

THE FORAGING ECOLOGY OF THREE SPECIES OF BATS AT
THE SAVANNAH RIVER SITE, SOUTH CAROLINA

by

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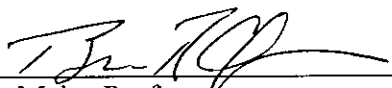
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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Bats are important components of many ecosystems. The roles of bats potentially include nutrient cycling, insect population control, disease transmission, and hosting obligate ectoparasites (Marcot, 1996). In tropical rain forests, fruit-eating bats also disperse seeds, and reforest large tracts of land (Tuttle, 1983). Many tropical trees require bat pollination or seed dispersal (Heithaus, 1982). Many cacti in North American deserts only flower at night and are pollinated primarily by bats (Fleming and Heithaus, 1986; Tuttle, 1991; Fleming et al., 1996). Insectivorous bats often consume agricultural pests (Whitaker, 1972, 1993, 1995; Whitaker and Clem, 1992) and some bats intercept agricultural pests during migration at high altitudes, preventing large-scale agricultural losses (McCracken, 1996). Although bats may impact the habitats that they occupy, little is known about most species of bats.

Although there are many indications that bat populations are declining, no formal records have been kept to accurately monitor population levels. Most claims of species declines have been based on decreases in the numbers of bats in hibernacula (Clawson, 1987; Anonymous, 1988; Anonymous, 1995). However, tree-roosting bats do not congregate consistently in any one area. Therefore, researchers are not able to monitor tree-roosting species numbers accurately.

Nine of the 18 bat species in the Southeastern United States use forests for roosting habitat. All of these species forage within or over these forests. The effect of forest fragmentation and other silvicultural practices on Southeastern bats is not well

known. Changes in forest structure and composition can affect the foraging and roosting patterns of tree-bats (Erickson and West, 1996; Grindal, 1996). Since little is known about the ecology of tree-bats, it is essential to investigate habitat use, including home range and feeding ecology of these animals.

In this study, I determined the habitat use patterns, including home range, of three common tree-bat species in the Southeastern United States: the red (*Lasiurus borealis*), Seminole (*L. seminolus*), and evening (*Nycticeius humeralis*) bats. I also examined diet composition and how it relates to prey availability for these species.

LITERATURE REVIEW

Habitat Use.--Habitat selection occurs at many levels. The most general level, the *gamma* level, is at the landscape scale (Whittaker, 1960). At the *beta* level, bats select specific habitats within the landscape. At the *alpha* level, bats choose where within a habitat they forage or roost. Although certain species may not be selective at one scale, they may be selective at another. Furlonger et al. (1987) found that the red, hoary (*L. cinereus*), big brown (*Eptesicus fuscus*), and Myotis (*Myotis* spp.) bats that they studied did not select among habitats (*beta* selection). However, they were selective in choosing where to forage within habitats (*alpha* selection). The bats were associated primarily with edge and cover.

Some methods of data collection are more appropriate for examining certain levels of selection. For example, radio-telemetry can be used to determine landscape level selection. Habitat selection also can be determined with telemetry if the habitats are well-defined and are larger in size than the inherent error associated with telemetry (Zimmerman and Powell, 1995). Radio-telemetry is suited poorly for determination of *alpha* level selection. The inherent error in telemetry often exceeds the fine scale selection that must be documented. For most animals, this level of selection is documented by visual and auditory observation. Recent advances in night vision

equipment enables researchers to observe bats flying at night, but the validity of species identification using this method may be questioned (Barclay and Bell, 1988).

Advances in monitoring bat calls has allowed researchers to document bat use of specific habitats (Fenton, 1970). Special recorders document the presence of species in a sampling area (no more than 0.5 ha) surrounding the equipment. Unlike telemetry, this method cannot detect habitat use across large scales. Thus, this technology can be used to examine *alpha* and *beta* level selection, and studies have demonstrated both levels of habitat selection (Hickey and Neilson, 1995; Walsh and Harris, 1996; Furlonger et al., 1987).

Chemoluminescent tags glued to bats also may be used to examine habitat use. The method has obvious limitations because the observer may have difficulty maintaining visual contact with the flying bat. For logistical reasons, this method is best suited for observations at the *beta* and *alpha* level (LaVal et al., 1977; Barclay and Bell, 1988).

Data on habitat use of tree-roosting bats are lacking at all levels of selection. Much of the available information on tree-roosting species is limited to anecdotal notes recorded in papers focusing on cavern or cavity-roosting bats. Museum collection records can provide an additional source of habitat-use information. However, in the Southeastern United States, information on the habitat use patterns still are lacking for the red, Seminole, and evening bats.

Red bats do not exhibit landscape level selection (Furlonger et al., 1987). Red bats have been collected in most landscapes (Shump and Shump, 1982; Whitaker and Hamilton, 1998) and in most habitat types (Davis and Mumford, 1962; LaVal et al., 1977; Zinn, 1977; Laerm et al., 1980). However, at the *alpha* level, red bats often are selective, choosing edge and cover over contiguous and open areas (Constantine, 1958; Furlonger et al., 1987; Bryan and MacGregor, 1988). In Texas, Manning et al. (1987) caught red bats while they foraged under the canopy of pecan trees (*Carya illinoensis*).

In northern Florida, Zinn (1977) reported that fine scale habitat selection changed by season. Red bats foraged only as high as 10 m above the ground in summer and fall along the river swamp edges, but in winter and spring this species foraged up to 20 m and expanded their use of habitat into the swamp and over water.

Seminole bats are reported from uplands, prairies, shrub swamp, blackgum (*Nyssa sylvatica*) forest, bay forest, cypress (*Taxodium distichum*) and mixed cypress swamps, longleaf pine (*Pinus palustris*) and turkey oak (*Quercus laevis*), flatwood pines habitats, and edge-type habitat such as roads and sharp ecotones (Blair, 1935; Moore, 1949; Ivey, 1959; Laerm et al., 1980). Barkalow (1948) and Constantine (1958) reported that these bats use similar habitats as red bats. On Sapelo Island, Georgia, they used terrestrial habitats and did not include salt marsh or open water in their home ranges. During June and July, these bats utilized primarily pine and oak habitats (Krishon et al., 1997). Seminole bats in northern Florida fed at heights of 20 to 30 m above open water and water-swamp edge habitats (Zinn, 1977).

The evening bat is primarily a Coastal Plain species (Hamilton, 1930; Barbour and Davis, 1974; Caire et al., 1989; Sealander and Heidt, 1990; Krishon et al., 1997). Evening bats are reported from many habitats including pastures, cypress swamps, blackgum swamps, streams, and uplands (LaVal et al., 1977; Laerm et al., 1980; Manning et al., 1987). Evening bats tend to fly high above the canopy after leaving the roost then descend below the canopy after dark to feed at 10 to 20 m above the ground along edges of rivers and over pastures (Blair, 1935; LaVal et al., 1977; Zinn, 1977; Manning et al., 1987; Sealander and Heidt, 1990). A male evening bat on Sapelo Island, Georgia, used pine habitats, clearings and oak habitats (Krishon et al., 1997).

Food Habits.--Food habit studies may use one of three methods to collect data: observation, analysis of digestive tract contents, and analysis of fecal samples. Visual observation is not feasible for bats. The accuracy of digestive tract analysis and fecal analysis is debated in the literature. Although Rabinowitz and Tuttle (1982) argue that

digestive tract analysis offers a more accurate depiction of the true diet, sacrificing individuals is not always possible. Captured bats often are needed for an ongoing study or are protected legally, consequently fecal analysis provides an acceptable depiction of diet (Kunz and Whitaker, 1983; Brack and LaVal, 1985; Lacki et al., 1995).

Most food habits studies do not assess prey availability (Whitaker, 1994). Others only sample the insect communities near the site of capture or in a few selected habitats but fail to address the relative amount of time that a bat spends foraging in a given habitat. To accurately assess prey selectivity, researchers must determine where bats are foraging, how much time they spend foraging there, and what prey are available in that area (Whitaker, 1994). There are difficulties associated with determining each of these selectivity factors.

Methods for assessing prey availability are inherently biased (Kunz, 1988). Common methods for assessing insect abundance include Malaise traps, flight impact traps, sticky traps, sweep nets, and light traps. All of these methods have attributes that make them better suited for some situations over others (Kunz, 1988). Light traps are the most common method for assessing prey availability (Taylor and Carter, 1961; Black, 1974; Brack and LaVal, 1985; Jones, 1990; Sample and Whitmore, 1993; Churchill, 1994; Lacki et al., 1995; Sierro and Arlettaz, 1997; Cater et al., 1998).

The food habits of red bats are poorly known, particularly in the Southeastern United States. Ross (1961, 1967) examined fecal pellets and digestive tracts from red bats in California, and determined that Lepidoptera and Orthoptera were the primary components. Red bat digestive tracts from Indiana and Illinois were dominated by Lepidoptera, Coleoptera, and Homoptera (Ross, 1967; Whitaker, 1972; Feldhamer et al., 1995). In northern Florida, Zinn (1977) found that Coleoptera was the most common food item, followed by Hymenoptera and Odonata. Hickey et al. (1996) examined the culled moth wings of foraging bats in Ontario, and found that hoary bats took larger moths than the red bats. Over the course of a year, Lepidoptera was the

primary food source of red bats from the Great Dismal Swamp, except in March when Diptera were utilized more (Whitaker et al., 1997).

Until recently, little was known about the food habitats of the Seminole bat. Sherman (1935) found a flightless cricket (Orthoptera) in the mouth of a single specimen collected in Florida. Other digestive tracts collected from Florida contained Coleoptera, Diptera, Homoptera, Odonata, and Hymenoptera (Sherman, 1939; Zinn, 1977). Carter et al. (1998) examined fecal samples from Sapelo Island, Georgia, where Coleoptera, Lepidoptera, and Hymenoptera were the most important food items. When the diets of Seminole bats were compared to the insect communities from the habitats where radio-tracked bats foraged, Carter et al. (1998) found that these bats selectively avoided Homoptera and Diptera.

Until the 1990s, little information was available on the food habits of the evening bat. Digestive tracts examined from Indiana and Illinois were dominated by Coleoptera, Hymenoptera, Homoptera, Lepidoptera, Hemiptera, and Diptera (Ross, 1967; Whitaker, 1972; Feldhamer et al., 1995). Coleoptera were the dominant item in three stomachs of evening bats from northern Florida (Zinn, 1977). Hymenoptera, Diptera, Odonata, and Lepidoptera also were used. Whitaker and Clem (1992) examined the food habits by month from May to October in Indiana. Throughout all months, Coleoptera accounted for the majority of the diets. Lepidoptera and Homoptera also were important parts of the summer diet. Coleoptera and Hymenoptera were the dominant food items in fecal samples from Sapelo Island, Georgia. Carter et al. (1998) compared fecal sample contents to available insect prey for male, female and juvenile evening bats. Male evening bats used fewer Coleoptera than available in the environment. All three groups used Homoptera less than available and juveniles utilized Diptera less than available.

