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Habitat Use of Urban Bats in Springfield, Missouri

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HABITAT USE OF URBAN BATS IN SPRINGFIELD, MISSOURI

A Thesis

Presented to

The Graduate Faculty of the Department of Biology

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Sarah Jane Robertson

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Biology Department

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ABSTRACT

During the summers of 1998-2000, the Anabat II bat detector system was placed in a mosaic of habitats within Springfield, Missouri and surrounding rural areas in southern Missouri to compare the activity indices of nine bat species between urban and rural environments. A total of 1,876 echolocation call sequences was recorded, identified to species and analyzed; 1,066 were from 42 Springfield sites, and 810 were from 22 rural locations. For all species combined, urban bat activity tended to be higher than rural activity, but those differences were only significant at the reading taken 3 hours after sunset. *Eptesicus fuscus* activity was significantly higher in the urban environment while *Myotis septentrionalis* activity was significantly higher in rural environments. For *Myotis lucifugus, M. grisescens, M. sodalis*, *Lasiurus borealis*, *L. cinereus* and *Nycticeius humeralis* there were no significant differences between urban and rural bat activity scores. Springfield was divided into five different habitat types in which passive boxes were placed from sunset until 07:00 hours. The five habitat types included: parks, parks with caves, ponds, residential neighborhoods, and commercial areas. *Eptesicus fuscus* activity was recorded over all the microhabitats within Springfield, and there were no significant differences among habitats. *Lasiurus cinereus* and *Myotis septentrionalis* activity was recorded over residential neighborhoods. *Lasiurus borealis* and *Myotis grisescens* were recorded over all but commercial areas, with activity for *M. grisescens* being highest in parks with caves. *Myotis lucifugus* activity was over residential ponds and parks with and without caves, and *M. sodalis* was recorded over parks with caves. *Pipistrellus subflavus* activity was highest over parks with caves even though activity was recorded over all the sampled microhabitats. Radio telemetry was employed during the summers of 1999 and 2000, and the foraging habitats and roosting sites were determined for six *Eptesicus fuscus*, four *Lasiurus borealis*, one *Pipistrellus subflavus* and one *Myotis grisescens*.

This abstract is approved as to form and content

Lynn Robbins, Ph.D.
Chairman, Advisory Committee
Southwest Missouri State University

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INTRODUCTION

When compared to native ecosystems, the urban environment is severely disturbed and dominated by humans and their artifacts (Stearns and Ross, 1978). A conspicuous consequence of urban development is that it fragments natural habitats into a mosaic of smaller, more isolated units of differing size and shape (Dickman, 1987; Adams and Dove, 1989). The vegetation within these patches is sometimes little changed from that of natural flora present before urbanization, however, there commonly exists continuous disturbance from humans as well as invasion of a few exotic, introduced species such as the house sparrow (*Passer domesticus*) and starling (*Sturnus vulgaris*) (Kunick, 1982; Johnsen and VanDruff, 1987). As these vegetative patches approach the urban center, they become even smaller and more isolated due to the surrounding roads, cleared areas, buildings and residential areas, and this typically brings about a reduction in species richness (Cousins, 1982; Adams and Dove, 1989).

The application of island biogeography theory to these terrestrial habitat "island" patches has been suggested by Davis and Glick (1978). Within each city there exists a conglomeration of habitat islands, and these islands' viability as suitable wildlife habitat depends considerably upon immigration of animals. This immigration is affected by the spatial arrangement of the islands and the greenways (Salwasser, 1987) or corridors extending from these urban patches toward outlying rural areas. A small city has been likened to functionally similar large oceanic islands close to the mainland; corridors to both urban "islands" and oceanic islands are relatively short and easily traversed by a variety of organisms (Davis and Glick, 1978). However, as with the theory of island biogeography, the number of new species immigrating onto the island patches in a city

will eventually drop as the individuals arriving will already have conspecifics established. The rate of extinction will ultimately rise, mainly due to the fact that every species runs the risk of becoming extinct, and the more species that have arrived, the more species that are at risk (Cox and Moore, 1995). Initially, a small number of species can occupy several niches for lack of competition found on the "mainland". These species may become overly abundant, however, and competition will arise with the arrival of more species, resulting in smaller population sizes. Smaller populations are more prone to extinction, and thus, with the arrival of new species to urban "islands," the rate of extinction must rise until equilibrium is reached between colonization and extinction (Cox and Moore, 1995).

When taking conservation values into consideration, the most commonly used criterion is species richness, defined as the number of species in a habitat patch (Margules and Usher, 1981). This criterion is most strongly influenced by area and the type and diversity of the habitat, in relatively undisturbed sites (Dickman, 1987). In urban environments, factors such as pollution and high levels of human disturbance influence species richness (Davis, 1982). Cousins' (1982) study of bird populations showed that species richness was negatively correlated with the degree of urbanization (Dickman, 1987). Dickman's study (1987) of vertebrates in an urban environment found that mammalian species richness declined rapidly with barren ground within patches, such as paths, and also with increasing contiguity to houses. Vegetation density, especially 21-50 cm above ground, typically increases numbers of mammalian species, but this is sparse in urban environments. The few species of reptiles and amphibians encountered occurred equally in undisturbed and disturbed patches, and were sometimes

abundant in cultivated gardens. The main limiting factor for amphibians was proximity to water. For all the vertebrate taxa combined, more species were found in two smaller vegetative patches than would be expected in one large patch equivalent to their combined areas.

There are varying degrees of urbanization, from heavily industrialized locations of concrete seas, to more of an agricultural setting with low-density residential areas and surrounding farmland. Leedy and Adams (1986) summarized the features that characterize most urban areas:

1. Buildings, streets, roads, parking lots, and other artificial constructions occupy much of the ground surface and form a largely impermeable and sterile covering of the soil which probably once supported native vegetation or cultivated crops.
2. Runoff from paved areas is higher and more rapid with little infiltration to the underlying strata, which means a reduced rate of recharging of natural groundwater reservoirs and a lowering of the water table.
3. Reduction in groundwater results in increased variation in natural stream flows.
4. Runoff, particularly the first surges following a storm, may contain pollutants and toxic materials stemming from the urbanized areas.
5. Runoff from new construction in urban areas carries much more sediment per unit of area to receiving waters than runoff from developed areas or even from agricultural areas.

6. Rainfall often increases downwind in heavily urbanized and industrialized areas.
7. The urban cores of large cities are generally warmer than the outer suburbs or surrounding countryside.
8. Air and noise pollution often are considerably greater in urbanized locations as compared with surrounding areas.
9. Except for well-tended, heavily fertilized, and mulched lawn and garden areas, urban soils are likely to be modified detrimentally by mixtures of bricks and other building materials, and by compaction and loss of topsoil.
10. Urban development often results in a loss of wildlife species considered specialists, and an increase of species considered generalists.
11. Urban areas generally have fewer species of wildlife but a greater total animal biomass than non-urban areas.

The two aforementioned avian species and other introduced species such as Norway rats (*Rattus norvegicus*) (Johnsen and VanDruff, 1987), house mice (*Mus musculus*) (Schwartz and Schwartz, 1981), and native species such as raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*) (Rosatte et al., 1987), opossums (*Didelphis virginianis*), and white-tail deer (*Odocoileous virginianis*) (Whitham and Jones, 1986; Koch, 2000) are among species readily encountered in urban environments. Because of their ease in adapting to human development, in many cases, these animals become too prolific, and populations become diseased, suffer from lack of food, or their numbers out-compete other native species. As a result of these factors, these species have been

vigorously studied, but many other urban species have been neglected, and among these are bats.

Chiroptera

Bats constitute one of the largest, most successful and most widely distributed mammalian orders, with a total of more than 960 species. In these respects, they are second only to the ubiquitous rodents with estimates of about 1,700 species, but bats are certainly more diverse in their biology. One quarter of all mammals are bats, and aside from the cold regions north of the Arctic Circle, the Antarctic, and a few isolated islands, there are no parts of the world where bats are absent (Hill and Smith, 1984; Altringham, 1998).

The order Chiroptera is divided into two distinct suborders: Megachiroptera includes the single family Pteropodidae, the Old World fruit bats; and Microchiroptera which includes the other 17 families of bats. The megachiropterans are not known to hibernate and also use visual orientation to navigate and forage. For microchiropterans heterothermy and extended hibernation periods are well documented for some families. Echolocation is primary means of orientation for microchiropterans, and prey is easily captured in total darkness (Vaughan, 1986). The focus of this paper will be concerned with members of its largest family, Vespertilionidae, the vesper or evening bats, in the state of Missouri.

Vespertilionids lack the distinctive facial features, such as nose leaves, and flaps or pads on the lower lips, that are characteristic of other families, but their ears are variable. The eyes are typically small, but the tail membrane is large, and coupled with the wings, serves as an insect catching apparatus. Evening bats are almost exclusively

insectivorous, feeding by fly-catching, gleaning, and aerial hawking (Altringham, 1998). With few exceptions, the vesper bats are drab looking bats with pelage shades of brown, black and gray. With this cryptic coloration, the evening bats are unparalleled at exploiting a vast array of roost sites: hollow trees, tree holes, tree foliage, under bark and leaf litter, in flowers, inside bamboo stalks, abandoned birds' nests, animal burrows, caves, mines, tunnels, buildings, bridges, storm drainage systems, and others (Altringham, 1998).

The majority of vesper bats have but a single offspring for the year, but a few species, such as the genus *Lasiurus*, have been known to regularly birth twins, triplets or even quadruplets. Mating usually takes place in the fall, and often intermittently during hibernation, but implantation of the embryo(s) occurs in the spring when the bats awaken from hibernation. The smallest bats' gestation and infant dependency period is about three months, which, when one equates a bat to another animal of comparable size, is very lengthy (Findley, 1993). During the months of May, June, and July, the mothers of some species form maternity colonies in hollow trees, caves and buildings, opting for warmer temperatures as growth rate of the young may be positively correlated with increase in temperature (Barbour and Davis, 1969; Tuttle, 1975; Altringham, 1998). Females hang from the wall, tree, or ceiling by their thumb hooks and feet, and spreading themselves into an apron, catch the naked, blind newborn(s) with their cupped tail and interfemoral membrane. The new mother then licks the baby to free the wings and legs which are plastered to the body and may sever the umbilical cord and eat the placenta (Cahalane, 1964; Schwartz and Schwartz, 1981). Bat mothers provide substantial parental care, enveloping their young in their folded wings during upside-down diurnal

hanging. In some species, mothers will take their new offspring with them during foraging bouts in the evening. For such a small animal, this is a tremendous load, especially considering a bat will eat up to 50% of its own body weight per night (Hickey and Fenton, 1990). A hoary bat has been documented foraging while carrying her twins who's combined weight totaled more than 25% of the total weight of the mother (Cahalane, 1964). Mother bats have also been known to be defensive of their young; cases of mothers fending off blue-jay attacks via teeth, hisses and wing flapping and even of alighting on human beings who were carrying off bat babies have been reported (Cahalane, 1964). By the time the young are half-grown, usually by two weeks of age, they are able to support themselves while roosting, and the mother forages alone again. At three to four weeks the young are volant and ready to venture out nightly on their own foraging bouts.

One of the richest areas for vesper bats in the eastern part of North America is the Ozark Plateau in Missouri and Arkansas (Findley, 1993). The urban study area, the city of Springfield, Missouri, is positioned in the heart of the Ozark Plateau. This area is underlain by limestone and dolostone, creating karst topography. As a result, many caves, springs, and sinkholes that have filled with water and became small ponds, dot the landscape. The mean summer and winter temperatures and precipitation are, respectively, 24.44° C with 29.26 cm of rain and 1.11° C with 18.08 cm of rain and 28.96 cm of snow.

