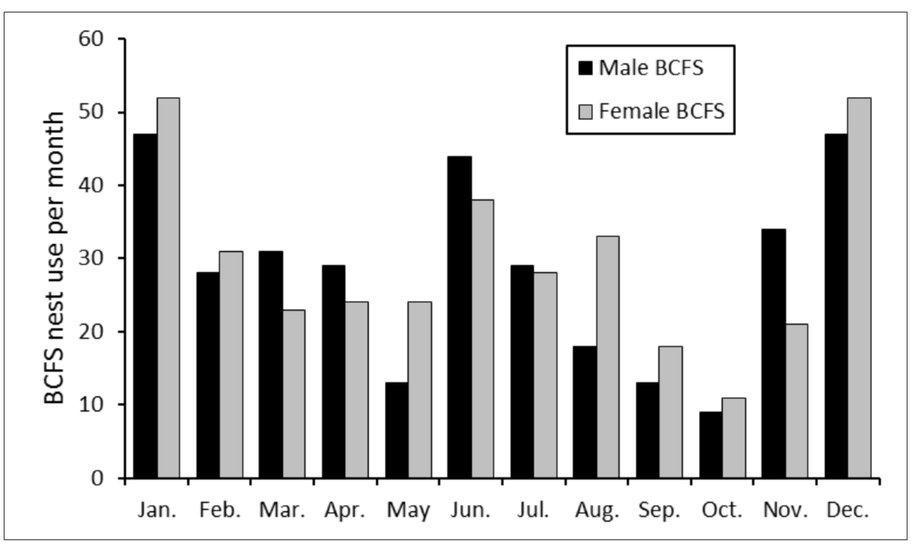

Figure 10. Total male (n = 10) and female (n = 10) BCFS telemetry location daytime nest use (n = 697) per month in the BICY BCFS study area, May 2007–April 2011.

Diet

On 702 occasions, BCFS were either directly observed consuming food items, or evidence of fresh BCFS food item use was observed ≤ ≈ 10 m of a BCFS or BCFS occupied tree (Fig. 6). Of the 702 BCFS food item use observations, 12 food species were identified: (1) Cypress seed cones (n = 460); (2) Pine seed cones (n = 130); (3) Bromeliad (*T. fasciculata* Sw.) floral buds/meristematic stem tissue (n = 84); (4) *Annona glabra* L. (Pond apple) fruit (n = 13); (5) Cabbage palm fruit (n = 5); (6) Coco-plum berries (n = 2); (7) Eastern lubber grasshopper (n = 2); (8) Purple thistle flowers/seeds (n = 2); (9) Saw palmetto berries (n = 1); (10) Wax myrtle berries (n = 1); (11) Fungi spp. (n = 1); and (12) *Ximenia americana* L. (Hog plum) fruit (n = 1).

Mortality

Of the 10 radio-collared male BCFS, 6 individuals died of unknown causes, 1 individual died from predation consistent with *Lynx rufus* Schreber (Bobcat), 2 individuals were of unknown status (i.e., their intact radio-collars were recovered underwater with no evidence of mortality), and 1 individual was de-collared and released at the end of the 4 year study. Mean number of radio-collared days prior to confirmed mortality for males (n = 7) was 203.8 ± 234.6 days. Of the 10 radio-collared female BCFS, 6 individuals died of unknown causes, 3 individuals were of unknown status (i.e., radio-collar failures), and 1 individual was de-collared and released at the end of the 4 year study. Mean number of radio-collared days prior to confirmed mortality for females (n = 6) was 298.0 ± 158.5 days.