Although habitat use and food habits often are studied independently, they are closely-related components of feeding ecology. Animals make many choices when

feeding. They choose not only what to eat but where to feed. Management decisions cannot be based on one component alone. The interdependence of these components must be considered.

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CHAPTER 2

SUMMER HOME RANGE AND HABITAT USE OF THE RED (*LASIURUS BOREALIS*), SEMINOLE (*L. SEMINOLUS*), AND EVENING BATS (*NYCTICEIUS HUMERALIS*).

Carter, T. C., M. A. Menzel, B. R. Chapman, and K. V. Miller. To be submitted to *Journal of Mammalogy*.

Abstract: We examined home-range size and habitat use of red (*Lasiurus borealis*), Seminole (*L. seminolus*) and evening (*Nycticeius humeralis*) bats in the Upper Coastal Plain of South Carolina during June, July, and August of 1996 and 1997. A total of 113 bats were caught during 1996 and 1997. Fifty-two bats were fitted with radio transmitters. Locations and home-ranges from these bats were imported into GIS and overlaid on vegetation maps to determine habitat use. Home-range size did not differ among species. However, home-range sizes tended to be smaller during parturition than later in summer. There were no differences in habitat use among the species. Collectively, they used bottomlands and pine forests more than upland hardwoods ($P=0.0002$). Habitat use was not different from availability.

Key words: bats, *Lasiurus borealis*, *Lasiurus seminolus*, *Nycticeius humeralis*, habitat selection, habitat use, home range, South Carolina

INTRODUCTION

The home-range and habitat-use patterns for even the most common bats are poorly understood. The lack of information hinders efforts to conserve bats, their roosts, foraging areas, or hibernaculum (Fenton, 1997). Many cave bat species have been the subject of study because of their dwindling numbers and vulnerability. However, monitoring tree-bat populations is difficult because roosting and foraging sites are widely distributed across the landscape.

Tree-bats rely exclusively on forest habitats for all resources. Few studies have examined species selection of forest habitats (Vonhof, 1995). Because habitat selection by individuals can impact survival rates and individual fitness, we examined the home-range size and habitat use of the red (*Lasiurus borealis*), Seminole (*L. seminolus*), and evening (*Nycticeius humeralis*) bats. Our specific objectives were to document the habitat requirements of these species and to determine if habitat partitioning occurs

among these species. These species were chosen because of their abundance in the area and also because red and Seminole bats are morphologically similar.

STUDY AREA

This study was conducted at the U.S. Department of Energy's Savannah River Site, National Environmental Research Park (SRSNERP). Established in 1972, the SRSNERP is located in Aiken, Barnwell, and Allendale Counties, near Aiken, South Carolina (33°0-25'N, 81°25-50'W) in the Upper Coastal Plain physiographic province. The site is characterized by gentle rolling hills with broad flat regions. The average summer temperatures are 27°C, and 9°C during the winter. The average annual rainfall is 120 cm (Langley and Marter, 1973).

The SRSNERP is managed by the USDA Forest Service. The Forest Service recognizes over 80 specific forest types. However, for this study we followed the major community types described by Workman and McLeod (1990), which include sandhills, old fields, pine plantations, upland hardwoods, bottomland hardwoods, swamp forests, Carolina bays, and water areas. This study was conducted in the southwestern section of the SRSNERP, centered around a 70 year-old, 120 ha bottomland hardwood forest along the Savannah River. All major communities except old fields were present in the area surrounding the study site.

METHODS

Bats were captured from June -- August 1996 and 1997, using 15 mist net systems similar to those described by Gardner et al. (1989). Nets were placed in areas of concentrated bat activity such as roads, skidder trails, streams, and over ponds (Dalquest, 1954; Jones, 1966). Species, age, sex, forearm length, and weight were recorded for each individual. Age classes were defined as adult or juvenile based on epiphyseal-diaphyseal fusion (Anthony, 1988; Nowak, 1994).

Small radio-transmitters (0.45 g, LB-2, Holohil Systems Ltd., Ontario, Canada) were glued to the back of the selected species with Skin-bond[®] surgical adhesive (Pfizer Hospital Products Group, Inc., Largo, Florida). These transmitters had an effective range of 1.6 km and a battery life of approximately 21 days. Because they weighed less than 5% of the bats' body weights, the transmitters likely had negligible effect on bat movements (Aldridge and Brigham, 1988; Hickey, 1992).

Bats were tracked using R2000 ATS (Advanced Telemetry Systems, Inc., Isanti, MN) receivers and three-element folding Yagi antennas. Foraging locations were determined using standard two-station triangulation techniques (Springer, 1979). Simultaneous triangulation minimized location error resulting from animal movements (Schmutz and White, 1990). Researchers maintained contact via two-way radios. Telemetry stations normally were positioned so that the bearings from the stations crossed at a 90° angle for most triangulation attempts (White, 1985), but this was not always possible. Bat location attempts were made at intervals exceeding 4 min to alleviate autocorrelation (Swihart and Slade, 1985; White and Garrott, 1990). Telemetry station locations were recorded using a global positioning system (GPS) unit (Trimble Navigation Limited, Sunnyvale, CA). To obtain the exact locations of the foraging bats, the Universal Transverse Mercator (UTM) coordinates of the telemetry stations and the azimuths of the bats from those stations were entered into the program LOCATE (Kie et al., 1996).

We used the program CALHOME to calculate home-ranges (Kie et al., 1996) for bats that had 20 or more locations. Home-ranges were calculated using the Adaptive Kernel method with 95 percent contour (Worton, 1989) to exclude sallies from the home-range analysis (Hayne, 1949). All home-range calculations were made with the default bandwidth and grid cell size of -50. The size of the 95 percent contour was compared among species using an Analysis of Variance (ANOVA) and, if significant ($P < 0.05$), Tukey's mean separation test (SAS Institute Inc. 1990) was used.

Bat locations and the home-range polygons derived from the locations were imported into PC Arc/Info, Geographical Information Systems (GIS, Environmental Systems Research Institute, Inc., Redlands, CA). Coverages were developed separately for each bat. Land-use GIS coverages, including vegetation maps, roads, streams, power-lines, railways, Carolina bays, and water areas, were obtained from the USDA Forest Service at SRSNERP. The vegetation coverages contained 80 different vegetation types for the SRSNERP. For the habitat-use analysis, the vegetation types within the study area were recategorized into three major habitat types: pine forests; upland hardwood forests; and bottomland hardwood forests. Pine forests were designated as any area where the predominant tree species (>75%) was *Pinus* and included plantations of loblolly pine (*P. taeda*), longleaf pine (*P. palustris*), and slash pine (*P. elliottii*). Upland hardwood forests included any site composed primarily of upland hardwood species (>75%) as defined by Workman and McLeod (1990). Bottomland hardwood areas were reclassified to include Workman and McLeod's (1990) swamp forests vegetation type and areas that were composed primarily (>75%) of bottomland hardwood species.

Locations for each bat with more than 15 locations were overlaid on the recategorized vegetation coverage maps and the percent of points falling on each habitat calculated. The home-range polygons were overlaid on the vegetation coverage and the proportion of each habitat type within the 95% contour was calculated. An arcsine square-root transformation was used on the proportional data. An ANOVA and the Tukey's mean separation test were used to detect differences in habitat use among species using both locations and home-range data. If no differences were detected, an ANOVA was used to compare habitat types for bats as a group (SAS Institute Inc., 1990).

A 4-km radius circle encompassing all the home-ranges was centered on the study site to determine habitat availability. We used a Chi-square test to detect

preference or avoidance for each species separately (SAS Institute Inc., 1990). Confidence intervals were used to determine where preference or avoidance occurred (Neu et al., 1974).

Since some areas were classified as both a vegetation type and an aquatic area (i.e., some bottomland forests), we separated these habitats during analysis. Carolina bays (Schalles et al., 1989) also were included in the water coverage. Point locations were overlaid on the recategorized water habitat and the percent of points occurring in water areas was recorded. Available water area was determined as the proportion of the 4-km radius circle that was composed of water habitat. Proportional data was transformed and an ANOVA was used to test differences in water use among species. A Chi-squared test was used to detect preference or avoidance for each species. (SAS Institute Inc., 1990).

Edge habitats were defined as roads, power lines, stream corridors, and railways. Each of these coverages was buffered 30 m past their actual boundaries to account for telemetry error. The proportional data were transformed using an arcsine square-root transformation. The transformed proportions of bat locations that fell within edge habitats were compared among species using an ANOVA (SAS Institute Inc., 1990). The available edge habitat was determined by the proportion of the 4-km radius circle that was composed of edge-type habitats. A Chi-squared test was used to compare use versus availability (SAS Institute Inc., 1990).

RESULTS

A total of 113 bats comprising eight species was caught during 552 net nights. Fifty-seven bats were caught during the summer of 1996, and 56 bats were caught during the summer of 1997 (Table 1). Twenty-six bats were fitted with radio-transmitters during each year (Table 2). A total of 582 attempts was made to locate the bats in 1996 and 972 attempts were made in 1997. The bearing intersection

error rate of 30% resulted in approximately 1090 animal locations for the study. We determined that the bearing error was 7° . At an effective range of 1.6 km, the error polygon was 4 ha.

We found no relationship between the number of locations (≥ 20) and the size of the home-ranges (Mares et al., 1980; Adam et al., 1994). We recorded ≥ 20 locations for 5 red bats, 5 Seminole bats, and 6 evening bats and used these in the home-range analysis (Table 2). Home-range sizes did not differ among the three species. The 95% contour home-range of the red bats averaged 453.2 ha (SE ± 137.4 ha) and ranged from 878.5 to 125.8 ha. Average home-range size of the Seminole bat, 423.8 ha (SE ± 107.7 ha), was similar to that of the red bat and ranged from 704.4 to 189.2 ha. The mean 95% contour of evening bats was 285.3 ha (SE ± 110.3 ha) with a maximum and minimum home-range size of 761.0 and 38.7 ha.

We obtained ≥ 15 locations for 7 red bats, 6 Seminole bats, and 11 evening bats (Table 2). Habitat use did not differ among the species. All three species used bottomland hardwoods and pine areas more than upland hardwood areas ($P=0.0002$), but they did not utilize these habitats more or less than they were available. Red bats mainly used bottomlands (55%), and pine stands (40%), followed by uplands (5%). Seminole bats used pine stands (55%), bottomlands (35%) and uplands (11%). The evening bats mostly used pine stands (59%) and bottomlands (37%). The available habitats within the area were primarily bottomlands (71%) and pine stands, mostly plantations (27%). Upland habitats only occupied 2% of the study area.