Springfield was established in 1839 and has since experienced a 2% average annual growth rate with punctuated increases at times when the city annexed adjacent areas. Springfield currently has an area of 117 square kilometers with a population of just over 155,000. Between the years of 1961 and 1986, the residential area remained at 30%,

the commercial area went up from 4.6% to 5.9%, industrial land use jumped from 3.3% to 10%, public areas of schools and parks averaged about 9% and streets made up 18% of the city area. The total developed area rose from 66.4% to 74% in this 25 year span (Dave Fraley, Ph.D., Director-Environmental Compliance – City Utilities of Springfield, personal communication).

Seven counties in southern Missouri: Greene, Newton, Oregon, Phelps, Pulaski, Texas, and Vernon comprised the rural study area (Figure 1). Within these counties, 22 locations were monitored, including two National Guard training sites, multiple areas within the Mark Twain National Forest and a wooded area outside of an urban area. The dominant vegetation was an oak-hickory-pine forest with an understory of redbud (*Cercis canadensis*), dogwood (*Cornus* sp.), sumac (*Rhus* sp.), blackberries (*Rubus* sp.), buckbrush (*Andrachne phyllanthoides*), poison ivy (*Rhus toxicodendron*), and grapevine (*Vitis* sp.).

In total, nine species of bats were monitored in both urban and rural areas: *Eptesicus fuscus*, the big brown bat, *Lasiurus borealis*, the red bat, *L. cinereus*, the hoary bat, *Pipistrellus subflavus*, the eastern pipistrelle, *Myotis grisescens*, the gray bat, *M. lucifugus*, the little brown bat, *M. sodalis*, the Indiana bat, *M. septentrionalis*, the northern long-eared bat, and *Nycticeius humeralis*, the evening bat.

Eptesicus fuscus, the big brown bat

The big brown bat is one of the most widely distributed bats in North America, ranging from Canada to northern South America and the Caribbean Islands; it is most common in the central United States. True to its name, it is a large, dark to cinnamon

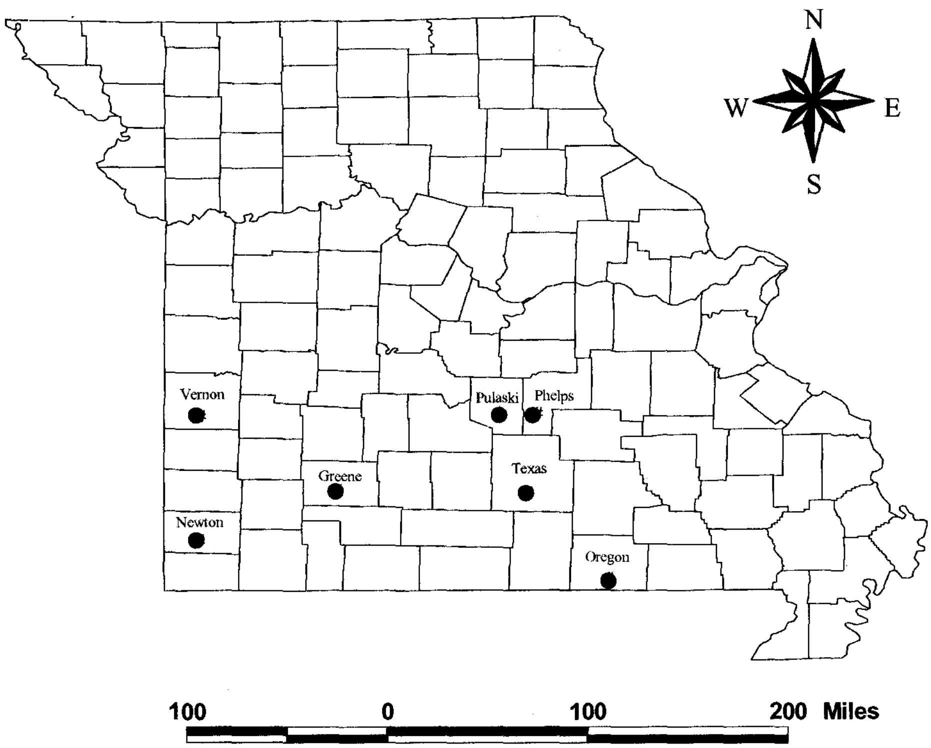


Figure 1. Map of Missouri. Dots indicate counties from which rural samples were taken. Springfield is located within Greene county.

brown colored bat without any distinctive markings. Big brown bats weigh 14-21 grams, have a forearm length of 42-51 mm, and a wingspan of 325-350 mm (Tuttle, 1988).

This species is very tolerant to human presence, and regularly takes advantage of attics and eaves in homes, church steeples, schools, mines, and storm sewers in addition to caves, hollow trees, under loose bark, and rock crevices. Breeding occurs in the fall, but the big brown bat does not begin gestation until the following spring. The sperm that had been dormant within the female during hibernation fertilize the eggs shed in early April. Females return to established maternity colonies of 30 – 2,000 individuals, in attics, chimneys, hollow trees or caves, while the males remain in their hibernaculum roost alone or may congregate into smaller bachelor colonies in separate man-made structures or caves (Schwartz and Schwartz, 1981). After the young have fledged, and the nursery colony has disbanded, males and females may be found in the same roosting site.

Just as the big brown bat is a generalist in roost site selection, such is the trend in diet. *Eptesicus fuscus* consume a wide variety of insects, but prefer gleaning beetles (nearly 60% of their diets [Whitaker, 1995]) from agricultural areas, meadows and from around street-lights in rural areas (Geggie and Fenton, 1985). Big brown bats leave their day roosts at about sunset to feed. After about one hour of foraging, the big brown bat's stomach is filled (Schwartz and Schwartz, 1981), and it may return to its day roost, or it may seek out a temporary night roost near its foraging area so as to forage again before returning to the day roost. *Eptesicus fuscus* are considered to be relatively slow, steady flyers, but are adept at abrupt changes of direction and highly maneuverable flight (Schwartz and Schwartz, 1981).

Being extremely hardy, they are capable of surviving subfreezing body temperatures, and are among the last bats to go into hibernation. Healthy bats have even been caught while flying in blizzard conditions (Tuttle, 1988). If there is a cave or mine within 241 km big brown bats will probably migrate to them. In comparison to other Missouri bats, their seasonal movements are modest; many stay within 16 km of their banding site (Schwartz and Schwartz, 1981), and it is the only mid-western species which regularly hibernate in their summer anthropogenic roosts (Whitaker, 1995). However, *Eptesicus fuscus* have good homing abilities and can travel 724 km to return to a particular site from which they were taken (Schwartz and Schwartz, 1981).

Lasiurus borealis, the red bat

Red bats are among the most abundant bats in much of Canada, the United States, except the southern half of Florida and along the Rocky Mountains in the northwestern United States through New Mexico, and its range also extends into much of Latin America. With long, angora-like, rufous colored fur that is frosted at the tips, the red bat is considered by many to be among the world's most beautiful mammals. Males are a brighter red than females, with the latter tending to be more frosted in appearance. This coloration distinguishes *Lasiurus borealis* from all of Missouri's bats, and the furred dorsal surface of the tail membrane and undersurface of the main wing bones differentiates the red bat from all but the hoary bat of the same genus. The pelage is longer on the neck than on the rest of the body thereby creating a slight ruff. Red bats are a medium sized bat, weighing 12-18 grams with a forearm length of 35-45 mm, and a wingspan of 290-332 mm (Schwartz and Schwartz, 1981; Tuttle, 1988).

Adults primarily roost in the foliage of deciduous trees, and characteristically frequent forests or shade trees around urban and rural areas in the summer months. By day, they hang by one foot, and wrapped tightly in their wings and large furred tail membrane, resemble dead leaves (Barbour and Davis, 1969). Rarely do they roost in buildings or caves. They live solitary lives, although several may share the same roost tree, and only congregate to migrate and mate; females do not form maternity colonies.

Among the earliest evening fliers, red bats start to forage around dusk, and continue to feed into the night. Feeding territories are usually established within 600 – 1,000 m of the roost, and the bats are easily observed flying back and forth in an elliptical flight path (Barbour and Davis, 1969; Tuttle, 1988). They are often found along the edges of forests, fencerows, flood plain timber, and corncribs, feeding on emerging insects, particularly moths. Street lamps are known to draw concentrations of red bats (Hickey and Fenton, 1990; Hickey et al., 1996). Red bats are fully adept at maneuvering with agility in close quarters, due to their narrow pointed wings. Early in the evening they fly high in slow, erratic flight patterns, but they usually descend to forage at heights of treetop level and lower. Being swift flyers, red bats have been timed at 64 km per hour in level flight (Barbour and Davis, 1969).

In the milder climates of their range, it is not unusual for red bats to be year-round residents. However, most undertake long seasonal migrations in groups of up to 100 individuals (Tuttle, 1988). Like birds, migratory waves of red bats have been known to utilize storm fronts to increase flight speed, and thus can achieve speeds of up to 129 km per hour. Traveling at such speeds limits the range of echolocation and reaction time of

the bat, and many dead bats have been found at the base of high-rise buildings and communication towers during migration (Tuttle, 1988).

As red bats are well adapted at surviving low temperatures, it is not unusual to encounter a hibernating bat over-wintering as far north as Ohio, where temperatures can fall below -17.78° C. Those bats that do not migrate indicate a preference for tree hollows. When the ambient temperature rises, the bats may arouse and feed on what flying insects are readily available, often in bright sunlight as early as three hours before sunset (Schwartz and Schwartz, 1981). Many other red bats migrate south in order to hibernate amid the foliage or other exposed roost in the milder weather conditions (Findley, 1993).

Lasiurus cinereus, the hoary bat

The hoary bat is the most widely distributed bat in North America, ranging from most of Canada, the United States, including Hawaii where it is the only indigenous mammal (Hall, 1981), and Mexico. Despite its vast range, it is encountered with relative infrequency and is considered rare throughout the state of Missouri (Schwartz and Schwartz, 1981).

Hoary bats are heavily furred with thick, soft, dark gray pelage that is white or silver frosted at the tips. The pale yellow fur around the neck is slightly longer than the rest of its fur, and it encircles the black face in a sort of mane. As one of North America's largest bats, it weighs 21–42 grams, has a forearm length of 46-58 mm, and a wingspan of 380-410 mm (Tuttle, 1988). Like its close relative the red bat (*Lasiurus borealis*), the dorsal surface of the tail is entirely furred as are the undersides of the wings

along the major bones. The hoary bats' size and coloration are its main distinguishing characteristics, and thus it is easily differentiated from other Missouri bats.

Behaviorally, hoary bats are very similar to red bats in that they are mainly solitary except during mating and migration, roost in foliage, and feed heavily on moths (Tuttle, 1988). One major difference, however, is hoary bats prefer evergreens to deciduous trees; probably on account of crypticity. In summer several individuals of the same sex may aggregate, but no nursery colonies are formed (Schwartz and Schwartz, 1981).

Though hoary bats will consume a number of smaller insect prey such as mosquitoes, dragonflies, beetles and wasps, they feed extensively on moths (Schwartz and Schwartz, 1981). However, *Lasiurus cinereus* has been documented consuming only larger prey when smaller insects were available (Barclay, 1985; Altringham, 1998). This may not be associated with being a specialist but instead may be related to having lower frequency echolocation pulses, larger body size and hence, more powerful flight, and therefore only detecting prey at greater distances as opposed to smaller, closer insects (Barclay and Brigham, 1991).

Like red bats, hoary bats in northern populations will likely perform long seasonal migrations, some to subtropical or even tropical areas, but little is known about what the bats do when they get there. Other hoary bats may over-winter in tree cavities (Tuttle, 1988).