Predator/BCFS interaction

On 45 occasions, either *Buteo lineatus* Gmelin (Red-shouldered hawk) or *Strix varia georgica* Latham (Florida barred owl) were recorded in the vicinity (≤ ≈ 25 m) of, or interacting with radio-collared BCFS. Of these 45 records, Red-shouldered hawks were observed engaging BCFS (e.g., BCFS directed vocalization, perching adjacent to an occupied BCFS nest or bromeliad, or actively pursuing BCFS within the canopy) 7 times, and Florida barred owls were observed engaging BCFS 4 times. Although no Bobcat sightings were recorded, their tracks were observed within the study area and 1 deceased radio-collared BCFS had wounds consistent with Bobcat canine penetration.

DISCUSSION

Caveats/limitations associated with the UGA vegetation map data

The accuracy of the UGA vegetation map data (Madden et al. 1999, Welch et al. 1999) used to determine the area of the 7 general habitat types within the 923-ha BICY BCFS study area and individual BCFS home ranges (Fig. 9) was tested by Bradley and Woodmansee (2008) who visited and analyzed the vegetation characteristics at 254 randomly selected locations in BICY, Everglades National Park, and Biscayne National Park. Bradley and Woodmansee (2008) found that the major UGA vegetation classes (e.g., Forest, Scrub, Savanna, Prairies, Marshes, Shrublands, and Exotics) were incorrectly classified 22–38.5% of the time. In addition, the UGA habitat GIS polygon boundaries (derived from color-infrared aerial photo interpretation/analysis; Welch et al. 1999) were frequently incorrectly delineated (Bradley and Woodmansee 2008). Therefore UGA vegetation map-based results (Fig. 9) need to be viewed with caution. That being said, due to the relatively small number of study area habitats (n = 7), dominance of pine forest and cypress dome swamp habitats (which are conservatively estimated to occupy > 75% of the study area), and distinct primary habitat boundaries (e.g., semi-circular shaped cypress domes) that are distinguishable on aerial photos, it is likely that the potential vegetation classification error is near or < the 22% error minimum reported by Bradley and Woodmansee (2008). Although the UGA vegetation map data contains significant habitat classification and polygon boundary errors, it is currently (2013) the only data of its type available for BICY. Big Cypress fox squirrel habitat use inferences are best made using our BCFS telemetry location habitat data (Figs. 7, 8).

Data collection sampling period bias

Study BCFS exhibited diurnal behavior and were typically found occupying nests within ≈ 1 hour of sunset and beginning daily activity ≈ 1–2 hours after sunrise, which is consistent with other southeastern fox squirrel studies (Jodice 1990, Moore 1957, Weigl et al. 1989). Although attempts were made to evenly rotate BCFS monitoring efforts within 4 3-hour time periods (0700–1000, 1001–1300, 1301–1600, and 1601–1900), there was significant data collection bias towards the 1001–1300 sampling period. Of the total BCFS monitoring efforts (n = 2061), 27.4% (n = 565) occurred during 0700–1000, 46.2% (n = 953) during 1001–1300, 18.4% (n = 380) during 1301–1600, 6.1% (n = 125) during 1601–1900, and 1.8% (n = 38) during 2 incidental time periods (0612–0659; n = 22, and 1901–2000; n = 16). Monitoring effort sampling period bias was largely a result of daily early afternoon thunderstorm activity during the wet season (May 1–Oct 31), project staff/work schedule constraints, and travel time to/from the remote study area. Although bias towards the 1001–1300 sampling period limits the inferences that can be made from our daytime nest use data (Fig. 10) and our ability to make some intraspecific spatiotemporal data comparisons (which we do not attempt to do), it has little or no effect on the core summary findings presented in this report.