The proportions of habitats within the home-ranges were similar to the distribution of the animal locations (Table 3). No differences were detected among the species use of different vegetational types. Collectively the three species used bottomland hardwoods significantly more than both pines and upland hardwoods ($P=0.0001$) and pine areas significantly more than upland hardwood areas ($P=0.0001$). However, they used these habitat types to the same degree as they were available. The

home-range habitat composition of red bats was similar to the points distribution. The home-ranges were dominated by bottomlands (56%) and pine stands (40%). Uplands (6%) were used to a lesser extent. Seminole bat home-range composition was different from the points distribution. The home-ranges of Seminole bats were mostly over bottomlands (66%). Pine stands (29%) and uplands (5%) were used less frequently. Similarly, the habitat composition of evening bat home-ranges was different from the distribution of points across the habitats. Evening bats used mostly bottomlands (63%). Pine stands and uplands made up 35% and 2% of the evening bat home-ranges, respectively.

Use of water habitats did not differ among the three species (Table 3). Water habitats were utilized in the same proportions as they were available. Edge habitats composed 12% of the study area. Although no statistical differences were found, all three species appeared to use edge habitats more than they were available. Seminole bats were found along edge 59% of the time, followed by red bats at 39% of the time and evening bats at 36% of the time.

DISCUSSION

The bearing error in this study was larger than those reported in other studies. However, because of the relative closeness of our research animals, the error polygon was 4 ha, smaller than error polygons of other studies (Springer, 1979; Edge and Marcum, 1985; Laundré et al., 1987; Reynolds and Laundré, 1990; Schmutz and White, 1990).

We were unable to detect differences in the size of the home-ranges for any of the species probably because there was a large variance in home-range sizes among individuals within a species. A seasonal shift in home-range size was observed for all species. During parturition early in the summer, home-ranges generally were small. Small home-ranges during parturition and lactation also are documented in other studies

(Barclay, 1989; Clark et al., 1993; Adam et al., 1994; de Jong, 1994; Krishon et al., 1997; Jablonowski et al., manuscript in preparation). As the summer progressed, the home-range size tended to increase.

These three species appear to be generalists in their habitat selection. However, the inherent coarseness of these analyses can only lead to conclusions that are relevant at the landscape scale. Habitat selection may occur at a finer scale. These species may be using areas that contain both favored and non-favored habitats, but since these habitats are so evenly spaced throughout the study area, selection for habitats may not be visible. Within a home-range, these bats may choose micro-habitats using characteristics that cannot be measured using existing telemetry methods. Study designs that aim at this level of selection have shown that bats often are selective of micro-habitats (Kunz, 1973; de Jong, 1995; Storz, 1995; Brigham et al., 1997; Walsh and Harris, 1996; Krishon et al., 1997; Menzel et al., 1998).

Red bats are habitat generalists at the landscape level, occurring commonly in most habitats. Near the Okefenokee Swamp, red bats were found in uplands, blackgum (*Nyssa sylvatica*) forests, and mixed cypress (*Taxodium distichum*) forests (Laerm et al., 1980). They forage over pastures, over and within deciduous forests, use forest gaps and openings, river corridors, roads, forest edge, and small lakes and ponds (Constantine, 1958; Davis and Mumford, 1962; LaVal et al., 1977; Bryan and MacGregor, 1988; Whitaker and Hamilton, 1998). Furlonger et al. (1987) found that red bats used terrestrial habitats more than they were available and the bats were associated positively with woody vegetation cover and the presence of edge. In northern Florida, red bats used the swamp/river edge under 10 m during the summer and fall (Zinn, 1977). During the winter, they also included the adjacent water areas and foraged from 5 to 20 m above the ground. During spring they expanded their habitat use into the adjacent swamp. Although red bats may be habitat generalists on

the landscape scale, at a finer scale these animals may exhibit specific micro-habitat associations (Furlonger et al., 1987).

The Seminole bat is associated with Spanish moss (*Tillandsia usneoides*) but it forages in many habitats. Constantine (1958) reported that Seminole bats foraged along forest edges, roads, and streams. Seminole bats have been reported from prairies, uplands, pine flatwoods, longleaf pine (*Pinus palustris*) turkey oak (*Quercus laevis*), lake border, swamp, blackgum forest, pure bay forest, and mixed cypress (Blair, 1935; Barkalow, 1948; Moore, 1949; Ivey, 1959; Laerm et al., 1980). In northern Florida, Zinn (1977) reported that Seminole bats foraged 20 to 30 m above open water areas and along the edge of the cypress swamp. On Sapelo Island, Georgia, a juvenile female had a home-range of 289.6 ha, an adult male had a home-range of 141.5 ha, and an adult female had a home-range of 79.2 ha (Krishon et al., 1997). The juvenile female used beach dunes (41%), pine habitats (19%), clearings (16%), and oak habitats (15%). The adult male used mostly pine habitats (74%), oak habitats (11%) and salt marshes (15%). The adult female used mostly oak (44%) and pine (43%) habitats. We found that Seminole bats use mostly pine forests and bottomland habitats, the most common habitats available.

The evening bat is a Coastal Plain species. Where it occurs outside of the Coastal Plain, it is considered uncommon (Hamilton, 1930; Barbour and Davis, 1974; Caire et al., 1989; Sealander and Heidt, 1990; Krishon et al., 1997). The evening bat occurs over streams and pastures, among cypress trees, and along lake fronts (Blair, 1935; LaVal et al., 1977; Manning et al., 1987). An adult male evening bat from Sapelo Island, Georgia, had a home-range of 15.1 ha and primarily used pine habitats (76%; Krishon et al., 1997).

Most insectivorous bats are presumed to be habitat generalists. However, many factors should be considered when interpreting habitat use patterns of these species.

Both the level of selection examined and the techniques used to gather the data can have a profound effect on the results of habitat-use studies.

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Table 1. -- Bat species captured at the Savannah River Site, South Carolina, during 552 mist-net nights.

Species	1996	1997	Total	Capture per Net Night
<i>Nycticeius humeralis</i>	28	26	54	0.098
<i>Lasiurus borealis</i>	19	13	32	0.058
<i>Lasiurus seminolus</i>	6	12	18	0.033
<i>Pipistrellus subflavus</i>	1	2	3	0.005
<i>Eptesicus fuscus</i>	2	0	2	0.004
<i>Plecotus rafinesquii</i>	0	2	2	0.004
<i>Myotis lucifugus</i>	1	0	1	0.002
<i>Myotis austroriparius</i>	0	1	1	0.002
Total	57	56	113	0.205

Table 2 -- Number of bats tracked at Savannah River Site, South Carolina. Includes the number of bats where greater than 15 and 20 foraging locations (Pts) were retrieved for each species.

Species	1996		1997	
	Tracked ≥ 15 Pts	≥ 20 Pts	Tracked	≥ 15 Pts ≥ 20 Pts
<i>Nycticeius humeralis</i>	12	4	12	7
<i>Lasiurus borealis</i>	11	4	6	3
<i>Lasiurus seminolus</i>	3	1	8	5
Total	26	9	26	15

Table 3. -- Habitat-use (%) by animal location (Pts) and home range composition (HR) and percent of habitats available in the study area for three bat species tracked at the Savannah River Site, South Carolina, in 1996 and 1997.

Habitat	<i>Lasiurus borealis</i>		<i>Lasiurus seminolus</i>		<i>Nycticeius humeralis</i>		Available Habitat
	Pts	HR	Pts	HR	Pts	HR	
Bottomland	55	56	35	66	37	63	71
Pine	40	40	55	29	59	35	27
Upland	5	6	11	5	4	2	2
Water Areas	23		18		13		24
Non-Water Areas	77		82		87		76
Edge Areas	39		59		36		12
Non-Edge Areas	61		41		64		88

CHAPTER 3

FEEDING ECOLOGY OF THE RED (*LASIURUS BOREALIS*), SEMINOLE (*L. SEMINOLUS*), AND EVENING BATS (*NYCTICEIUS HUMERALIS*).

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Abstract: We collected fecal samples from red (*Lasiurus borealis*), Seminole (*L. seminolus*), and evening (*Nycticeius humeralis*) bats at the Savannah River Site, South Carolina, during the summers of 1996 and 1997. Diets were compared to estimates of prey availability, which were based on samples of the insect communities in available habitats and the amounts of time the bats foraged in each habitat. Diets differed among species. All species fed selectively. Red bats consumed mostly Coleoptera in the beginning of the summer and used Lepidoptera more toward the end of the summer. Red bats selectively avoided Lepidoptera and Tricoptera in early summer, Diptera and Tricoptera in the middle, and Diptera, Hymenoptera, and Tricoptera during late summer. Diets of Seminole bats were dominated by Coleoptera and Hymenoptera in early summer. However, they used Coleoptera, Hemiptera, and Tricoptera less than they were available. In mid-summer Lepidoptera also became an important food item. Hymenoptera was used more than available, and Hemiptera, Diptera and Tricoptera were consumed less than they were available. No Seminole bats samples were collected during late summer. Evening bats consumed primarily Coleoptera, Hymenoptera, Hemiptera, and Homoptera during early and mid summer. Lepidoptera, Diptera, and Tricoptera were avoided during early and mid summer. Evening bats consumed mostly Hemiptera, Homoptera, Coleoptera, and Hymenoptera during late summer. They used Hemiptera and Homoptera more than they were available and avoided Coleoptera, Lepidoptera, and Diptera.

INTRODUCTION

Many researchers have reported on the diets of insectivorous bats (Ross, 1961, 1967; Kunz 1974; Griffith and Gates, 1985; Feldhamer *et al.*, 1995). However, the relationship of diet and prey availability for these bats is rarely examined. Some researchers (Black, 1974; Belwood and Fenton, 1976; Brack and LaVal, 1985; Barclay, 1991; Sample and Whitmore, 1993; Churchill, 1994; Lacki *et al.*, 1995; Sierro and

Arlettaz, 1997; Whitaker *et al.*, 1997) have compared bat diets with the insect fauna found at capture locations, but actual feeding sites of these bats were not known. To determine what insects are available to bats, it is necessary to determine where the bats are foraging and to collect insects from these sites. The insect communities in each habitat must also be weighted by the amount of time that each bat species spends foraging in each habitat (Whitaker, 1994). In this study, we radio-tracked bats to determine foraging sites, collected insects from the sites that bats used, and compared fecal sample contents to the available prey. Our objective was to determine diet composition and determine if selective foraging occurs in these species.

STUDY AREA

This study was conducted at the Savannah River Site, a 780-km² nuclear production facility in Upper Coastal Plain of west-central South Carolina. The site is south of Aiken, South Carolina in Aiken, Barnwell, and Allendale Counties. It is bound by the Savannah River for 35 km along the southwestern edge. The area was designated the first National Environmental Research Park (SRSNERP) in 1972. The forested areas are managed by the USDA Forest Service (USDAFS; Langley and Marter, 1973).