In most of the hoary bats' summer range, there appears to be a sexual segregation; adult males are rarely found in the central and eastern United States or in the prairie

provinces of Canada, which is where the majority of females rear their young. Instead the males are most concentrated in the western United States (Tuttle, 1988).

Pipistrellus subflavus, the eastern pipistrelle

The eastern pipistrelle is the most abundant bat that ranges over the eastern half of the United States. This delicate, silken, yellowish brown to sienna colored bat weighs a mere 2-5 grams, has a forearm length of 31-35 mm and a wingspan of 208-258 mm (Barbour and Davis, 1969). In summer, male pipistrelles roost singly in trees, caves, and reportedly in anthropogenic structures such as buildings or barns. Especially in the spring or fall, a solitary pipistrelle is occasionally discovered hanging on a building wall; often in full daylight (Barbour and Davis, 1969; personal observation). Females may establish nursery colonies in caves or buildings; presumably in the same general area as their wintering sites (Schwartz and Schwartz, 1981).

A notoriously weak flyer, the pipistrelles' flight is erratic, and the foraging area along the tree-line over watercourses is small (Barbour and Davis, 1969). Pipistrelle diets consist of wasps, leafhoppers, moths and many aquatic forms of beetles.

Usually roosting alone, pipistrelles are profound hibernators, and often do not arouse when heterospecifics do; an individual will often remain in one position for weeks (Barbour and Davis, 1969). During this time, beads of condensation may collect on the fur, giving the bats dazzling appearances in the beam of a flashlight (Schwartz and Schwartz, 1981). A hardy species, *Pipistrellus subflavus* regularly utilizes caves for hibernation that heterospecifics find unsuitable. Cave populations do not reach a maximum density until December or later, and these populations are smaller during milder winters (Barbour and Davis, 1969).

Myotis grisescens, the gray bat

The gray bat is concentrated within the karst topography regions of Kentucky, Tennessee, Alabama and Missouri, with desultory colonies occurring in adjacent states (Barbour and Davis, 1969; Choate and Decher, 1996). Its pelage is a uniform gray, and it is the largest species of *Myotis* in Missouri with a weight of 5-14 grams, a forearm of 40-46 mm and a wingspan of 275-300 mm (Barbour and Davis, 1969). Its foot appears quite large in relation to its body for the wing membrane attaches at the ankle as opposed to the base of the toes as in other species of *Myotis*.

The gray bat is Missouri's only species of bat that inhabits caves year-round, and it is this reliance on caves that has placed this species on the Endangered Species List by the U.S. Fish and Wildlife Service. As spelunking and commercializing of caves have gained in popularity among the public, *Myotis grisescens* has suffered an 80% decline in populations within the past 50 years (Schwartz and Schwartz, 1981). Highly intolerant to any disturbances, entire colonies have been known take flight if a light is shined on them, to abandon roost sites if disturbed repeatedly, and pregnant females may abort their young if too distressed (Barbour and Davis, 1969; Schwartz and Schwartz, 1981).

The presence of gray bats is strongly affiliated with a riparian landscape, as they feed extensively on newly emergent aquatic insects, such as stone flies and mayflies, and rivers provide flight corridors along which to forage (Tuttle, 1976). Females form maternity colonies in the summer, apart from males and yearlings, but close to these advantageous feeding sites (Schwartz and Schwartz, 1981).

A mass migration takes place in autumn, and 95% of the gray bat population hibernates within nine caves, with 50% of the population occupying but one cave (Tuttle,

1986). Great mats of up to 100,000 individuals and several layers thick form on the ceilings of these caves (Barbour and Davis, 1969). These large winter colonies are in deep caverns with vertical shafts, accessible only to those possessing the elaborate gear required for vertical cave exploration (Barbour and Davis, 1969). Spelunking by amateurs craving the challenge of scaling a vertical pit, and even disturbance caused by careless biologists needs to be minimized if this species is to not face extinction.

Myotis lucifugus, the little brown bat

With its wide distribution over Canada to the southern United States the little brown bat is considered to be among the most abundant bats in the United States. A medium sized *Myotis*, little brown bats weigh 7-9 grams with a forearm length of 34-41 mm, and a wingspan of 222-315 mm. Its fur is a sleek, glossy russet to olive brown (Schwartz and Schwartz, 1981).

In summer, the sexes segregate; the females into maternity colonies of up to several thousand, and the males into much smaller groups. Summer roosts are in tree cavities, caves, rock crevices, under the bark of trees and in man-made structures such as buildings (Nagorsen and Brigham, 1993). Attics are a favored choice of females in which to raise their offspring, as attics commonly reach temperatures of up to 54° C.

Roosting locations are often within close proximity to water, which is where bats begin their foraging at late dusk. Aquatic insects such as midges, caddis flies, and mayflies make up the major prey, however, little brown bats are capable of switching their foraging techniques and preferred prey types quickly to exploit insect concentrations fully (Nagorsen and Brigham, 1993).

The distances traveled in migration are dependent upon the availability of adequate hibernacula (Barbour and Davis, 1969). Caves and mines are preferred sites, and the bats either form tightly packed clusters or align themselves in a linear arrangement along a cave wall (Barbour and Davis, 1969).

Myotis sodalis, the Indiana bat

This bats' relatively small range comprises the New England states to the eastern mid-western states. Appearing remarkably similar to *Myotis lucifugus*, it is differentiated by a keel in the calcar and dull, as opposed to glossy, brown pelage. Indiana bats weigh 2-5 grams, have a forearm length of 35-41 mm, and a wingspan of 240-267 mm (Barbour and Davis, 1969).

In the active months, males typically remain near the hybernacula and females form moderate nursery colonies beneath the bark of trees. Weather patterns strongly affect the choice of tree; bitternut hickory (*Carya cordiformis*) was the more favorable roost during springtime cold fronts while the shagbark hickory (*Carya ovata*) was favored during cold autumn weather (Humphrey et al., 1977). This choice of cryptic roost sites compounded by the Indiana bat being a rather shy species, results in infrequent encounters with this bat.

Indiana bats forage primarily over forested areas, focusing along the tree-line. Moths comprise the main component of the Indiana bats' diet, though beetles, caddis flies, and various other flies constitute a small portion as well (Schwartz and Schwartz, 1981).

In early fall, *Myotis sodalis* begin to swarm around cave entrances to copulate. By mid-October, hibernation is underway within a very small number of suitable caves located in Kentucky, Indiana and Missouri (Schwartz and Schwartz, 1981).

The Indiana bat faces a similar issue as the gray bat of summer habitat and hybernacula being destroyed by humans through careless forestry tactics and ignorant spelunking, and thus is listed alongside its close relative on the Endangered Species List.

Myotis septentrionalis, the northern long-eared bat

The range of the northern long-eared bat is the northeastern United States to the southeastern corner of Canada. It is a medium sized *Myotis*, with a weight of 2-5 grams, a forearm length of 32-39 mm, and a wingspan of 228-258 mm (Barbour and Davis, 1969). The defining characteristic of this species is the long ears, (17-19 mm) and long, dagger-like tragus. Although not especially rare, *M. septentrionalis* seems to be locally and irregularly distributed (Barbour and Davis, 1969). Winter and summer ranges are identical.

This solitary species is an inhabitant of dense timber and roosts in tree cavities, under bark and in cliff crevices during summer months. Small nursery colonies of no more than 30 animals are formed at this time, and old barns have even been exploited for this purpose (Schwartz and Schwartz, 1981). Northern long-eared bats emerge at dusk and forage over small ponds and forest clearings under the tree canopy. Flying just over the understory, this species regularly gleans prey such as moths, beetles, flies, caddis flies and leafhoppers from twigs and foliage (Nagorsen and Brigham, 1993).

Copulation occurs just prior to hibernation. Hybernacula are often shared with *M. lucifugus*, but *M. septentrionalis* often arrives at caves two to eight weeks after little

brown bats have entered hibernation. Northern long-eared bats either hibernate alone in deep crevices or in small clusters, rarely touching other species (Schwartz and Schwartz, 1981; Nagorsen and Brigham, 1993).

Nycticeius humeralis, the evening bat

This nondescript, brown bat can be easily distinguished from all other brown bats by the possession of but two upper incisors; all other brown bats have four. Evening bats are smaller than *Eptesicus*, weighing 2-9 grams, having a forearm length of 33-39 mm, and a wingspan of 260-280 mm. Their tragus is short and blunt, separating this species from *Myotis*. The evening bats' range encompasses the southeastern quarter of the United States.

Nycticeius humeralis inhabits cavities in trees, behind loose bark, and in buildings in summer, and this is where maternity colonies, often consisting of hundreds of individuals, are formed (Barbour and Davis, 1969). Rarely is an individual encountered in a cave.

Little is known about their feeding behavior and seasonal movements. Brown fat is accumulated in the fall, but the bats soon disappear (Tuttle, 1988). Recapture of banded individuals suggest that some members of this species migrate southward, and the influx of evening bats in Florida during the winter supports this hypothesis (Tuttle, 1988). However, further study of this species would be of value.

Anabat II

Until recently, the study of bats away from roost sites has relied primarily on direct capture via mist nets and/or Tuttle traps (Kunz and Kurta, 1988). While this is currently among the most favorable methods used to obtain data concerning population

structure (Barclay, 1991), sex, age and reproductive condition (Kuenzi and Morrison, 1998), there are many biases inherent to such conventional methods. Not all bat species, and not all individuals within a species, are equally susceptible to capture (O'Farrell, 1997). *Myotis sodalis* tend to forage along the tree-line, *Tadarida brasiliensis*, Brazilian free-tailed bats, have been sighted or tracked by radar at altitudes of 3,000 m (Williams et al., 1973), and *Myotis septentrionalis* glean prey off of foliage and twigs in forest clutter, just over the understory (Nagorsen and Brigham, 1993); all of these species being very arduous to impossible to capture. The collecting surfaces of mist nets and Tuttle traps are very diminutive relative to the potential air space surrounding such devices, and the varying ability of bats to detect and exhibit learned avoidance of these traps further limit their effectiveness (O'Farrell, 1997).

Many studies have moved toward the use of ultrasonic detectors as opposed to more conventional methods of monitoring bat activity (Kunz and Brock, 1975; Woodside and Taylor, 1985; Balcombe and Fenton, 1988; Forbes and Newhook, 1990; Pye, 1992; Ekman and DeJong, 1996). In particular the Anabat II bat detector system (Titley Electronics, Ballina, Australia) has become increasingly popular over recent years (Hayes and Hounihan, 1994; O'Farrell, 1997; Britzke et al., 1999). This system detects bat echolocation signals, and can record them to either a tape recorder or laptop computer. Using the Anabat II detector system, species identification (Fenton and Bell, 1981; Fenton, 1982; Fenton and Merriam, 1983), richness and diversity, range distribution, bat community structure, temporal patterning of activity (Richards, 1989; Hayes, 1997), and the habitat utilization by a species can be determined (Bell, 1980; Thomas, 1988; Betts, 1998). This passive method of monitoring activity holds many

possible advantages. Among them, the bats never have to be physically handled, and many locations that would otherwise be considered impractical by trapping standards can be monitored simultaneously with little effort (Cross, 1986). Sites can also be monitored repeatedly; capture success with mist-netting often decreases substantially on successive nights (LaVal, 1970; Kunz, 1973; Kunz and Brock, 1975; Kuenzi and Morrison, 1998).