Survey methods

Due to the secretive nature of BCFS and their low visual survey detection rate in known occupied habitats (Eisenberg-Munim et al. 2007, Eisenberg et al. 2011, Jodice 1990, Jodice and Humphrey 1992), we relied on non-sighting based survey methods to determine occupancy. Since the late 1980s, Jodice (1990) and biologist at BICY have known that BCFS strip bark from cypress trees to use as nest substrate and that searching for the presence of stripped cypress bark on trees and the location of BCFS nests may prove to be a valuable survey technique. Our study developed and refined physical sign-based survey techniques that identify current and recent BCFS occupancy within cypress associated habitats. A good indicator of current BCFS occupancy (confirmed by trapping results) is the presence of fresh stripped cypress bark (as determined by color; Fig. 3A, B) incorporated into BCFS nest structures (Fig. 2B, C) and adjacent fresh partially consumed BCFS food items (Fig. 6). Recent BCFS occupancy was indicated by the combined presence of non-fresh BCFS nests, stripped cypress bark on trees, and partially consumed BCFS food items. Although non-fresh stripped bark nests were regarded as a sign of "recent" occupancy, these nest types were frequently used by radio-collared BCFS. Nests that were found in a state of ruin and not associated with used food items were termed "old" and rarely used by study BCFS. Knowing the seasonal timing of BCFS habitat and food species use (Figs. 6, 7) allows surveyors the ability to prioritize search habitats and focus BCFS sign search patterns. The best time of year to conduct BCFS occupancy surveys within cypress swamp associated habitats is in the dry season when water levels are receding and dormant deciduous cypress trees have shed their needles (Nov–Apr; Vince and Duryea 2004), thereby improving visibility within the canopy. Cypress needle/twig accumulations on the forks of cypress tree branches and corvid/raptor nests can at times look like BCFS stick substrate nests. Therefore, it is important to verify that a stick-based structure has been improved upon by BCFS in order to identify it as a BCFS nest. Of the 403 BCFS nests documented within the study area, 401 had stripped cypress bark incorporated into them – the other 2 nests were enhanced with Spanish moss.

Nest-site location/BCFS habitat

Survey and monitoring efforts revealed that BCFS construct the majority of their nests in discrete cypress domes that meet pine forest edges. Little or no BCFS sign was observed when surveying within the interior of large contiguous cypress dome swamp-cypress prairie mosaic habitats or within the interior of large contiguous pine forest habitats. Survey efforts also revealed that cypress domes with naturally short hydroperiods or unnaturally restricted hydroperiods (due to their proximity to manmade hydrologic barriers) often contain dense midstory/understory shrub layers and reduced sign of BCFS use. Big Cypress fox squirrels prefer to occupy spatially close habitats that in conjunction provide year-round sources of food and optimal nesting conditions. It is easy to overestimate potential BCFS habitat when determinations are based on general habitat types at the landscape level. Stand-level and microhabitat composition, condition, and proximity delineate BCFS habitat.

Habitat characteristics/Eastern gray squirrels

The prescribed fire maintained pine forests within the study area have open canopy and low/sparse understory habitat characteristics that BCFS are known to prefer (Ditgen et al. 2007, Duever et al. 1986, Eisenberg et al. 2011, Humphrey and Jodice 1992, Koprowski 1994a, Williams and Humphrey 1979). In addition, the largely intact surface rainfall driven hydrology within the study area's cypress domes create natural open understory and sparse groundcover conditions within cypress dome interiors, due to sustained hydroperiods that hinder the growth of many plant species. Studies have shown that *Sciurus carolinensis* Gmelin (Eastern gray squirrel) prefer habitats with dense understory/groundcover characteristics and that large forested habitats with dense understory/groundcover often contain high Eastern gray squirrel densities (Brown and Batzli 1984, Koprowski 1994a, 1994b; Nixon et al. 1978). The habitat conditions within the study area explain the absence of a detectable

Eastern gray squirrel population (i.e., no Eastern gray squirrel sightings or bycatch occurred during monitoring/trapping efforts).