SRSNERP is characterized by gentle rolling ridges with broad flat regions with a total elevation change of less than 100 m (Whipple *et al.*, 1981). The climate ranges from hot summers to mild winters, with an average temperature of 27°C during summer and 9°C in the winter. The frost-free period is approximately 240 days long. The average yearly rainfall is 120 cm (Langley and Marter, 1973).

Although the USDAFS recognizes over 80 specific forest types at the SRSNERP, we condensed community types as described by Workman and McLeod (1990), and included sandhills, old fields, pine plantations, upland hardwoods, bottomland

hardwoods, swamp forests, and Carolina bays. The specific study area was located in the southwestern section of the SRSNERP along the Savannah River.

MATERIALS AND METHODS

Bats were captured from June to August in 1996 and 1997 using 15 mist net systems similar to those described by Gardner *et al.* (1989). These nets were placed in areas of concentrated bat activity such as roads, skidder trails, streams, and over ponds (Dalquest, 1954; Jones, 1966). Upon capture, species, age, sex, forearm length, and weight were recorded for each individual. Age classes were defined as adult or juvenile based on the level of epiphyseal-diaphyseal fusion (Anthony, 1988; Nowak, 1994). All bats were placed in plastic cups for no more than 1.5 h to collect fecal pellets. All bats were released the same night.

Fecal samples were analyzed in random order using methods described by Whitaker (1988). Insect fragments were identified to the ordinal level. Since Lepidoptera often are represented only by their scales, we used a modified version of Black's (1972) method for percent volume estimation. Percent occurrence and percent volume of all orders were estimated visually. Summer diets were examined within species to determine if there were differences among the early, middle, and late summer periods. Proportional data were transformed using an arcsine square-root transformation and analyzed using an Analysis of Variance (ANOVA) and a Tukey's mean separation test (SAS Institute Inc. 1990).

We used 12-volt black-light insect traps (BioQuip Products, Gardena, CA) to collect insects from the habitats where bats carrying radio-transmitters foraged. Traps were placed in one of three replicates of each habitat for three nights each week. Insects were retrieved after each sampling period and frozen for subsequent analysis. A subsample was identified and percent occurrence and percent volume were recorded for each insect order. Only insects from 2 to 24 mm were considered consumable (Carter *et al.*, 1998).

Foraging habitats were delimited by radio-tracking bats instrumented with LB-2 radio-transmitters (0.45 g, Holohil Systems Ltd., Ontario, Canada) glued to the back with Skin-bond® surgical adhesive (Pfizer Hospital Products Group, Inc. Largo, Florida). Transmitters had an effective range of 1.6 km and a battery life of approximately 21 days. The transmitters weighed less than 5% of a bat's body weight and presumably had a negligible effect on activity (Aldridge and Brigham, 1988; Hickey, 1992).

Bats were tracked using R2000 ATS (Advances Telemetry Systems, Inc., Isanti, MN) receivers and three-element folding Yagi antennas. Foraging locations were determined using standard two-station simultaneous triangulation techniques (Springer, 1979; Schmutz and White, 1990). Bat location attempts were made no closer than 4 minutes apart to alleviate the problem of autocorrelation between animal locations (Swihart and Slade, 1985; White and Garrott, 1990). Telemetry station locations were recorded using a global positioning system (GPS) unit (Trimble Navigation Limited, Sunnyvale, CA). To obtain estimated locations of foraging bats, Universal Transverse Mercator (UTM) coordinates of telemetry stations and azimuths of readings from those stations were entered into the program LOCATE (Kie *et al.*, 1996).

The bat locations were imported into PC Arc/Info, Geographical Information Systems (GIS, Environmental Systems Research Institute, Inc., Redlands, CA). Land-use GIS coverages were obtained from the USDAFS at SRSNERP. Bat locations were overlaid on the vegetation coverage. The proportions of locations within each habitat type were calculated. Vegetation types within the study area were categorized into four major habitat types: pine forests, upland forests, bottomland forests, and water areas. Pine forests include areas in which the dominant trees (>75%) were *Pinus* species and included plantations of loblolly pine (*P. taeda*), longleaf pine (*P. palustris*), and slash pine (*P. elliottii*). Upland hardwood forests included sites that were composed >75% upland hardwood species (as defined by Workman and McLeod 1990).

Bottomland hardwood forests incorporated Workman and McLeod's (1990) swamp forests vegetation type and areas that were composed of >75% bottomland hardwood species. Water areas were streams, ponds, lakes, and Carolina bays.

Prey availability incorporates the habitat types in which a bat fed and the composition of the insect community in each habitat type. We multiplied the percentage of time that a bat spent in each habitat type by the proportion of each insect order in that habitat type (Whitaker, 1994). If the diet differed (t-test) from our estimates of the insect community, we assumed selective feeding (Whitaker, 1988). The Bonferroni adjusted alpha level for these tests was 0.005. However, we considered significance to be at the 0.05 level.

RESULTS AND DISCUSSION

A total of 638 fecal pellets from 91 bats were examined during 1996 and 1997. Differences in insect communities and diet compositions occurred during the summer. Diets of the three bat species differed from one another during all of the periods. In early summer red bats consumed more Coleoptera than Seminole bats ($p = 0.018$). Red bats fed on Lepidoptera more often than did evening bats, especially in late summer ($p = 0.014$). However, red bats also tended to feed in areas that had higher densities of Lepidoptera. During mid-summer, evening bats consumed more Hemiptera than did Seminole bats ($p = 0.0279$). During late summer, evening bats consumed more Hemiptera than did red bats ($p = 0.0242$). Hymenoptera (primarily flying ants, Formicidae) also were an important component of the diets of these species. When present, flying ants often comprised a large proportion of the sample, although the unpredictability of Hymenoptera emergences probably prevents it from being a reliable food source. Coleoptera were the most reliable food resource, composing 50% or more of available prey.

The diets of red bats were dominated by Coleoptera (Table 1) in early summer (n=9) and Coleoptera, Hymenoptera, and Lepidoptera during mid-summer (n=10). Lepidoptera and Tricoptera, and Diptera and Tricoptera were used less than available during early and mid summer, respectively. During late summer, red bats consumed mostly Lepidoptera and Coleoptera (n=4). Diptera, Hymenoptera, and Tricoptera were used less than were available.

In California, red bats fed primarily on Lepidoptera and Orthoptera (Ross, 1961, 1967). Coleoptera, Homoptera, Lepidoptera, and Hymenoptera are the most common food items in Indiana and Illinois (Ross, 1967; Whitaker, 1972; Feldhamer *et al.*, 1995), whereas in North Carolina and Florida red bats used mostly Lepidoptera, Coleoptera, and Diptera (Zinn, 1977; Whitaker *et al.*, 1997). Hickey *et al.* (1996) examined the culled moth wings of foraging red bats and hoary bats (*L. cinereus*) in Canada, and found that hoary bats took larger moths than the red bats.

Coleoptera were used heavily during early summer, but consumption decreased as availability decreased during mid and late summer. Thus, red bats apparently are not selective in the bulk of their diets. However, they may develop search images for common prey items resulting in a reduced use of the less common insect orders. Insects from some orders (i.e. Hymenoptera) often emerge in irregular swarms. While not regularly available, these groups may be locally common and can make up a substantial portion of the diet when available.

Seminole bat fecal samples were recovered only during early and mid-summer (Table 1). During early summer, Seminole bats (n=5) consumed mostly Hymenoptera by volume, although Coleoptera and Hemiptera were found in samples more frequently. Coleoptera, Hemiptera, and Tricoptera were used less than available. Coleoptera, Lepidoptera, and Hymenoptera were the primary foods during mid-summer (n=7). Hymenoptera were taken in greater proportion than available, whereas Diptera, Hemiptera, and Tricoptera were avoided.

Until recently, there have been few reports of Seminole bat food habits. Based on four bats from Florida, Seminole bats fed on Coleoptera, Homoptera, Odonata, Diptera, Hymenoptera, and Orthoptera (Sherman, 1935, 1939; Zinn, 1977). Carter *et al.* (1998) examined 24 fecal samples from coastal Georgia and reported that Seminole bats fed primarily on Coleoptera, Lepidoptera, and Hymenoptera and used Homoptera and Diptera less than they were available. In our study, Hymenoptera (primarily, Formicidae) composed a large proportion of the diets, and when found in samples, they usually composed a large proportion of the sample. Indicating that like red bats, these bats may use Hymenoptera when locally common.

During early summer (n=32) and mid summer (n=9), evening bat samples were composed primarily of Coleoptera, Hymenoptera, and Hemiptera (Table 1). Lepidoptera, Diptera, and Tricoptera were consumed less than they were available. Lepidoptera, Tricoptera, and Diptera were used less than available during both these periods. In late summer, evening bat samples (n=4) were composed of Hemiptera, Homoptera, Coleoptera, and Hymenoptera. Coleoptera, Lepidoptera, and Diptera were utilized less than available, whereas Hemiptera and Homoptera were used more than available.

Other studies of the evening bat diets similarly report Coleoptera as the most important food source for evening bats, although Hymenoptera, Hemiptera, and Homoptera also are common (Ross, 1967; Zinn, 1977; Whitaker, 1972; Whitaker and Clem, 1992; Feldhamer *et al.*, 1995; Carter *et al.*, 1998). Carter *et al.* (1998) found that male evening bats used fewer Coleoptera than available. Males, females, and juveniles all used Homoptera less than available and juveniles also utilized Diptera less than available. Lepidoptera, while important for many species of bats, apparently receives little use by this species.

Choice of foraging location is important when considering prey availability. Selection of foraging location can affect diet composition as much as prey selection

within that area. Therefore, foraging ecology should include not only what is consumed but also how that relates to the available insects in the areas where the animals are foraging.

While many insectivorous bats have been reported as diet generalists, all three species we examined exhibited selectivity at all times. Because the bulk of the diets consists of the most common prey items, they may appear as generalists. However, these bats avoided the less common prey taxa, thus demonstrating selectivity. Some of the less common taxa (i.e. Hymenoptera) may be locally common at times, and were used extensively. The samples we examined confirmed the infrequent but substantial use of these ephemeral food resources by these bats. While diet composition may be a factor in the foraging strategy of these bats, it would appear that prey density is also an important component.

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Table 1. -- Percent occurrence (Occ.), and percent volume (Vol.) of insect taxa recovered from fecal samples of three bat species, compared to the insect taxa available (Avl.) by volume in the environment at the Savannah River Site, South Carolina. Significance (Sign.) levels are given for t-tests of percent volume in fecal samples and percent available.