While data collected using bat detectors can provide estimates of activity of bats, it is not possible to use bat detectors to estimate population abundance (Hayes, 1997); each echolocation sequence recorded may represent separate recordings of several individual bats or may be repeated recordings of a single bat (Fenton et al., 1973). Bat detectors can erroneously record low species richness because some echolocation calls are similar among heterospecifics, and thus are not identified as separate species. Bat species are also not all equally conspicuous to bat detectors due to differences in the frequency and intensity composition of their calls (Thomas et al., 1987). Geographic and individual (Brigham et al., 1989) variation of calls in conspecifics further complicates ultrasound data, but with the abundance of new publications (Erickson and West, 1996; Hayes and Adam, 1996; Krusic and Neefus, 1996; Lance et al., 1996; Hayes, 1997; O'Farrell, 1997; Betts, 1998; Britzke et al.,1999; Murray et al., 1999; O'Farrell and Gannon, 1999; O'Farrell et al., 1999a; O'Farrell et al., 1999b) and reference recordings (O'Farrell, 1997) in this area, there is potential of overcoming the occasional difficulty of species differentiation (Kuenzi and Morrison, 1998; Murray et al., 2001).

Radio Telemetry

Radio telemetry has become a popular method for studying the activities and movement patterns of many nocturnal creatures, including bats (Bradbury et al., 1979;

Aldridge and Brigham, 1988; Catto et al., 1996). Some advantages of radio tracking include:

1. Direct observations of the tagged individual during the day or night is possible as the animal's location can be determined. Cryptic roosts can be located in this manner.
2. Radio tracking provides more continuous and detailed information on habitat use, foraging ranges, nocturnal social contacts and the like, than any other existing marking method; individual animals can be located and monitored over considerable distances, often for periods of weeks.
3. Aspects of the animal's behavior, physiology, or environment, such as flying, resting, clustering or passing through a roost entrance can be deduced by noting changes in the quality of the signal pulse caused by either the animal, through characteristic movements, or by the investigator through temperature-sensitive or other signal-altering components.
4. Since transmission frequencies are unique, more than one animal can be tracked at a time and associations among individuals can be monitored (Bradbury et al., 1979; Wilkinson and Bradbury, 1988).

Bradbury et al. (1979) stated that the most commonly used transmitter frequency is around 150 MHz, in the 2-meter band. As this frequency does not bend around hills, over ridges or other obstacles, it is limited to line-of-sight reception. Lower frequencies that can bend around obstacles require impractically long antennas, but frequencies as low as 30 MHz have been used because inexpensive FM radios may be used as receivers. However, in using such low frequencies, the range is compromised. Alternately,

frequencies as high as 400 MHz allow improved directional accuracy with a small antenna at close range, but vegetation causes these signals to attenuate quickly.

The main limitations are the initial equipment investment and the 5% "rule" (Aldridge and Brigham, 1988). To minimize disruption of natural behavior and not inhibit in-flight maneuverability, thus hindering the bat's ability to forage optimally, the transmitter, battery and the attachment materials should not exceed 5% of the animal's weight. Up until the recent advent of transmitters weighing less than one gram, telemetry was restricted to bats weighing 15 grams or more, effectively eliminating most of the animals monitored in this study.

Conservation

Bats have faced many problems when confronted with integrating with humans. Bats are regarded as a delicacy in some countries, and no limit to the amount of bats harvested has been issued (Fenton, 1998). Particular species with exceptionally large ears, such as *Corynorhinis townsendii*, are becoming threatened or even endangered due to people collecting them for such a novelty (Feldhamer et al., 1999). Thirty million Mexican Free-tails lived in Eagle Creek Cave, Arizona in 1963 and were known as the world's largest bat colony. By 1969, just six years later, their numbers were reduced to a mere 30,000 – a 99.99% decline (Tuttle, 1988). Documentation of the cause of the decline is not readily available, but the hillside in front of the cave is littered with shotgun and rifle casings. This left 350,000 pounds of insects uneaten every night, thereby appallingly upsetting nature's balance. "Such losses leave us increasingly dependent on pesticides that already threaten other species' success and many aspects of our own lives" (Tuttle, 1988).

The use of anthropogenic structures by bats has long been a point of contention between the bats and cohabitating humans. Unwarranted fears bred by popular misconceptions and general lack of education coupled with exaggerated rabies scares and supposed health risks have resulted in deliberate and unnecessary eradication of bats (Constantine, 1970; Tuttle, 1988; Fenton, 1998; Pierson, 1998). Many of the poisons used to exterminate bats create serious health problems for people, such as the toxic anticoagulant chlorophacinone. This powder is blown into attics in amounts of up to 8.16 kg at a time, it takes years to degrade, and bats do not necessarily die immediately. Dying bats fall to the ground where they remain active for days, thereby increasing the potential of human contact (Tuttle, 1988). Once people are educated about bats, their unwarranted fears may be ameliorated, and their desire to help protect these beneficial insectivores should become an important issue.

The conservation minded public is mainly responsible for a recent resurgence of interest in protecting North American bats through commercially available bat houses (Pierson, 1998). These small, artificial roosts have been moderately effective (Tuttle, 1988), but spatial and thermal choice appear to be critical (Tuttle and Hensley, 1993); proximity to a water source and direct sun for at least 12 hours being ideal.

Utilization of bat houses is a welcome start in the conservation of bats, however, there is still relatively little known about bats in urban areas.

Objectives of this study are:

1. To determine which species can live in urban environments.
2. To compare the temporal and spatial relationship to the amount of bat activity between urban and rural environments.

3. To contrast species' activity levels among different microhabitats within an urban environment.

4. To locate bat roosting sites and to determine if they are permanent or temporary and natural or man-made.

5. To ascertain whether the bats are foraging within or outside of the city limits. The bats will be monitored, habitat documented and assessments made as to whether or not man-made structures help or hinder the bats during their foraging activity.

6. To determine if urbanization has otherwise affected these bats' behaviors.

MATERIALS AND METHODS

The following data were collected during the spring, summer and fall seasons of 1998-2000 in Springfield, Missouri and the surrounding rural areas. Data from passive echolocation call sequence recordings, locations, captures, aging, sexing, banding, chemiluminescent tagging, radio telemetry and mapping were all recorded.

Passive Recordings

An Anabat II bat detector, Zero Crossing Analysis Interface Module, and a laptop computer hooked up to a car battery were placed within a lidded 75.71 L Rubbermade® container. The container had a 5.08 cm hole cut into one side so as to push a shallow U-shaped piece of 5.08 cm tubing partially into the chamber. The remainder of the tubing extended upwards out of the box. Two 1.27 cm holes were drilled into the tube where it became parallel with the ground so as to avoid any moisture entering the closed container. The microphone of the Anabat was positioned inside the portion of tubing within the box thereby recording any potential echolocation call sequences to the laptop. These passive boxes were placed in secure locations in the urban environments until 07:00 hours to monitor the nightly activity of the bats. The passive box was not utilized in the rural setting as the Anabat II bat detector system was under the constant care and supervision of a researcher. As according to Missouri Department of Conservation guidelines, recordings were taken until 24:00 hours in the rural environment.

A mosaic of habitats was chosen in urban areas of Springfield in which to place passive boxes: parks with streams and a scattering of trees, parks with caves and ponds, alongside residential and commercial ponds, within residential areas, and commercial areas of businesses and high traffic (Figure 2). Special care was taken to conceal the

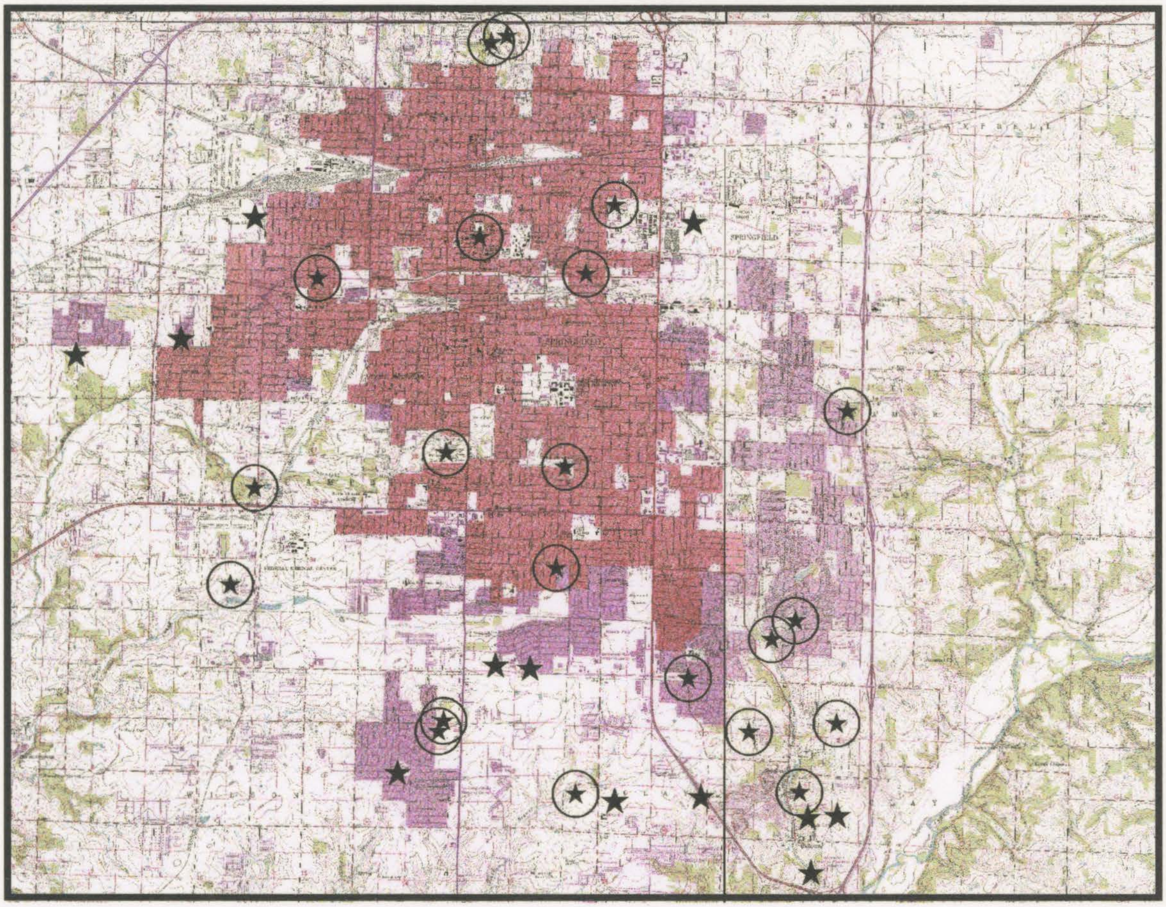
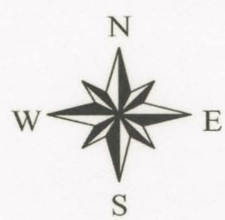


Figure 2. Land Usage Map of Springfield. Circled stars depict passive box locations with recorded bat activity. Stars indicate passive box locations which yielded no activity.



passive box in as cryptic a manner as possible so as to limit human disturbance. In the rural areas, including sites within Mark Twain National Forest, two National Guard training sites, and wooded locations outside the city limits of Springfield, the Anabat equipment was positioned alongside ponds, road cuts, clear cuts, a stream, near a cave and in possible flight corridors.

All echolocation call sequences recorded by Anabat II were quantitatively identified to species using a discriminate function analysis (DFA) model (Britzke et al., 1999; Britzke et al. in press). Depending on the species, the overall accuracy of the DFA model ranges from 80% - 100%. This variability is due to small sample sizes for certain species, and to similarity in call structure among *Myotis* species.