Home range

Male BCFS mean home range (95% KDE) size (75.6 ha) was 76.6 % > its nearest conspecific *Sciurus niger shermani* Moore (Sherman's fox squirrel) (42.8 ha; Kantola and Humphrey 1990) and reported mean male home range sizes (1.54–42.8 ha) for all subspecies of *S. niger* in natural habitats (Adams 1976, Benson 1980, Geeslin 1970, Hilliard 1979, Kantola and Humphrey 1990, Koprowski 1994a, Weigl et al. 1989). Female BCFS mean home range size (10.4 ha) was < female Sherman's fox squirrel (16.7 ha; Kantola and Humphrey 1990) and within the reported female mean (0.85–17.2 ha) for *S. niger* subspecies in natural habitats (Adams 1976, Benson 1980, Geeslin 1970, Hilliard 1979, Kantola and Humphrey 1990, Koprowski 1994a, Weigl et al. 1989). The relatively large home range areas of male BCFS are likely a result of long-distance mating-related movements between widely spaced nest areas that are occupied by female BCFS in low densities. Female BCFS had mean 1.3 ha non-overlapping core areas centered within the boundary of discrete cypress dome nest areas that were often separated by > 500 m of pine forest habitat. Male BCFS made year-round movements of up to 1180.1 m ≤ 24 hours between occupied female BCFS core areas and cypress dome nest areas not occupied by study BCFS, especially during May–August (a known BCFS mating/breeding season; Ditgen et al. 1999) when 50.0% (n = 13) of male ≥ 500 m movements ≤ 24 hours (n = 26) and 58.8% (n = 10) of > 600 m movements ≤ 24 hours (n = 17) occurred.

Nest use/reproduction

Big Cypress fox squirrels exhibited diurnal behavior and correlative annual daytime nest use patterns (Fig. 10) consistent with food species availability (Fig. 6), thermoregulatory needs, predator avoidance, monitoring disturbance avoidance, and probable brood nesting. Although an increase of nest use by male and female BCFS from June–August (Fig. 10) coincides with peak cypress seed cone use (Fig. 6) and cypress domes present thermoregulatory benefits during warm summer months, an increase of nest use during this period (especially in Aug) by female BCFS (Fig. 10) may also represent nursing, based on an observation of BCFS young at a nest site in October (the only month BCFS young were observed) and known *S. niger* gestation periods of 44–45 days (Flyger and Gates 1982). Ditgen (1999) reported urban BCFS having 2 breeding seasons: (1) Winter: young were born December–February and emerged from nests January–April; and (2) Summer/Fall: young were born July–September and emerged from nests August–October. Although BCFS breeding seasons (Ditgen 1999) could not be determined by nest use patterns alone (female BCFS were located in 1 nest > 10 times in ≤ 30 days year-round and multiple nests were often in close proximity), our observation of increased long-distance male BCFS movements during May–August and BCFS young at a nest site in October verify a Summer/Fall mating/breeding season in natural habitats.

Diet

The 3 primary study documented BCFS food sources were pine seed cones, cypress seed cones, and bromeliad floral buds/meristematic stem tissue. South Florida slash pine seed cones develop between late August and mid-September, begin to mature in September, and then release their seeds from October–March (Lohrey and Kossuth 1990). Pine seed cones were used by BCFS year-round with peak use during September–October when cone crops are abundant and prior to seedfall (Fig. 6). Pondcypress seed cones develop March–September, mature October–December, and then disintegrate on the tree (Bonner 1974, Gunderson 1977). Cypress seed cones were used by BCFS May–March with peak use during June–August, when cone crops are abundant and pine seed cones are not yet widely available (Fig. 6). The epiphytic bromeliad *T. fasciculata* Sw. has non-deciduous leaves and can flower any month of the year in Florida (Larson et al. 2005, Luther and Benzing 2009, Smith and Downs 1977) with peak flowering typically occurring March–May (Heppner and Frank 1998, Loope 1980, Nehrling 1944). The dominant BCFS use of *T. fasciculata* Sw. floral buds/meristematic stem tissue and the increased use of berries, fruit, flowers, and fungi from March–May, coincide with peak *T. fasciculata* Sw. flowering and reduced availability of pine and cypress seed cones (Fig. 6). Scatter hoarding behavior by BCFS seen elsewhere (Ditgen et al. 2007, Jodice and Humphrey 1992) was not documented within the study area, in part due to lower elevation flooded soil conditions during the wet season and shallow upland pine forest soils with sparse duff layers.