	<i>Lasius borealis</i>			<i>Lasius seminolus</i>			<i>Nycticeius humeralis</i>					
	Occ.	Vol.	Avl.	Sign.	Occ.	Vol.	Avl.	Sign.	Occ.	Vol.	Avl.	Sign.
Early summer												
Coleoptera	100	74	59	ns ¹	80	30	58	0.089	97	51	58	ns
Hemiptera	56	10	19	ns	80	8	20	0.038	69	16	19	ns
Lepidoptera	44	5	8	0.081	40	9	8	ns	59	5	8	0.039
Homoptera	33	3	0	ns	20	10	0	ns	31	3	1	ns
Diptera	0	0	4	ns	0	0	3	ns	3	1	3	0.0001
Hymenoptera	33	8	2	ns	60	43	2	ns	69	23	2	ns
Tricoptera	0	0	7	0.04	0	0	7	0.054	16	1	8	0.056
Neuroptera	0	0	0	ns	0	0	0	ns	0	0	0	ns
Middle summer												
Coleoptera	80	38	48	ns	100	46	52	ns	100	45	49	ns
Hemiptera	80	13	9	ns	43	3	11	0.009	89	15	10	ns
Lepidoptera	50	16	21	ns	71	22	17	ns	78	6	19	0.019
Homoptera	70	10	2	ns	43	6	3	ns	67	13	2	ns
Diptera	0	0	9	0.002	0	0	6	0.0007	0	0	8	0.001
Hymenoptera	70	24	3	ns	86	19	3	0.039	67	20	3	ns
Tricoptera	0	0	6	0.0001	14	4	7	0.073	11	1	7	0.0001
Neuroptera	0	0	2	ns	0	0	1	ns	0	0	2	ns
Late summer												
Coleoptera	75	21	33	ns					100	21	49	0.013
Hemiptera	25	6	5	ns					100	29	6	0.007
Lepidoptera	100	63	41	ns					75	5	25	0.011
Homoptera	50	10	5	ns					100	24	6	0.021
Diptera	0	0	10	0.0003					0	0	6	0.0001
Hymenoptera	0	0	1	0.02					50	18	2	ns
Tricoptera	0	0	5	0.003					25	2	5	ns
Neuroptera	0	0	1	ns					25	1	0	ns

¹ ns = not significant

CHAPTER 4

A NEW METHOD IN THE STUDY OF BAT ACTIVITY PATTERNS

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Abstract: We used an automated receiving system to collect information on signal strength and inter-pulse period from radio transmitters to determine bat activity patterns.

With the automated receiving system, we determined the use of night roosts, daytime activity patterns, foraging time, and times of emergence. With the addition of temperature sensitive transmitters, periods of grooming, time spent in torpor, diurnal roost temperatures, and foraging temperatures also could be examined. This information can be used to construct energy budgets and test for temporal niche separation among bat species.

Key words: activity patterns, bats, data loggers, energy budgets, foraging, *Lasiurus borealis*, telemetry

INTRODUCTION

Radiotelemetry is a reliable method to investigate the movements and activity patterns of wildlife species (Cochran and Lord, 1963; Knowlton et al., 1968; Gilmer et al., 1971). However, often the time between successive observations or the amount of time necessary to collect each observation may limit the precision of the data obtained (Fenton, 1997). Use of an automated receiving system (ARS) can greatly increase the number of observations per unit of time and result in more detailed information. ARS's range from simple drum recorders (Gilmer et al., 1971; Watkins, 1972) to computer-integrated automated systems (Peterson and Dorcas, 1992; Douglas and Pickard, 1992; Exo et al., 1992; Lucas et al., 1992). Some telemetry companies offer data recorders for use with their telemetric equipment, however, these systems are limited to the collection of telemetry data and often are limited to one variable. For example, these systems can record variables like signal strength or pulse period, but not both. We developed a methodology to use data loggers that are independent of the receiving system to record

data on environmental conditions (temperature, light intensity, and relative humidity) as well as multiple inputs from a radio transmitter (inter-pulse period and signal strength).

METHODS AND MATERIALS

We used a Telonics TR-2 receiver (Telonics, Mesa, AZ) and a Telex omnidirectional antenna (Telex Communications Inc., Minneapolis, MN) to receive signals from 0.48-g radio-transmitters (Holohil Systems Ltd., Ontario, Canada). Transmitters were attached between the scapula with Skin Bond® brand surgical adhesive (Pfizer Hospital Products Group, Inc., Largo, Florida). Transmitter weight was < 5% of the weight of the bats (Aldridge and Brigham, 1988). The audible signals were transferred to a Telonics TDP-2 Advanced Digital Data Processor by a mono earphone cord. The signal was relayed from the TDP-2 to a Campbell Scientific 21-X Micrologger (Campbell Scientific, Inc., Logan, Utah) over four wires using differential voltage. The wires were attached to external ports of the Micrologger as specified in the programming. The Micrologger then performed data sampling and data manipulations as dictated by the program. All data was stored in a Campbell Scientific SM192 solid state storage module. A 12-volt external gel cell battery coupled to a solar panel powered the system. The complete system was placed in a plastic food cooler and a desiccant was added to lower humidity. Data were downloaded with the Campbell Scientific PC208 communications software. The total cost of the equipment was approximately \$5000.00.

We evaluated the utility of this system to monitor time of foraging and periods of activity and roosting of bats by positioning the ARS's in close proximity (≤ 20 m) of roost trees. The type of data collected, frequency of data collection, and data processing routines must be programmed into the Micrologger. Processing functions range from simple sampling and mean calculation to complex subroutines, such as automatically

switching on an array of sensors and recording the information from each. We programmed the Micrologger to record signal strength and inter-pulse period (IPP) once every second, to average the signal strength and the IPP over each minute, and to store these averages in the storage module. The time and date each data point also was recorded. The SM192 storage module can store 96,000 alphanumeric characters. In our study, one storage module could store ten days of data. Storage modules were easily switched in the field, allowing continuous monitoring during downloading and processing of data.

We calibrated the system to link variations in signal strength and IPP to corresponding degrees of activity. To calibrate the ARS, we conducted distance and position trials (Fig. 1). In these trials, we placed the transmitter in five positions to simulate bat positions: vertical (roosting position), vertical with a bend (roosting with the antenna slightly bent on foliage), vertical with a strong bend (roosting under bark), and two horizontal positions (flying position, one parallel and one perpendicular). At each distance and position, we recorded signal strength and IPP.

Although the transmitters that we used (LB-2, Holohil Systems Ltd.) were not designed to be temperature sensitive, temperature significantly affected inter-pulse period ($R^2 = 0.998$, $p \leq 0.001$). Thus, the IPP from LB-2 transmitters can be used as a relative indication of the temperature of the bat (Fig. 2).

RESULTS

We processed the data with Quattro Pro (Novell, Inc.) and generated graphs of IPP and signal strength over time. From these data we calculated the percent of the time an individual spent roosting, foraging, on night roosts, grooming, and out of range. We also could estimate the number of times the bats shifted on the roost, number of times they changed roosts, and the number of different night roosts used. Also, the earliest

and latest periods of activity can be determined. Therefore, data generated with this method can be used to compare the activity patterns of the bats of different species, age, or sex. By placing transmitters on individual of the same species in areas subject to different management practices, these data also can be used to examine the effect of land management practices on the activity patterns of bats.

An example of a data set obtained from one individual *Lasiurus borealis* during an 18 hour period is presented in Fig. 3. Once calibrated, the recorded data were easily interpreted. By examining the IPP, we determined when the bat warmed from torpid to an active temperature prior to flying (Fig. 3 @ 2000h). We also determined times when the temperature of the bats increased to the active level but the bat did not fly (Fig. 3 @ 0500h). During these periods, the bat likely was grooming. Although temperature affects the IPP of most transmitters, the transmitters we used were not designed to collect temperature data. Use of transmitters manufactured for the collection of temperature data (Barclay et al., 1996) would allow interpretation of more subtle changes in activity patterns. Roosting (inactive periods) was indicated by a constant signal strength and a constant IPP with a cooling down and warming up trend at the beginning and end of the roosting period (Fig. 3 @ 1900h, 0100h, 0400h). The signal strength and IPP shifted erratically when the bat was flying, with the strength of the signal decreasing as the distance between the bat and the ARS increased (Fig. 3 @ 2145 – 2300h). Because signal strength differed during the various roosting times, the data suggest that the bat used different night roosts (Fig. 3 @ 1900h, 0100h, 0400h).

This ARS also facilitates the analysis of microhabitat characteristics by roosting bats. Because the resting temperature of bats often falls to $\pm 1^\circ$ C of ambient temperature, this system can be used to investigate roost temperature selection. Temperatures of active bats on the roost also can be evaluated. When used in conjunction with external sensors, the Micrologger can monitor environmental

temperatures, humidity, barometric pressure and light intensity of many other unused roost locations. These reading then can be compared with information received from the bat to assess habitat preferences.

CONCLUSION

The ARS we devised using the Campbell Scientific Micrologger is a versatile system capable of collecting data that can not be obtained using other ARS's or traditional radio-telemetric techniques. Therefore, this system provides researchers with the ability to investigate important and unknown aspects of bat ecology.