Locating Urban Bats

To get a more complete view of urban bats, bats also needed to be located in Springfield. Many roosting sites were located with the help of the public. The media was utilized to inform the public about this project; KY3 News in Springfield reported on this research, and an advertisement was also placed in the Springfield Newsleader. Many phone calls were received from enthusiastic people willing to allow me into their homes or place of business to study "their" bats. On multiple occasions I visited elementary schools and presented information about my research and bats in general. Students were eager to volunteer information concerning bats they had seen in Springfield. The passive boxes proved effective as well in that if there was an abundance of one species of bat activity in one area, roosts could be located. Caves within city parks were also investigated for bat activity.

Capturing bats

Several techniques were employed in the capture and identification of these bats. Tuttle traps were used at the cave entrances (Kunz and Kurta, 1988), and the captured bats were visually identified according to Schwartz & Schwartz (1981). Mist nets were placed at cave entrances, in residential backyards, in the basements, attics and roofs of homes, and over swimming pools. Standard mist netting techniques were used (Gardner et al., 1989). An adjustable, up to 9.14 m, net assembly based on a pulley system was constructed and utilized (Kunz and Kurta, 1988; Gardner et al., 1989). Bats were also hand-captured upon and within buildings. The same identification technique was practiced.

Aging

While holding a live bat, one can easily asses its age (young of the year versus older individuals) and reproductive status (Anthony, 1988). The epiphyses of the hand and wing bones of juvenile bats have not yet fused to the diaphyses of the bones. Thus the characteristic knobby appearance of the joints in fully adult bats is lacking, and instead resembles a window through which light can pass (Findley, 1993).

Sexing

Females in advanced pregnancy are very conspicuous as their abdomen is twice the size of non-gestating bats, often with one to four distinguishable lumps. Lactating females have enlarged nipples and regularly have a gaunt appearance to their abdomen. A dark stain is often present at the vaginal opening if the bat had just recently delivered (personal observation). In males, the prepuce is distinguishably larger than the females' counterpart, and in sexually active males, the epididymides may be so swollen with

semen that they extend into the interfemoral membranes. The testes and epididymides are miniscule in sexually inactive males (Findley, 1993).

Banding

Numerical, color coded, plastic wing bands, size 2, from National Band and Tag Co. were applied to each bat's wing (Barclay and Bell, 1988). Special care ensured that the band could slip easily up and down the forearm so as not to puncture the delicate wing membrane and cause injury. A different color band was assigned to each roosting habitat.

Light tags

In 1998, small chemiluminescent light tags (Chemical Light Inc., Vernon Hills, Illinois) were affixed dorsally with skin-hesive surgical glue, and the bats were released. Foraging behavior could then be easily observed (Buchler, 1976), and, using the Anabat II bat detector, known call sequences viewed and recorded to a laptop computer. These known call sequences were later incorporated into Britzke's 1999 DFA model.

Radio Telemetry

In 1999 and 2000 radio transmitters were affixed dorsally with skin-hesive surgical glue. Holohil transmitters were chosen, and each weighed 0.65 g or 1.05 g so as not to exceed the "5% rule" (Aldridge and Brigham, 1988). The range of these transmitters was about 0.81 km, depending on atmospheric conditions (cloud cover and lightning) and human interferences such as electric lines, phone lines, security systems, personal computers, facsimile machines, and radios. The 1.05 g transmitter had a switch that emitted a slower transmission when it was vertical, or when the bat was roosting, and a more rapid transmission when it was horizontal, or when the bat was flying. Each bat

was tracked until it returned to its roost. Radio telemetry signals were picked up the following afternoon to ensure the bat was at the location where it was last heard. Radio telemetry proved most effective as the bat's whereabouts could be located at any time throughout the mean nine day life of the transmitter (Catto et al., 1996). This allowed for greater ease in locating night and day roosting sites and foraging habitats (Bradbury et al., 1979).

Mapping

The location of where each site a transmission was heard was recorded to the street level as a point on a city map of Springfield. These points were then re-plotted on four different quadrangles, and the U.T.M Coordinates were assessed using a U.T.M. Coordinate Grid. Arcview® software applied these coordinates and calculated the home range areas, the greatest distance from roost, and then sketched a superficial delineation overlain upon digitized topographic quadrangles, displaying the foraging area for each bat tracked.

Statistical Analysis

For each recording night (n = 46) the probability of eight of the nine bat species foraging in that particular recording location was calculated using BatID8 (Britzke et al. in press). *Lasiurus cinereus* was not included in this analysis due to the distinct nature of the call structure, which could thus be identified qualitatively. Any species with a p-value greater than 0.05 was considered not to be present (Appendix). Statistical analyses were calculated using Minitab 12. A two-sample T-test then compared mean activity levels for each hour after sunset (until midnight) across urban and rural settings for each of the nine species. To ascertain whether there was greater bat activity by habitat

partitioning within Springfield, a one-way ANOVA was calculated for recordings taken until 07:00 hours for each species. As the variance for these data sets were positively correlated with the means, the mean number of sequences were transformed using a logarithmic transformation prior to applying the two-sample T-test and ANOVA.

RESULTS

A total of 1,876 echolocation call sequences was recorded, identified to species and analyzed; 1,066 were from 42 Springfield sites (18 of which yielded zero calls from any species and were thus not included in the statistical analyses), and 810 were from 22 rural locations in southern Missouri. However, extraneous insect noise that compromised the clarity of some calls, periodic equipment malfunctions, and calls that did not fall within the parameters of known call sequences left many additional call sequences unidentified (Betts, 1998). For all species combined, urban bat activity tended to be higher than rural activity, but those differences were only significant at the reading taken 3 hours after sunset ($p = 0.025$) (Figure 3).

Eptesicus fuscus activity was considerably higher in Springfield when compared with the surrounding rural environments, with the overall means of call sequences per recording night being 14.29 and 1.95 respectively. Big brown bats accounted for a mean of 64.93% of recorded echolocation sequences per night in Springfield and 5.74% in rural environments. Calculated with a 95% confidence interval, the p-value for overall activity was significant at $p = 0.0087$ (Figure 4). Alternately, *Lasiurus borealis* displayed no significant differences in activity levels between urban and rural settings (Figure 5). The overall mean number of call sequences per recording night in urbanized areas was 2.13 and 1.95 in the rural areas ($p = 0.64$). The mean percentages of call sequences per recording night in the urban setting were 9.68% and 5.74% in the rural areas for *L. borealis*.

For three *Myotis* species, there was no significant difference between urban and rural bat activity scores. For *Myotis grisescens* ($p = 0.36$), the mean number of call

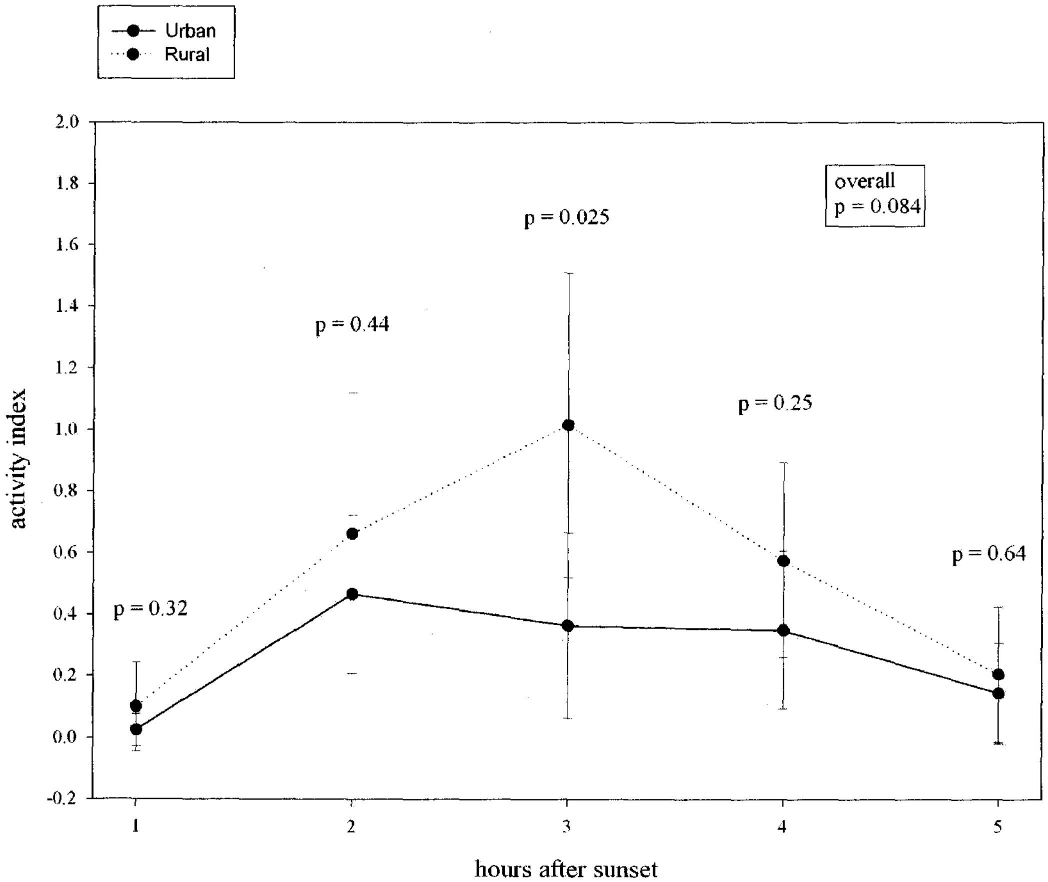


Figure 3. Overall activity in urban and rural environments.

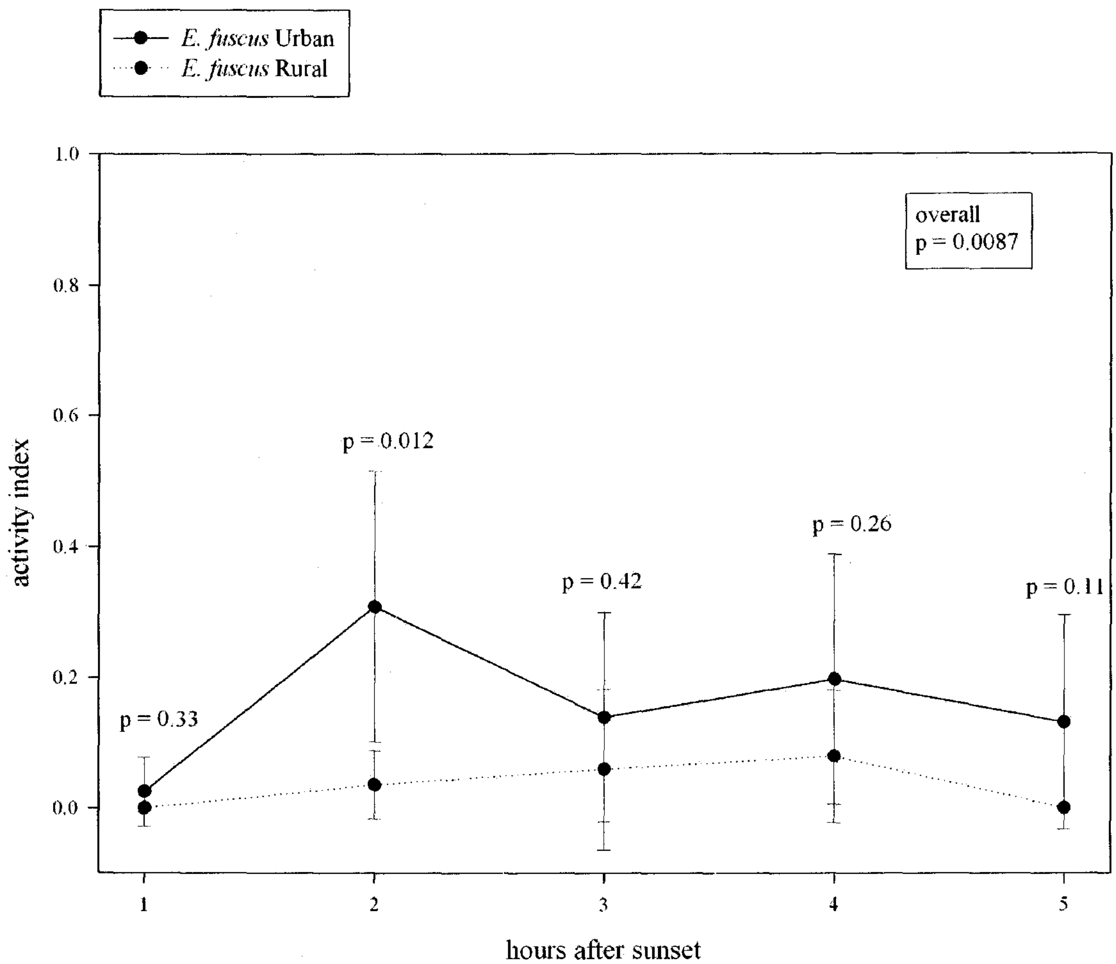


Figure 4. *Eptesicus fuscus* activity in urban and rural environments.