Threats to BCFS from the invasive Mexican bromeliad weevil

Metamasius callizona Chevrolat (Mexican bromeliad weevil; MBW), an invasive exotic species of weevil first reported in Florida in 1989 (O'Brien et al. 1990), has spread to the urban and natural habitats within the core of the BCFS range in Collier, Lee, and Hendry counties (Frank 1999). Mexican bromeliad weevil larvae burrow into and mine meristematic tissue (thereby killing the host plant), which has had a devastating effect on Florida's native bromeliad populations (Frank and Thomas 1994). Especially vulnerable are the large native bromeliad species *T. fasciculata* Sw., *Tillandsia utriculata* L. (Giant airplant), and *T. balbisiana* Schult. and Schult. f. (Frank and Cave 2005). Big Cypress fox squirrels use *T. fasciculata* Sw. for nest substrate, non-nesting refuge, and as an important seasonal food item (especially Mar–May). Although BCFS use of the less common bromeliad species *T. utriculata* L. and *T. balbisiana* Schult. and Schult. f. was not observed, vegetative/flowering similarities to *T. fasciculata* Sw. makes their use by BCFS likely. Mexican bromeliad weevils were not detected in the BICY BCFS study area and their extent of occurrence, area of occupancy, and effect within BICY remains unknown (due in part to limited monitoring/reporting). The 32,000 ha Fakahatchee Strand Preserve State Park (FSPSP) which is adjacent to BICY has recorded significant MBW caused mortality in bromeliad species (especially *T. utriculata* L. and *T. fasciculata* Sw.), including 3-year (2009–2012) > 50% mortality rates of *T. utriculata* L. (n = 870) within an 11.3 km/33.0 ha MBW/bromeliad transect survey area (M. Owen, FSPSP Biologist; and D. Giardina, FWC Everglades Region Biologist, pers. comm.). Currently, there are 2 known controls for MBW: (1) Application of carbaryl insecticide (Sevin, Rhone-Poulenc, Research Triangle Park, NC, USA);

and (2) The rearing and release of the fly *Lixadmontia franki* Wood & Cave, which is a parasitoid of MBW (Frank and Cave 2005). Due to regulations that restrict or ban the use of broad-spectrum carbaryl insecticide in natural areas (e.g., BICY and FSPSP) and the limited release and unknown long-term efficacy of the only known biological control (Frank and Cave 2005), little appears to be slowing the spread of the invasive MBW. This poses a serious threat to BCFS habitat quality and the unique subspecies. Therefore, it is imperative that current and future MBW control development, application, and efficacy research be supported, in order to protect Florida's native bromeliads and the host of plant and animal species that are dependent upon them for their survival.

Threats to BCFS from the Squirrel poxvirus

Squirrel poxvirus (fibromatosis) is an infectious disease (Robinson and Kerr 2001) that can cause high rates of mortality in infected squirrels (Terrell et al. 2002) and may pose a significant threat to BCFS population stability and viability. Squirrel poxvirus has a reported incubation period of 7–14 days before visible cutaneous tumors (fibromas) appear (Hirth et al. 1969) and typically either goes into remission or leads to mortality in < 2 months (Kilham 1955). In 1998, a widespread outbreak of Squirrel poxvirus in Eastern gray squirrels in Florida infected > 200 squirrels (across 7 counties) causing high rates of mortality (Terrell et al. 2002). The discovery of a Squirrel poxvirus-infected BCFS within BICY (Kellam 2010), which is the first confirmed case in natural habitats, may explain local BCFS extirpations described by Jodice and Humphrey (1992). Squirrel poxvirus can be transmitted from insect bites (e.g., mosquitoes and fleas) and by direct animal-to-animal passage (e.g., faecal-oral routes and fibroma/lesion contact) (Atkin et al. 2010, Bruemmer et al. 2010, Kilham 1955, Terrell et al. 2002). Bruemmer et al. (2010) found that attracting and congregating squirrels to the same place (via bird and wildlife feeding stations) could contribute to spread of the Squirrel poxvirus by creating a "hotspot" for the disease. Therefore, if Squirrel poxvirus is detected in a BCFS or Eastern gray squirrel population, the use of bird/wildlife feeding stations should be discouraged on private and public lands in and near the disease outbreak area until monitoring findings suggest otherwise.