ACKNOWLEDGEMENTS

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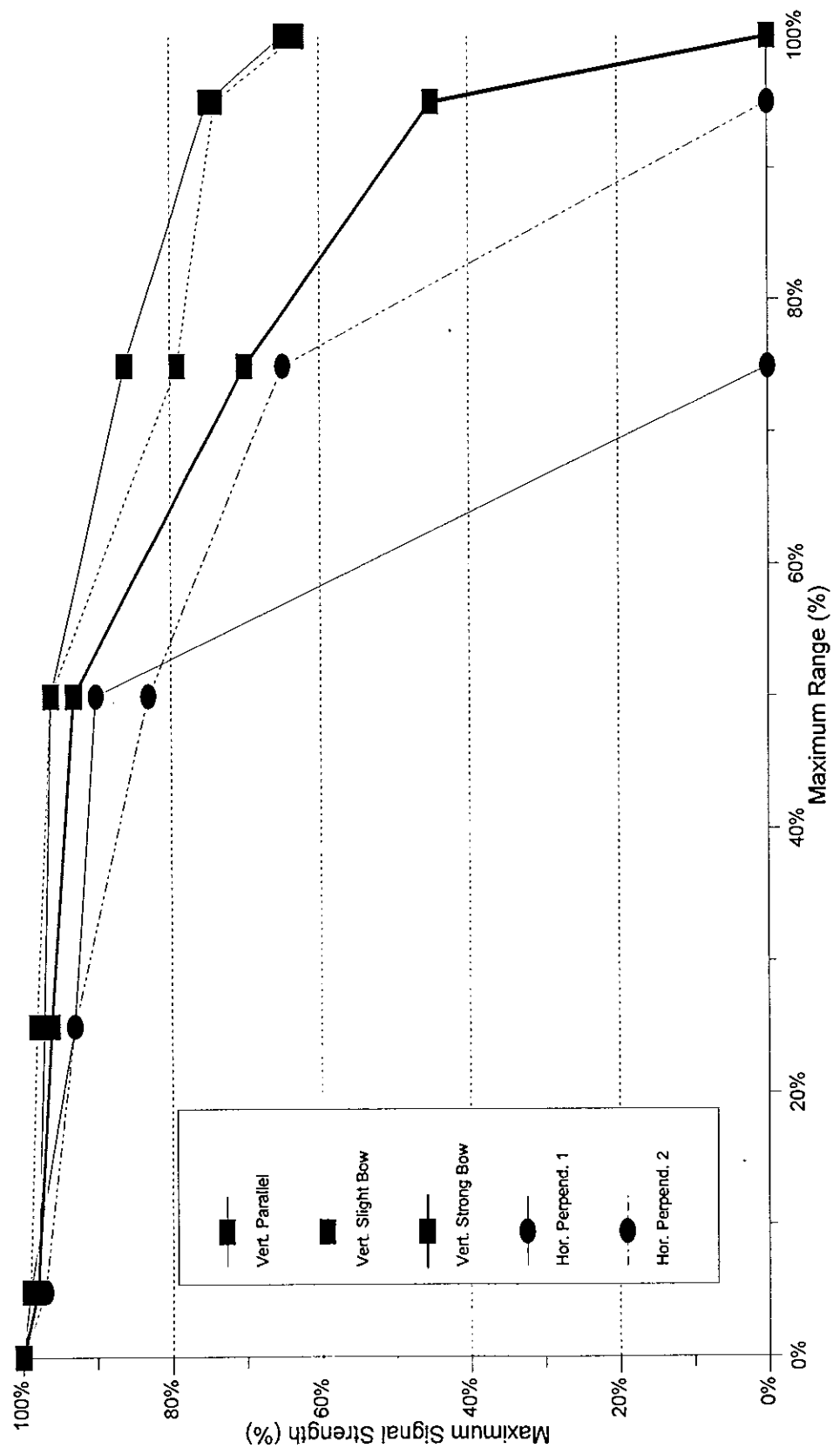
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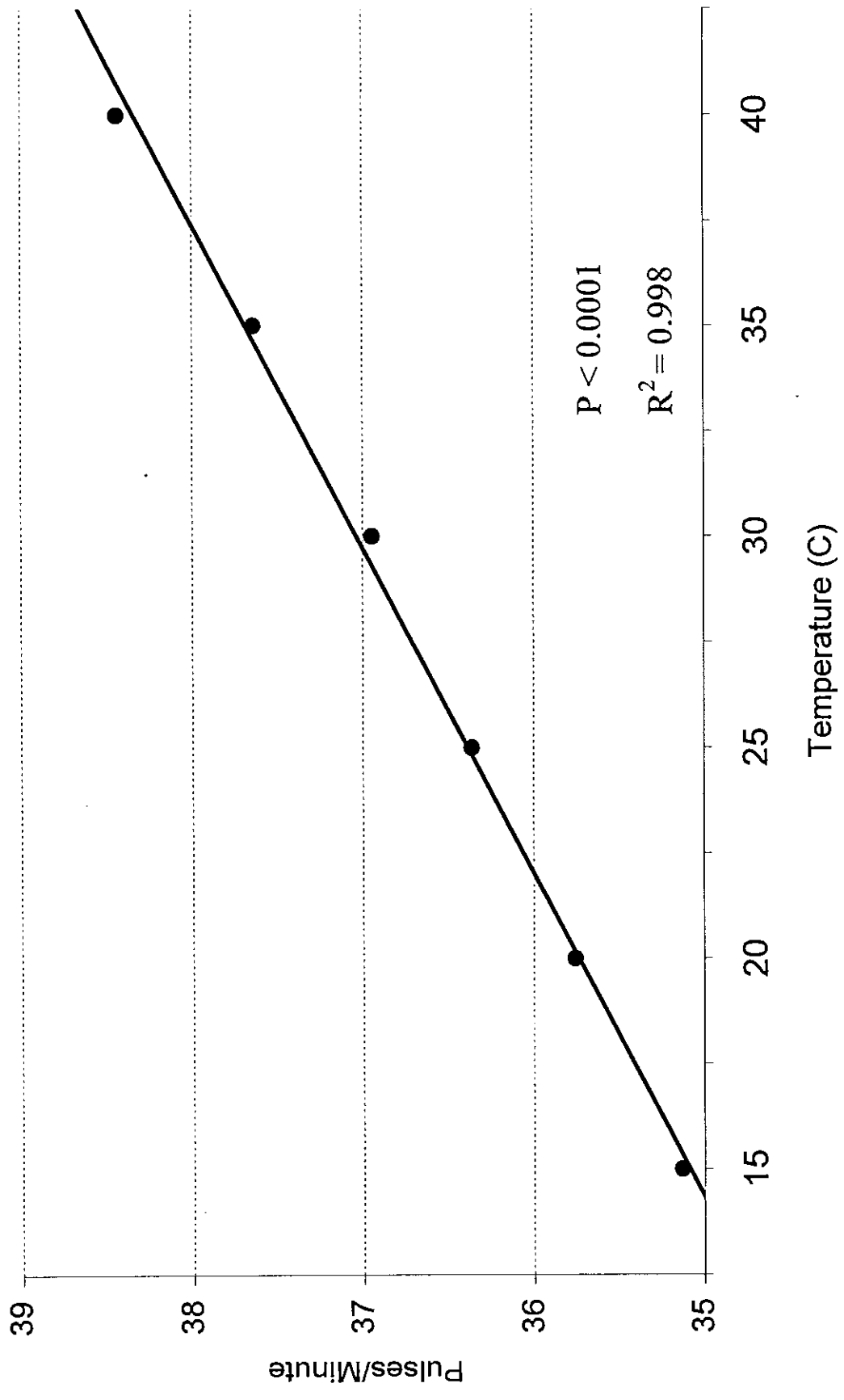
Figure Legends

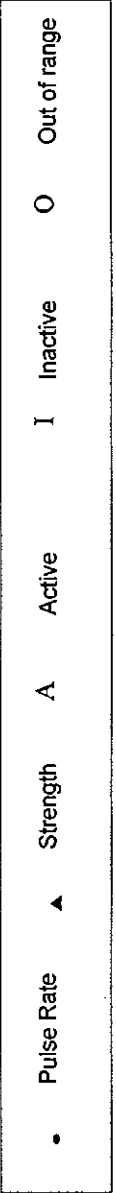
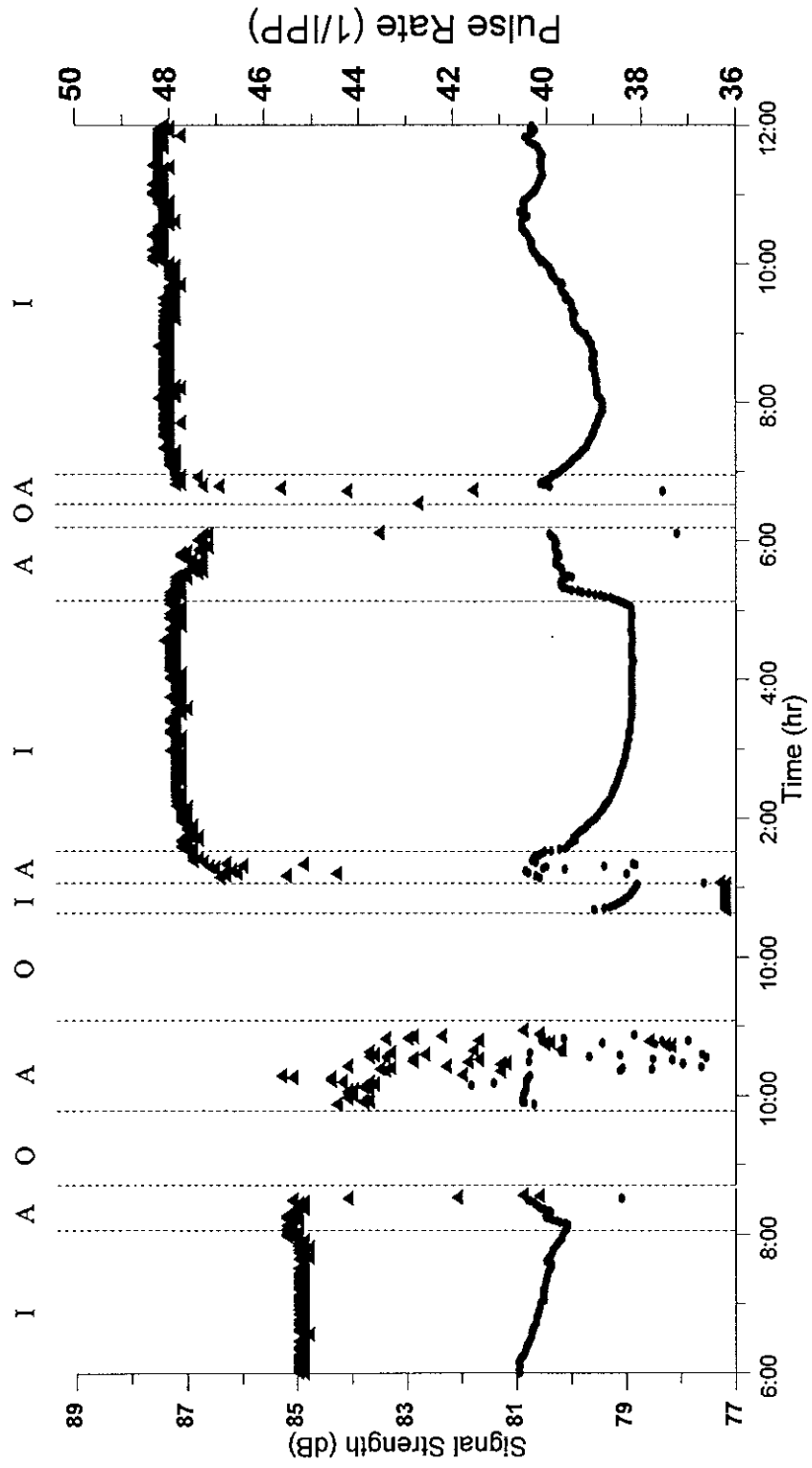
Fig 1.-- Calibration test of position and distance on strength readings of a transmitter. Transmitters were placed at five different positions at known distances from the automated receiving system.

Fig 2.-- Calibration test of the effects of temperature on inter-pulse period.

Fig 3.-- Example of the activity pattern of an individual red bat (*Lasiurus borealis*) after calibration of equipment. Pulse rate (1/inter-pulse period) is reported for ease of interpretation of the figures.







Appendix 1

Micrologger program.