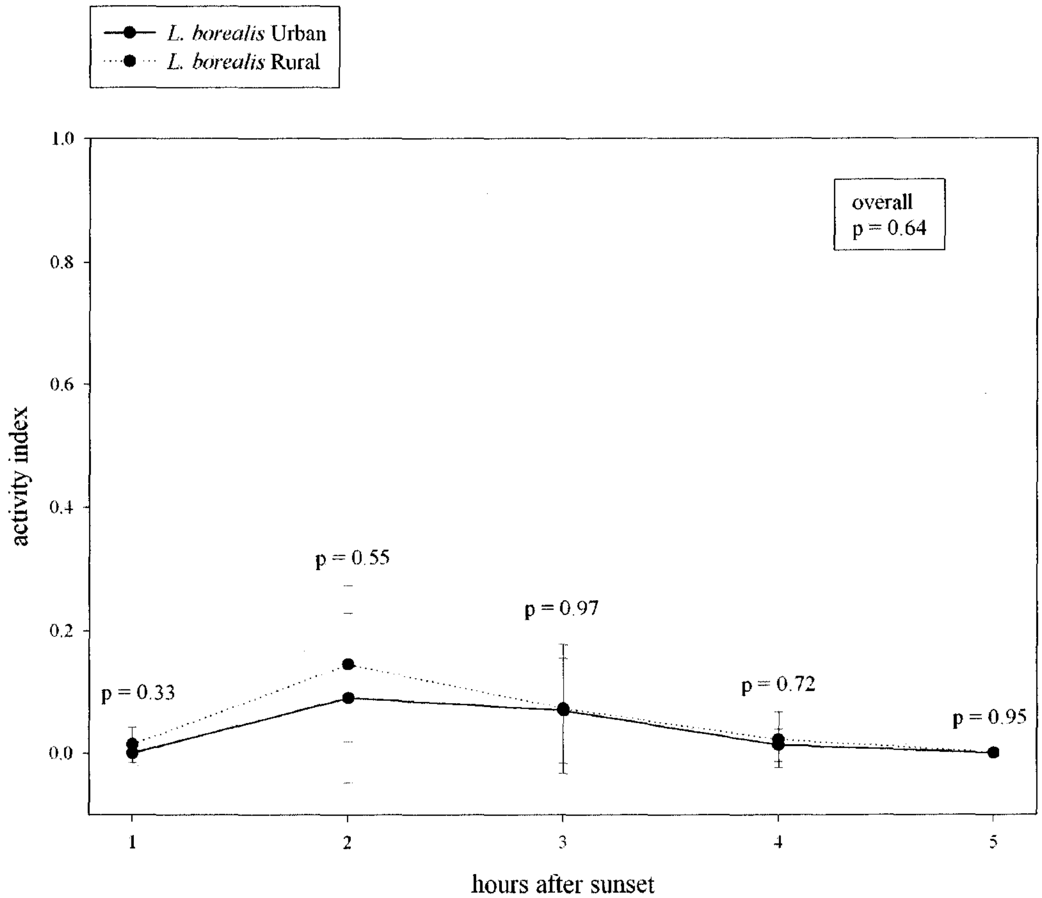


Figure 5. *Lasiurus borealis* in urban and rural environments.

sequences per recording night in Springfield was 1.88 and was 2.50 in rural locations, while the mean percentages of call sequences per recording night were 8.54% in the urban setting and 7.36% in the rural locations (Figure 6). *Myotis lucifugus* (p = 0.098) displayed a mean number of call sequences per recording night of 0.13 in urbanized areas and 0.77 in rural areas, which calculates to 0.59% and 2.27% respectively (Figure 7). The mean sequences per recording night of 0.04 for *Myotis sodalis* was 0.18% in urbanized areas and 1.18 (3.47%) in rural locations, (p = 0.24) (Figure 8).

The difference between urban and rural activity levels was significant (p = 0.0004) for *Pipistrellus subflavus* with an urban mean of 3.33 and the rural mean of 21.68 call sequences per recording night (Figure 9). The percentage of mean echolocation call sequences per recording night was 15.13% in Springfield and 63.77% in the rural areas.

Lasiurus cinereus displayed no significant difference in activity levels between urban and rural settings and totaled 0.21 mean call sequences (0.95%) in urban areas with 0 mean sequences per recording night in surrounding rural areas (p = 0.33). *Myotis septentrionalis* was significantly more active in rural settings (p = 0.037) and possessed a mean number of call sequences of 0 in urban settings and 2.05 (6.03%) in rural locations. *Nycticeius humeralis* displayed no significant difference in activity levels between urban and rural sites (p = 0.17), with the mean number of call sequences per recording night totaling 0 in Springfield and 1.91 (5.62%) in surrounding rural areas.

Urban Habitat Partitioning and Usage

Springfield was divided into five different habitat types in which passive boxes were placed from sunset until 07:00 hours. The five habitat types included: parks (Figure 10), parks with caves (Figure 11), ponds (Figure 12), residential neighborhoods

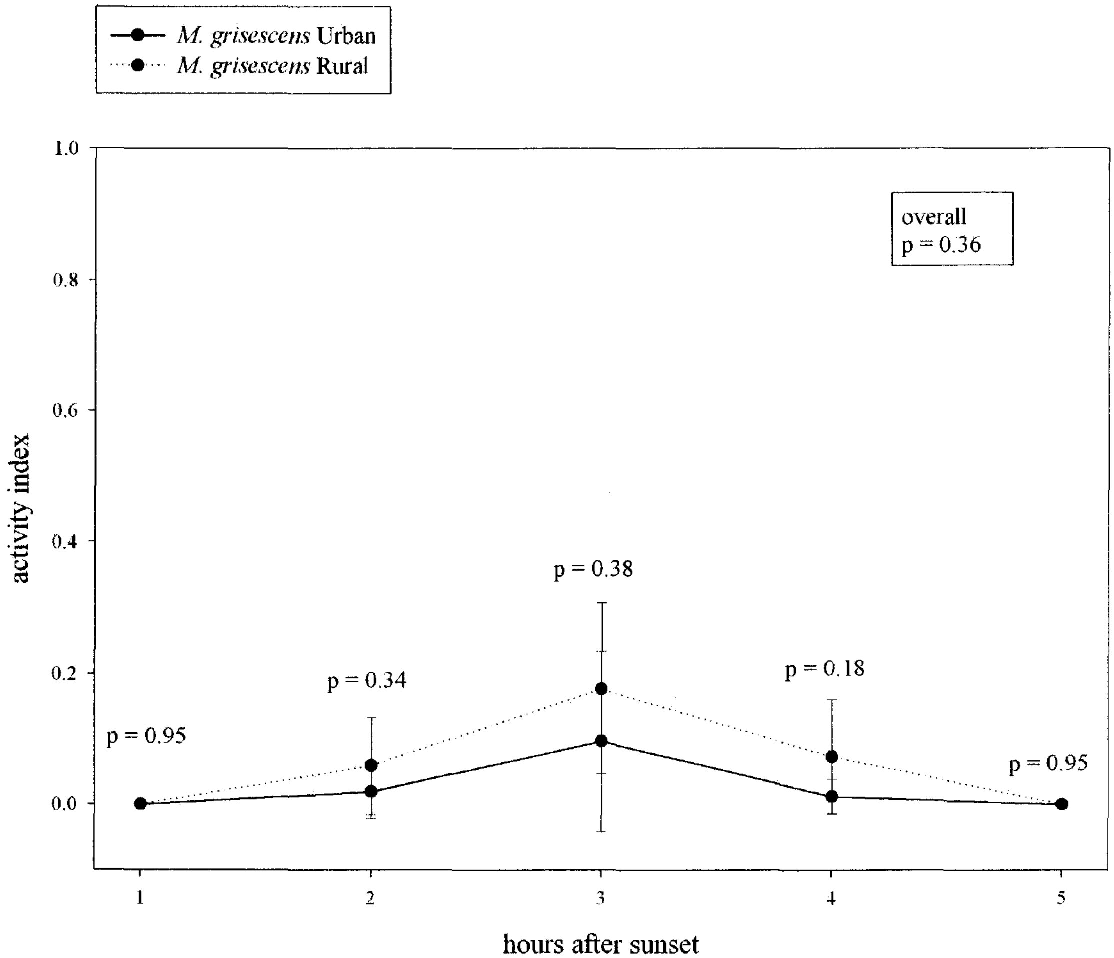


Figure 6. *Myotis grisescens* activity in urban and rural environments.

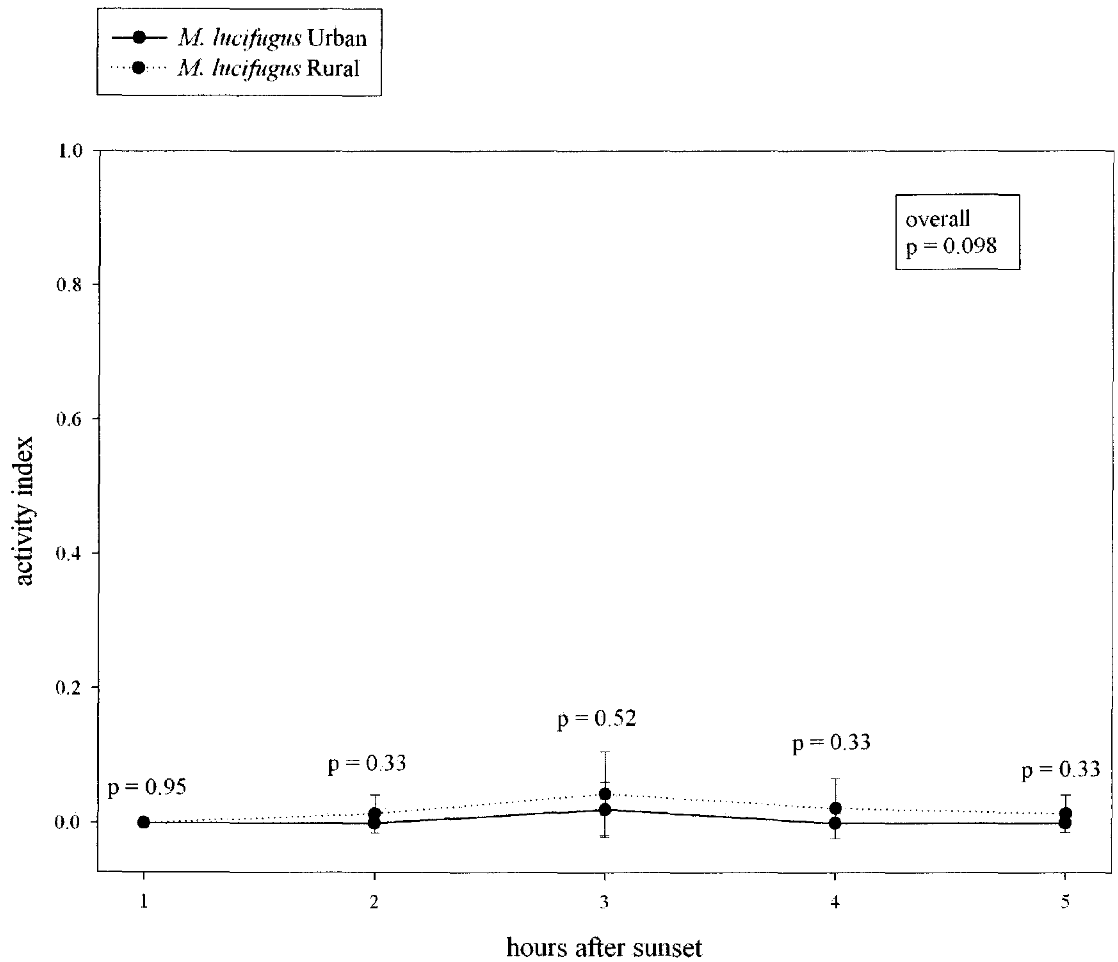


Figure 7. *Myotis lucifugus* activity in urban and rural environments.