Recent (2010–2011) documentation of Squirrel poxvirus-infected BCFS within natural habitats (n = 1; Kellam 2010) and urban green spaces (n = 2; J. Fitzgerald, Von Arx Wildlife Hospital director, Conservancy of Southwest Florida, pers. comm.) confirm the need for Squirrel poxvirus-BCFS research, monitoring and reporting in order to understand and mitigate the potential adverse effects this disease may have on BCFS populations range-wide.

Potential BCFS/Sherman's fox squirrel intergrade zones

The Caloosahatchee River, marshes/sloughs/bays of the Everglades region, and the Gulf of Mexico, are considered to be the northern, eastern, and southwestern boundaries, respectively, of the BCFS range (Eisenberg et al. 2011, Moore 1956, Williams and Humphrey 1979) and may act as gene flow barriers (Moncrief 1993) between BCFS and Sherman's fox squirrels. Recent (2007–2013) reported sightings of fox squirrels (spp.) < 1.5 km N. & S. of the Caloosahatchee River, at a lake in Kendall, Miami-Dade County, Florida (C. Tye, FWC Wildlife Biologist, pers. comm.), and just southeast of the Cape Sable/Whitewater Bay region of Everglades National Park (Pifer et al. 2011), suggest an examination of BCFS-Sherman's fox squirrel potential intergrade zones is needed.

CONCLUSION

The BCFS is currently (2013) an FWC Florida State listed Threatened species, a Florida Natural Areas Inventory (FNAI) ranked Imperiled species, and meets the International Union for Conservation of Nature (IUCN) Red List criteria for a Threatened species (FNAI 2001, FWC 2011). Although our study has provided new information on BCFS ecology within cypress dome swamp-pine forest mosaic habitats, the ecology and status of the BCFS in other natural habitat compositions range-wide is largely unknown. Important BCFS demographic parameters (e.g., fecundity, juvenile survival, recruitment, immigration, emigration, population growth, and population density) needed for robust population models and population viability analysis (PVA) are unknown. It is critical for the management of the BCFS that research be initiated to illuminate demographic parameters, habitat requirements, and the species extent of occurrence and area of occupancy. Big Cypress fox squirrel sign-based occupancy survey techniques need to be developed for implementation within Live oak woodlands, tropical hardwood forests, coastal broadleaf evergreen hammocks, mangrove swamps, non-native *Melaleuca quinquenervia* (Cav.) S.F. Blake (Melaleuca) and *Schinus terebinthifolius* Raddi (Brazilian peppertree) associated habitats, agricultural fields, and urban green spaces. The platform trapping techniques developed by our study will aid capturing BCFS in habitats that have sustained hydroperiods (e.g., cypress and mangrove swamps) and can be applied in conjunction with established ground-based wire box trap capture methods (Ditgen 1999, Jodice 1993, Kantola and Humphrey 1990, Tappe et al. 1993). Projected human population growth in southwest Florida (Zwick and Carr 2006) ensures that habitat degradation, fragmentation, and loss will remain the biggest threat to the BCFS (Eisenberg et al. 2011, Humphrey and Jodice 1992, Williams and Humphrey 1979). The long-term survival of the BCFS is dependent upon the habitat management practices of private and public lands, where the use of prescribed fire, the control of invasive non-native plants/animals, and the maintenance of natural hydrologic conditions are necessary to retain habitat characteristics that benefit the BCFS.

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