To start type

*1A

Screen [enter]

1:	1 A	Program 1
1:P	10 A	Battery Voltage
1:	1 A	
2:P	02 A	Voltage differential (IPP)
1:	1 A	
2:	5 A	
3:	5 A	
4:	2 A	
5:	1 A	
6:	0 A	
3:P	02 A	Voltage differential (Amplitude)
1:	1 A	
2:	5 A	
3:	6 A	
4:	3 A	
5:	0.0311 A	(0D0311A)
6:	2.5032 A	(2D5032A)
4:P	92 A	On time, do
1:	0 A	
2:	1 A	
3:	10 A	
5:P	77 A	Date Stamp
1:	0110 A	
6:P	71 A	Ave. Output Memory
1:	2 A	
2:	2 A	
7:P	96 A	Output to SM192
1:	30 A	

CHAPTER 5

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Bats are important components of forested ecosystems. My data collected at the Savannah River Site, National Environmental Research Park suggest that red (*Lasiurus borealis*), Seminole (*L. seminolus*), and evening (*Nycticeius humeralis*) bats are habitat generalists in regard to foraging habitat use. All three species primarily used bottomland hardwood forests and pine forests; the most common habitats in the study area. All three species tended to use edge habitats more than available.

The diets of these bats are species-specific. Red bats use mostly Lepidoptera and Coleoptera. Seminole bats feed primarily on Coleoptera and Hymenoptera. The evening bats consumed primarily Coleoptera, Hymenoptera, and Hemiptera. All three species avoided insect orders with low relative abundances, suggesting that their foraging strategy considers prey density as well as prey composition.

The habitat use and feeding patterns of the three species of bats we studied suggests that these bats would be resilient to changes in habitat structure and food resources. These species used the habitats that were available to them. However, none of the species used a single habitat exclusively, suggesting that these species may need more than one habitat for securing all resources. Therefore, maintaining the mosaic of habitats present at the Savannah River Site may be important. Conversion of large areas into a single habitat type may remove one or more needed resources, such as edge habitat.

Management practices should be timed around parturition in areas were bats may have chosen to establish maternity colonies or in areas that are heavily used as

foraging sites. In addition, the methods used in establishing or maintaining managed forests are important to consider. Maintaining vegetation diversity within a stand will provide the substrate necessary for a diverse prey base.

APPENDIX A

DATA OF SUMMER HOME-RANGE AND HABITAT USE OF THE RED
(*LASIURUS BOREALIS*), SEMINOLE (*L. SEMINOLUS*), AND EVENING BATS
(*NYCTICEIUS HUMERALIS*).

Appendix A. 1. Home range size of bats tracked at the Savannah River Site National Environmental Research Park, South Carolina, during June through August, 1996 and 1997. Size in hectares for 95, 60, and 30% confidence interval. Home ranges calculated using CALHOME (Kie et al., 1996) with the adaptive kernel method (default bandwidth and -50 grid cell size).

Code	Species	Condition	Time	95%	60%	30%	# of Pts.
labo	<i>Lasiurus borealis</i>	f - lac	June	182.3	16.5	1.6	24
labo	<i>Lasiurus borealis</i>	f - lac	June-July	125.8	14.2	4.8	30
labo	<i>Lasiurus borealis</i>	f - juv	July	514.4	57.8	30.7	47
labo	<i>Lasiurus borealis</i>	f - ad	July-August	564.9	80.4	8.7	24
labo	<i>Lasiurus borealis</i>	m - juv	July-August	878.5	5.4	1.6	42
lase	<i>Lasiurus seminolus</i>	m - ad	June	189.2	28.8	5.2	44
lase	<i>Lasiurus seminolus</i>	f - lac	July	279.6	12.7	4.6	52
lase	<i>Lasiurus seminolus</i>	f - juv	July-August	282.5	14.8	1.5	75
lase	<i>Lasiurus seminolus</i>	f - juv	July-August	704.4	32.6	7.3	82
lase	<i>Lasiurus seminolus</i>	m - juv	August	663.3	97.2	9.8	55
nyhu	<i>Nycticeius humeralis</i>	m - ad	June-July	298.0	4.4	1.6	29
nyhu	<i>Nycticeius humeralis</i>	f - ad	July	68.9	14.1	2.2	45
nyhu	<i>Nycticeius humeralis</i>	f - lac	July-August	38.7	5.3	2.1	24
nyhu	<i>Nycticeius humeralis</i>	f - ad	August	148.1	19.6	2.9	51
nyhu	<i>Nycticeius humeralis</i>	f - ad	August	397.4	53.0	13.4	33
nyhu	<i>Nycticeius humeralis</i>	f - juv	August	761.0	179.7	41.4	34
pisu	<i>Pipistrellus subflavus</i>	f - ad	August	395.6	56.0	15.4	40

Appendix A. 2. Distribution of bat locations by habitat type at the Savannah River Site National Environmental Research Park, South Carolina, during June through August, 1996 and 1997.

Year	Species	Bottomland	Uplands	Pine Stands	Water Areas	Total
1996	epfu ¹	10	1	1	2	14
1996	labo	3	0	10	10	23
1996	labo	3	0	3	3	9
1996	labo	5	2	24	10	41
1996	labo	1	0	0	0	1
1996	labo	14	5	2	1	22
1996	labo	0	0	23	7	30
1996	labo	2	1	3	2	8
1996	labo	7	0	3	0	10
1997	labo	12	0	3	0	15
1997	labo	13	1	13	20	47
1997	labo	13	0	0	4	17
1996	lase	2	0	2	0	4
1996	lase	15	5	31	1	52
1997	lase	11	20	18	6	55
1997	lase	4	2	58	12	76
1997	lase	6	1	3	8	18
1997	lase	15	2	22	5	44
1997	lase	9	2	53	17	81
1996	nyhu	2	0	45	5	52
1996	nyhu	0	0	4	0	4
1996	nyhu	2	0	2	1	5
1996	nyhu	15	4	3	0	22
1996	nyhu	2	0	20	2	24
1996	nyhu	2	0	5	0	7
1996	nyhu	25	1	2	1	29
1996	nyhu	0	0	1	1	2
1996	nyhu	7	2	2	0	11
1997	nyhu	1	1	23	8	33
1997	nyhu	8	1	19	6	34
1997	nyhu	5	1	13	2	21
1997	nyhu	4	1	9	1	15
1997	nyhu	11	0	21	13	45
1997	nyhu	1	0	11	4	16
1997	nyhu	6	0	13	3	22
1996	pisu	17	12	16	4	49

¹ *Eptesicus fuscus*

Appendix A. 3. Distribution of bat locations along edge habitat at the Savannah River Site National Environmental Research Park, South Carolina, during June through August, 1996 and 1997.

spec	Edge habitat	Total Points	Percent Use
labo	14	23	61
labo	26	41	63
labo	14	22	64
labo	8	30	27
labo	3	15	20
labo	17	47	36
labo	0	17	0
lase	22	55	40
lase	60	76	79
lase	12	18	67
lase	31	52	60
lase	20	44	45
lase	52	81	64
nyhu	23	52	44
nyhu	12	33	36
nyhu	15	34	44
nyhu	15	22	68
nyhu	2	24	8
nyhu	2	21	10
nyhu	1	15	7
nyhu	7	45	16
nyhu	13	16	81
nyhu	5	29	17
nyhu	14	22	64
pisu	5	49	10

Appendix A. 4. Percent habitat composition of bat home-ranges at the Savannah River Site National Environmental Research Park, South Carolina, during June through August, 1996 and 1997.

Species	Bottomlands	Pine Stands	Uplands
labo	58.6	35.5	5.8
labo	26.0	73.0	1.1
labo	37.9	52.2	9.9
labo	59.3	28.9	11.8
labo	98.3	6.2	1.7
lase	50.8	42.9	6.3
lase	90.5	7.7	1.8
lase	43.2	49.8	7.0
lase	83.6	13.6	2.8
lase	61.2	33.4	5.4
nyhu	78.7	18.6	2.7
nyhu	58.9	37.4	3.7
nyhu	15.8	84.2	0.0
nyhu	86.5	9.5	4.0
nyhu	74.4	25.6	0.0
pisu	87.8	9.6	2.5

Appendix A. 5. Percent distribution of available habitats based on proportions of a 4-km circle over the study area at the Savannah River Site National Environmental Research Park, South Carolina, 1996 and 1997.

Habitat	Percent
Bottomlands	71
Pine Stands	27
Uplands	2
Water Areas	24
Non-Water Areas	76
Edge Habitat	12
Non-Edge Habitat	88

APPENDIX B

DATA FROM THE FEEDING ECOLOGY OF THE RED (*LASIURUS BOREALIS*),
SEMINOLE (*L. SEMINOLUS*), AND EVENING BATS (*NYCTICEIUS HUMERALIS*).

Appendix B. 1. Distribution of all bat locations by species in each of three time periods: early, middle, and late summer, 1996 and 1997 at Savannah River Site National Environmental Research Park, South Carolina.

Period	Code	Species	Pine Stand	Uplands	Bottomlands	Water Areas	Harvested Areas	Total
early	LABO	<i>Lasiurus borealis</i>	58	7	40	1	7	113
early	LASE	<i>Lasiurus seminolus</i>	51	8	33	0	0	92
early	NYHU	<i>Nycticeius humeralis</i>	83	5	39	5	26	158
middle	LABO	<i>Lasiurus borealis</i>	48	1	40	18	2	109
middle	LASE	<i>Lasiurus seminolus</i>	109	12	23	50	1	195
middle	NYHU	<i>Nycticeius humeralis</i>	25	0	12	13	0	50
late	EPFU	<i>Eptesicus fuscus</i>	1	1	10	0	3	15
late	LABO	<i>Lasiurus borealis</i>	3	0	5	0	1	9
late	LASE	<i>Lasiurus seminolus</i>	20	12	17	3	0	52
late	NYHU	<i>Nycticeius humeralis</i>	87	3	21	13	0	124
late	PISU	<i>Pipistrellus subflavus</i>	7	11	10	2	9	39

Appendix B. 2. Percent composition by volume of fecal samples from bats collected during early, middle, and late summer from Savannah River Site National Environmental Research Park, North Carolina, during 1996 and 1997.