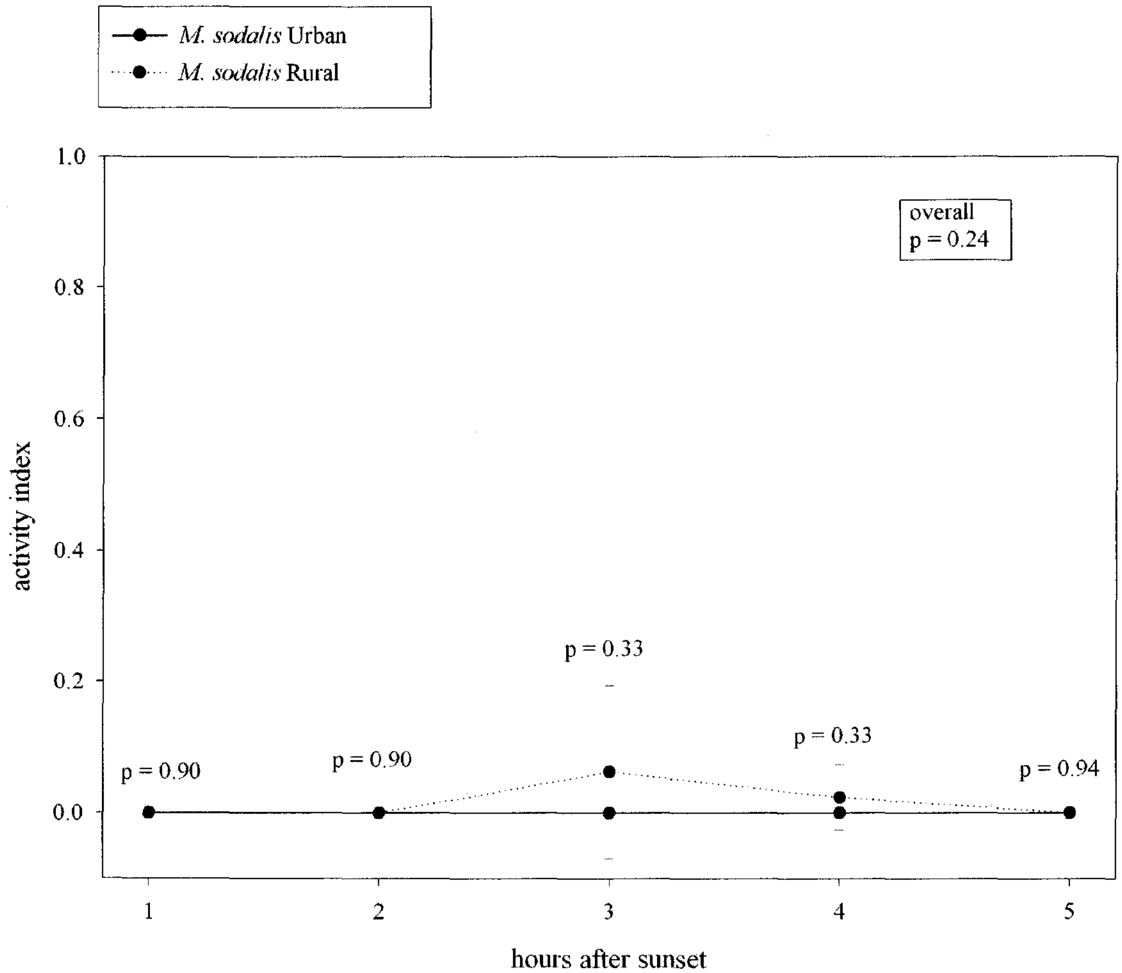


Figure 8. *Myotis sodalis* activity in urban and rural environments.

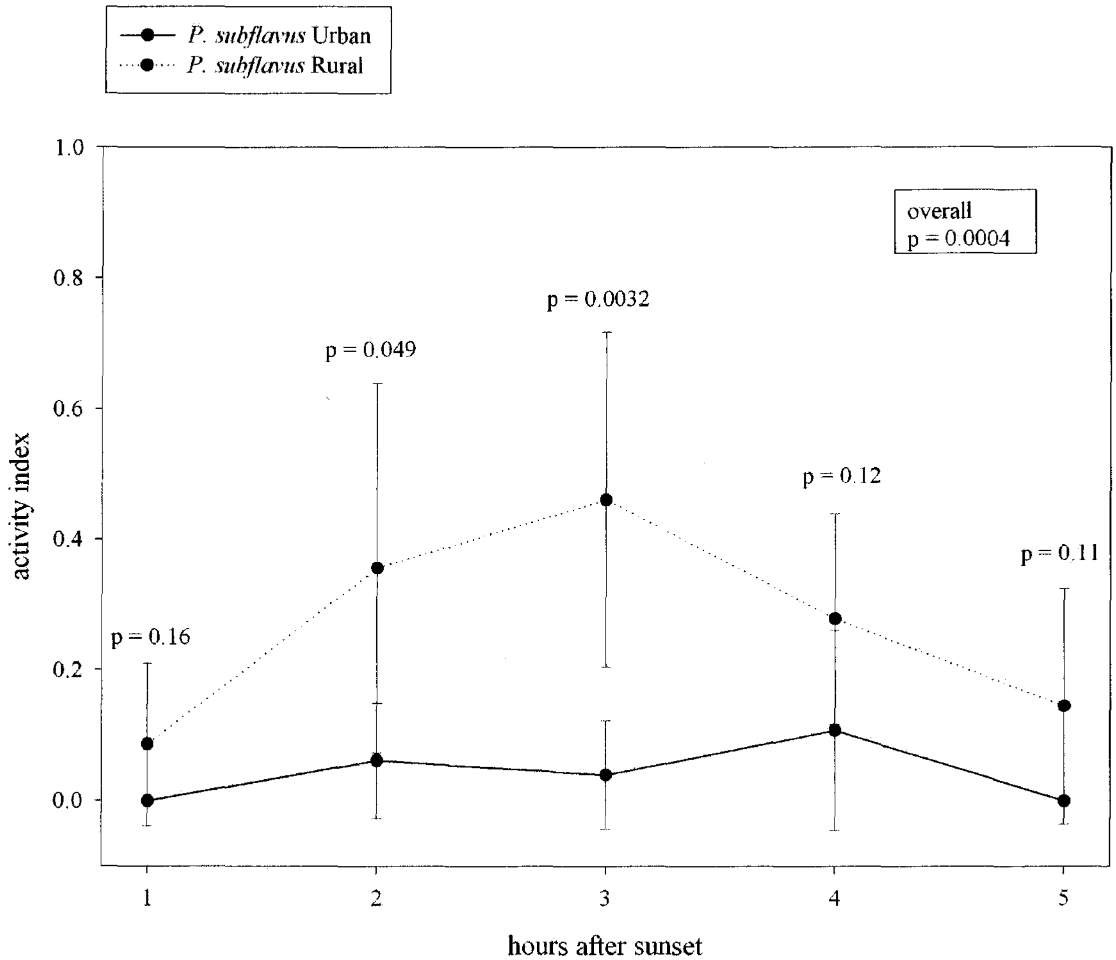


Figure 9. *Pipistrellus subflavus* activity in urban and rural environments.

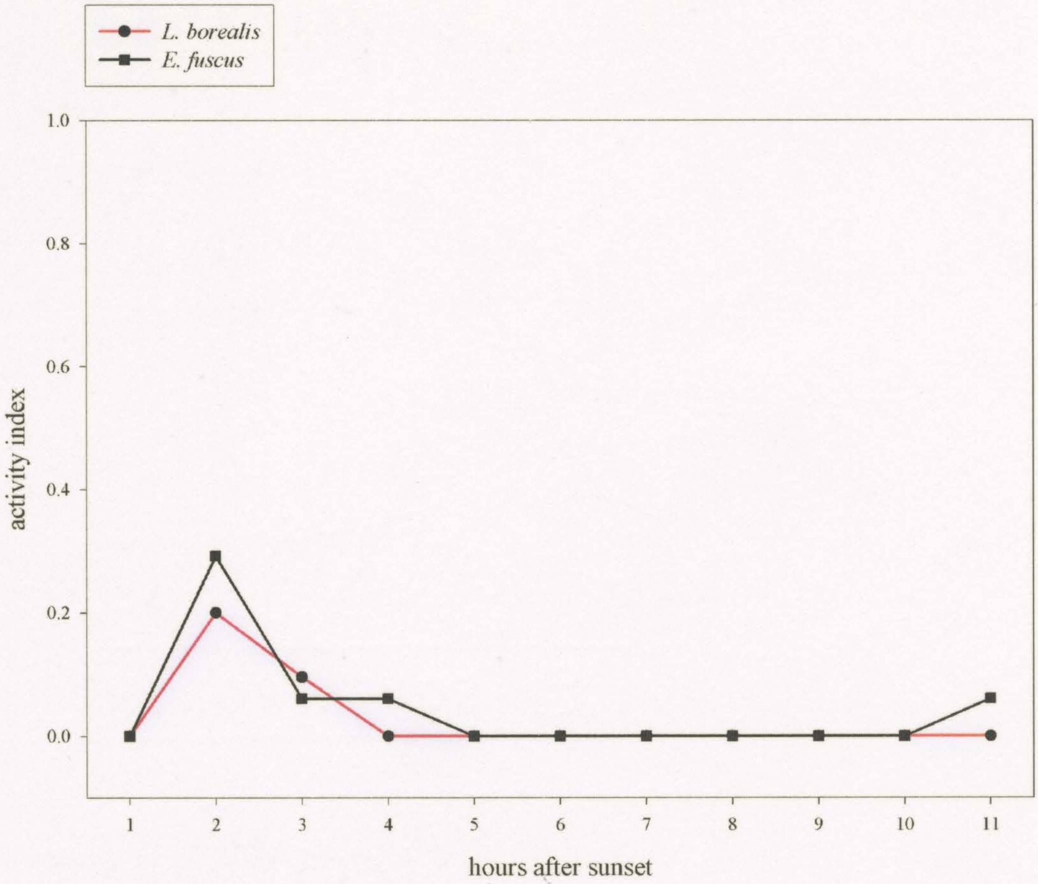


Figure 10. Urban bat activity within city parks.