Species	Period	Sex	Rel. Age	# Pellets	Coleo	Hemi	Lepido	Homo	Diptera	Hymen	Tricop	Neurop
labo	early	f-lac	adult	15	90	0	5	5	0	0	0	0
labo	early	f-lac	adult	15	85	0	10	5	0	0	0	0
labo	early	f-lac	adult	4	100	0	0	0	0	0	0	0
labo	early	f-lac	adult	6	90	0	10	0	0	0	0	0
labo	early	f-lac	adult	15	35	30	0	0	0	35	0	0
labo	early	f-lac	adult	7	75	25	0	0	0	0	0	0
labo	early	f-lac	adult	6	60	20	0	0	0	20	0	0
labo	early	f	juv.	4	95	5	0	0	0	0	0	0
labo	early	m	juv.	7	35	15	20	15	0	15	0	0
lase	early	f-lac	adult	3	0	5	0	0	0	95	0	0
lase	early	f-lac	adult	7	30	15	15	0	0	40	0	0
lase	early	m	adult	3	60	10	30	0	0	0	0	0
lase	early	m	adult	4	10	10	0	0	0	80	0	0
lase	early	m	adult	2	50	0	0	50	0	0	0	0
myau ¹	early	m	adult	15	0	0	100	0	0	0	0	0
nyhu	early	f	adult	20	40	30	15	0	0	10	5	0
nyhu	early	f	adult	5	90	10	0	0	0	0	0	0
nyhu	early	f-lac	adult	20	90	5	5	0	0	0	0	0
nyhu	early	f-lac	adult	8	20	15	5	0	0	60	0	0
nyhu	early	f-lac	adult	13	45	15	5	5	0	30	0	0
nyhu	early	f-lac	adult	10	0	0	0	0	0	100	0	0
nyhu	early	f-preg	adult	7	100	0	0	0	0	0	0	0
nyhu	early	f-preg	adult	1	85	0	0	15	0	0	0	0
nyhu	early	f-preg	adult	14	40	5	0	20	0	35	0	0
nyhu	early	f-lac	adult	9	85	5	5	0	0	5	0	0
nyhu	early	f-lac	adult	4	25	45	5	0	0	25	0	0
nyhu	early	f-lac	adult	3	80	0	0	0	5	15	0	0
nyhu	early	f-lac	adult		20	5	10	0	0	60	5	0
nyhu	early	f-preg	adult	17	30	15	5	0	0	35	15	0
nyhu	early	m	adult	3	55	15	5	10	0	15	0	0

Appendix B. 2. Continued

Species	Period	Sex	Rel. Age	# Pellets	Coleo	Hemi	Lepido	Homo	Diptera	Hymen	Tricop	Neurop
nyhu	early	m	adult	9	60	5	5	0	0	30	0	0
nyhu	early	m	adult	4	60	35	5	0	0	0	0	0
nyhu	early	m	adult	9	70	0	5	0	0	25	0	0
nyhu	early	m	adult	15	15	75	10	0	0	0	0	0
nyhu	early	m	adult	2	100	0	0	0	0	0	0	0
nyhu	early	m	adult	22	25	50	10	10	0	0	5	0
nyhu	early	m	adult	5	60	15	10	5	0	10	0	0
nyhu	early	m	adult	3	10	0	0	0	0	90	0	0
nyhu	early	m	adult	1	55	0	0	0	0	45	0	0
nyhu	early	m	adult	15	20	35	25	5	0	10	5	0
nyhu	early	m	adult	6	30	20	5	5	0	40	0	0
nyhu	early	f	juv.	4	50	35	0	0	0	15	0	0
nyhu	early	f	juv.	10	40	25	5	0	0	30	0	0
nyhu	early	f	juv.	3	90	0	0	10	0	0	0	0
nyhu	early	f	juv.	3	80	0	15	0	0	5	0	0
nyhu	early	m	juv.	1	45	35	0	20	0	0	0	0
nyhu	early	m	juv.	1	25	25	0	0	0	0	0	0
nyhu	early	m	adult	5	40	30	15	15	0	0	0	0
pisu	early	m	adult	2	33	33	0	0	0	33	0	0
pira ²	early	m	adult	7	95	0	0	0	0	0	5	0
epfu	middle	f	adult	3	65	10	25	0	0	0	0	0
labo	middle	f	adult	3	0	0	0	0	0	100	0	0
labo	middle	m	adult	5	35	15	0	10	0	40	0	0
labo	middle	f	juv.	7	90	5	0	5	0	0	0	0
labo	middle	f	juv.	12	45	25	5	10	0	15	0	0
labo	middle	f	juv.	15	80	10	0	5	0	5	0	0
labo	middle	f	juv.	4	15	35	0	35	0	15	0	0
labo	middle	m	juv.	1.5	10	0	90	0	0	0	0	0
labo	middle	m	juv.	7	40	15	10	15	0	20	0	0
labo	middle	m	juv.	3	0	15	30	15	0	40	0	0
lase	middle	f	adult	7	60	0	0	0	0	40	0	0
lase	middle	f	juv.	10	90	5	0	0	0	5	0	0

Appendix B. 2. Continued

Species	Period	Sex	Rel. Age	# Pellets	Coleo	Hemi	Lepido	Homo	Diptera	Hymen	Tricop	Neurop
lase	middle	f	juv.	3	30	0	50	0	0	20	0	0
lase	middle	f	juv.	?	5	5	60	0	0	0	30	0
lase	middle	f	juv.	4	60	0	5	5	0	30	0	0
lase	middle	f	juv.	5	40	10	5	15	0	30	0	0
lase	middle	f	juv.	3	35	0	35	20	0	10	0	0
nyhu	middle	f	adult	7	20	24	8	15	0	33	0	0
nyhu	middle	f	adult	15	30	25	5	25	0	10	5	0
nyhu	middle	f-lac	adult		65	10	5	10	0	10	0	0
nyhu	middle	f	juv.		70	0	15	15	0	0	0	0
nyhu	middle	f	juv.	8	75	5	0	0	0	20	0	0
nyhu	middle	f	juv.	6	65	25	10	0	0	0	0	0
nyhu	middle	f	juv.	5	30	25	0	45	0	0	0	0
nyhu	middle	f	subadult	6	25	5	5	5	0	60	0	0
nyhu	middle	m	subadult	12	30	15	5	0	0	50	0	0
epfu	late	f	juv.	6	55	35	5	5	0	0	0	0
labo	late	f	juv.	11	30	0	70	0	0	0	0	0
labo	late	f	juv.	2	0	0	100	0	0	0	0	0
labo	late	f	juv.	8	50	0	25	25	0	0	0	0
labo	late	f	subadult	10	5	25	55	15	0	0	0	0
myau	late	m		5	25	0	75	0	0	0	0	0
mylu	late	f	adult	6	30	0	70	0	0	0	0	0
nyhu	late	f	adult	15	10	25	5	10	0	45	0	5
nyhu	late	f	adult	9	25	25	0	25	0	25	0	0
nyhu	late	m	adult	3	35	20	10	35	0	0	0	0
nyhu	late	f	juv.	15	15	45	5	25	0	0	10	0
pisu	late	f	adult	1	0	10	10	0	0	0	80	0

1 *Myotis austroriparius*2 *Plecotus rafinesquii*

Appendix B. 3. Percent composition by volume of insect samples collected during early, middle, and late summer from Savannah River Site National Environmental Research Park, South Carolina, during 1996 and 1997.

Period	Stand	Coleoptera	Hemiptera	Lepidoptera	Homoptera	Diptera	Hymenoptera	Tricoptera	Other
early	Bottomlands	75	10	10	0	2	0	3	0
early	Bottomlands	68	10	15	2	5	0	0	0
early	Bottomlands	90	1	7	1	0	1	0	0
early	Bottomlands	50	0	20	0	30	0	0	0
early	Harvested Areas	78	10	5	1	2	1	3	0
early	Harvested Areas	55	7	10	2	3	3	20	0
early	Harvested Areas	89	3	4	0	0	3	1	0
early	Harvested Areas	44	8	25	5	5	5	8	0
early	Pine Stands	55	40	1	0	0	2	2	0
early	Pine Stands	25	30	5	0	0	5	30	5
early	Pine Stands	68	25	3	0	0	2	2	0
early	Uplands	62	5	15	0	3	0	15	0
early	Uplands	90	2	2	2	2	1	1	0
early	Uplands	45	3	45	0	0	0	0	7
early	Water Areas	90	5	5	0	0	0	0	0
early	Water Areas	73	2	20	0	0	0	0	5
early	Water Areas	20	5	60	0	10	0	0	5
early	Water Areas	43	3	35	5	0	1	5	8
middle	Bottomlands	37	10	25	3	5	0	0	20
middle	Bottomlands	65	5	20	0	5	0	5	0
middle	Bottomlands	40	0	30	5	15	10	0	0
middle	Bottomlands	5	0	55	1	30	0	1	8
middle	Bottomlands	26	7	30	1	24	1	11	0
middle	Harvested Areas	50	5	20	5	5	5	10	0
middle	Harvested Areas	45	15	10	10	5	10	5	0
middle	Harvested Areas	74	4	15	3	1	0	3	0
middle	Harvested Areas	65	4	23	2	3	1	2	0
middle	Harvested Areas	40	5	40	3	5	2	3	2
middle	Harvested Areas	50	10	30	2	5	1	2	0
middle	Pine Stands	43	5	30	2	5	5	10	0
middle	Pine Stands	51	15	10	2	2	15	5	0

Appendix B. 3. Continued

Period	Stand	Coleoptera	Hemiptera	Lepidoptera	Homoptera	Diptera	Hymenoptera	Tricoptera	Other
middle	Pine Stands	78	9	1	1	5	0	6	0
middle	Pine Stands	70	9	2	5	7	3	4	0
middle	Pine Stands	60	30	0	1	4	1	4	0
middle	Uplands	40	5	40	5	5	0	5	0
middle	Uplands	43	8	40	5	2	2	0	0
middle	Uplands	71	11	5	4	6	0	3	0
middle	Uplands	40	5	35	5	5	0	5	5
middle	Uplands	70	5	15	4	3	1	2	0
middle	Water Areas	10	2	75	0	2	0	8	3
middle	Water Areas	55	5	15	5	5	0	15	0
middle	Water Areas	40	10	25	5	5	0	15	0
middle	Water Areas	60	16	8	3	3	2	8	0
middle	Water Areas	45	7	14	2	16	2	14	0
late	Bottomlands	7	0	80	4	7	0	0	2
late	Bottomlands	5	5	70	0	8	0	2	10
late	Bottomlands	20	2	35	5	23	0	15	0
late	Bottomlands	35	5	40	5	10	0	5	0
late	Bottomlands	20	4	50	2	20	2	2	0
late	Harvested Areas	5	2	85	2	5	0	1	0
late	Harvested Areas	25	3	50	10	5	0	7	0
late	Harvested Areas	70	2	19	1	5	0	3	0
late	Harvested Areas	35	15	40	5	5	0	0	0
late	Harvested Areas	47	5	30	5	5	0	8	0
late	Pine Stands	45	3	29	12	6	3	3	0
late	Pine Stands	58	10	10	5	5	2	10	0
late	Pine Stands	81	10	4	1	3	1	0	0
late	Pine Stands	50	8	15	12	5	5	5	0
late	Pine Stands	55	5	20	8	2	0	10	0
late	Uplands	78	10	5	5	0	2	0	0
late	Uplands	15	2	70	2	5	2	2	0
late	Uplands	5	3	85	1	2	1	2	1
late	Uplands	79	10	5	1	4	0	1	0
late	Uplands	35	3	49	5	5	1	2	0

Appendix B. 3. Continued

Period	Stand	Coleoptera	Hemiptera	Lepidoptera	Homoptera	Diptera	Hymenoptera	Tricoptera	Other
late	Uplands	30	1	45	10	5	1	8	0
late	Water Areas	40	0	45	0	15	0	0	0
late	Water Areas	5	0	85	2	5	0	3	0
late	Water Areas	83	4	4	3	4	1	1	0
late	Water Areas	60	5	15	5	5	5	5	0