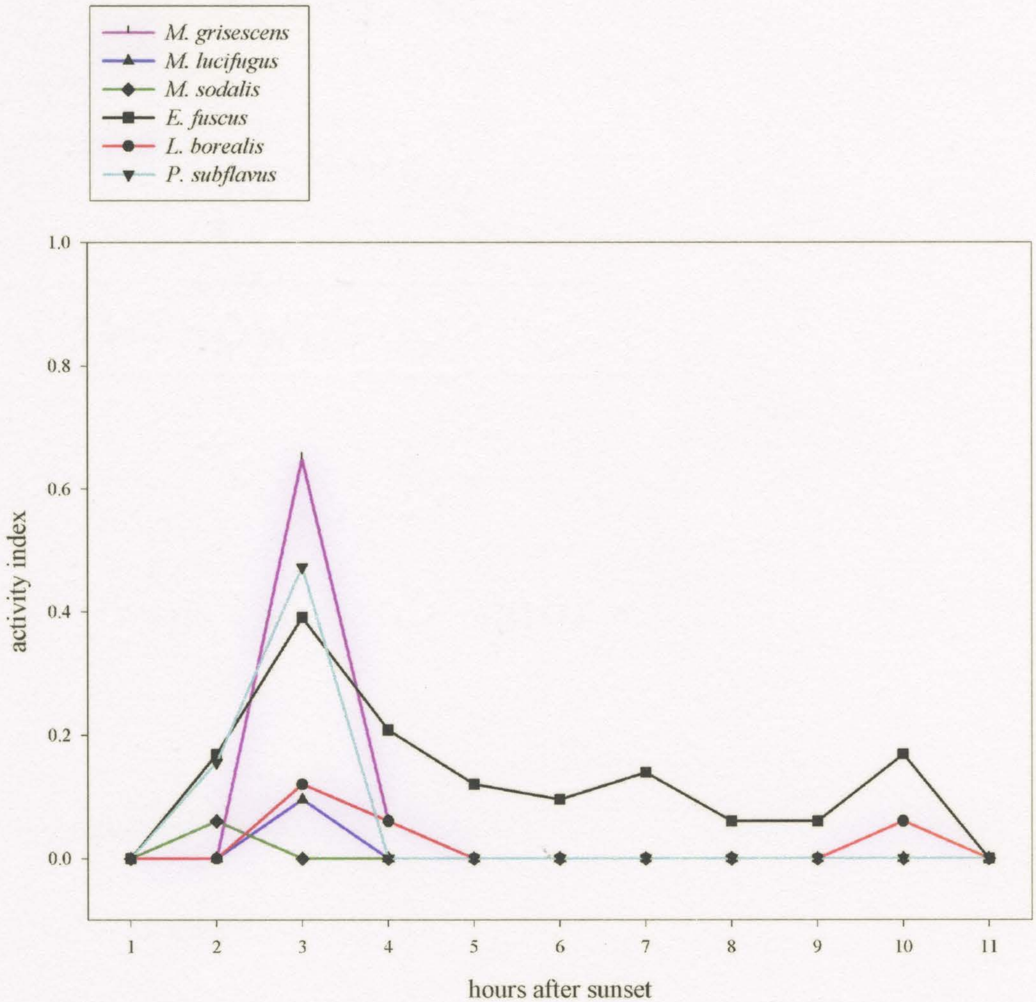


Figure 11. Urban bat activity over city parks with caves.

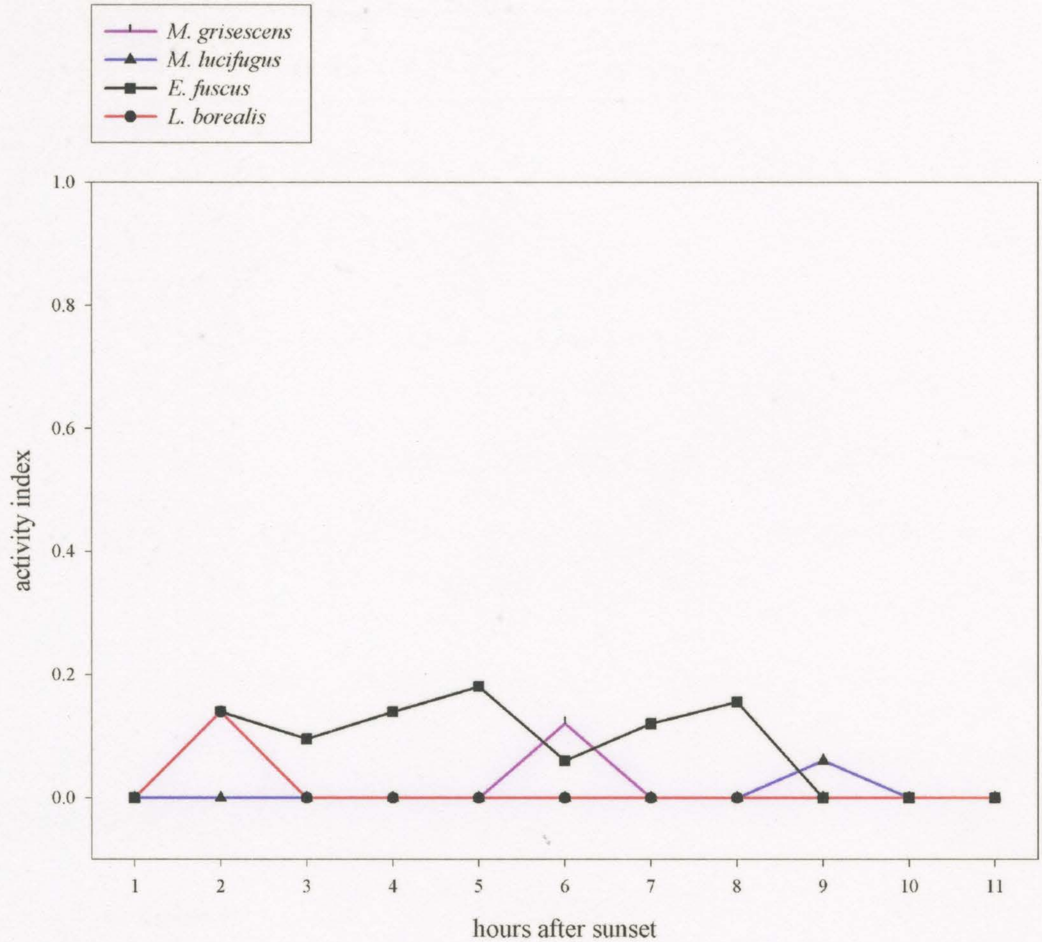


Figure 12. Urban bat activity around ponds.

(Figure 13), and commercial areas (Figure 14). During the summers of 1998 and 1999, a passive box was randomly placed in Springfield, totaling 42 recording nights. Eighteen of these sites yielded zero echolocation call sequence recordings throughout the night, whereas 24 sites recorded bat activity (Figure 2). Sites that resulted in zero activity were resampled. Only three of those yielded bat activity the second time. Those sites that totaled zero activity after two trials were not incorporated into the statistical analyses.

Eptesicus fuscus activity was recorded over all the microhabitats within Springfield, and there were no significant differences among habitats ($p = 0.698$) (Figure 15). Due to single call sequences recorded at two parks with caves, these data were not graphically represented. Most activity was within the residential areas, probably due to the abundance of available roost sites, but the high variability among sites and relatively low number of sites resulted in low statistical power. *E. fuscus* were captured at caves, residences and commercial areas.

Lasiurus borealis were recorded over parks with and without caves, residential ponds and residential sites (Figure 16), and there was no significant difference in activity among habitats ($p = 0.904$). *L. borealis* were also captured via mist-net in residential yards over swimming pools and at cave entrances. *L. cinereus* were only recorded flying over residential sites (Figure 17), although one was collected off of a building in the center of town.

Myotis grisescens were recorded over parks with and without caves, ponds in both commercial and residential areas, and residential neighborhoods (Figure 18). Though two parks without caves each had one call sequence, these data were not graphically represented. Activity was significantly higher in parks with caves ($p = 0.012$), and this is

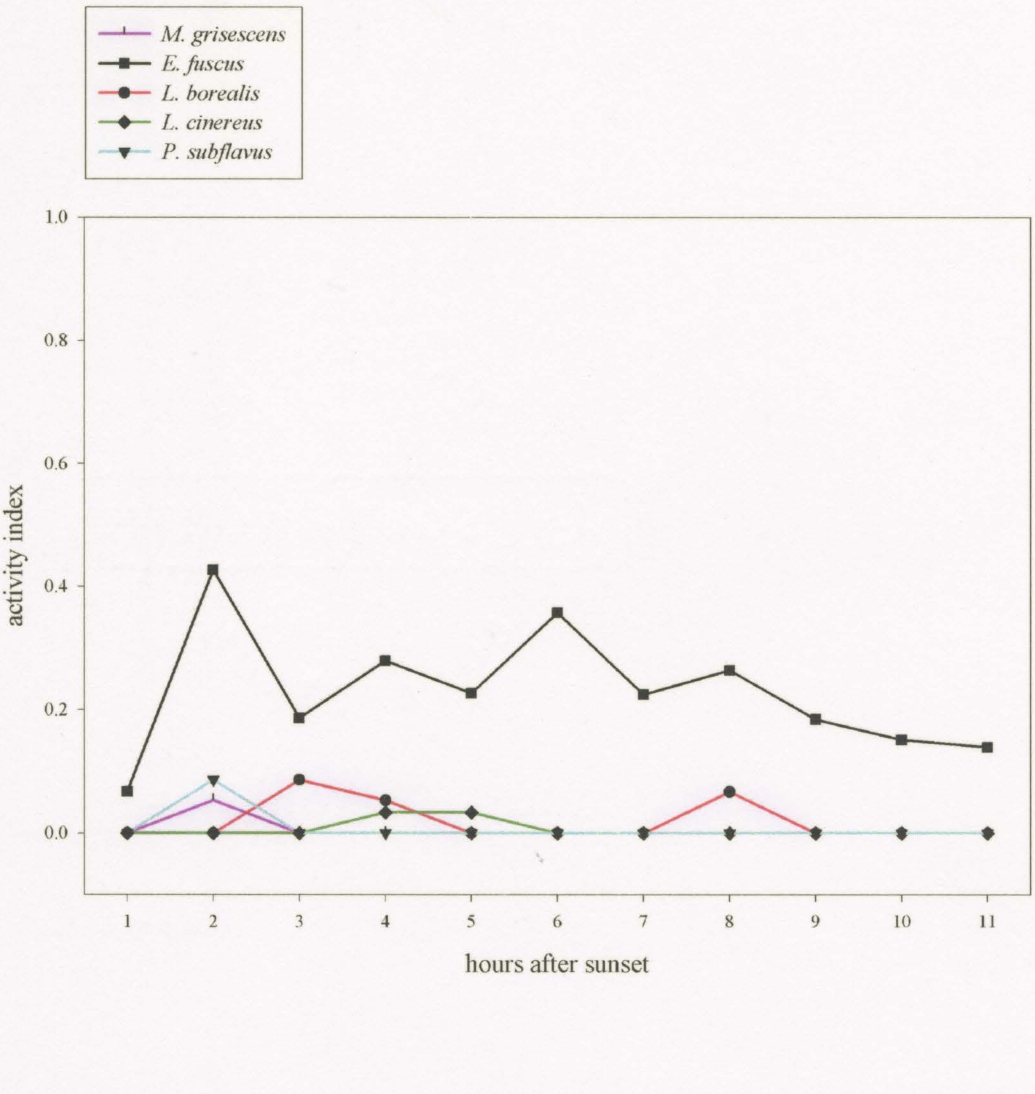


Figure 13. Urban bat activity over residential neighborhoods.

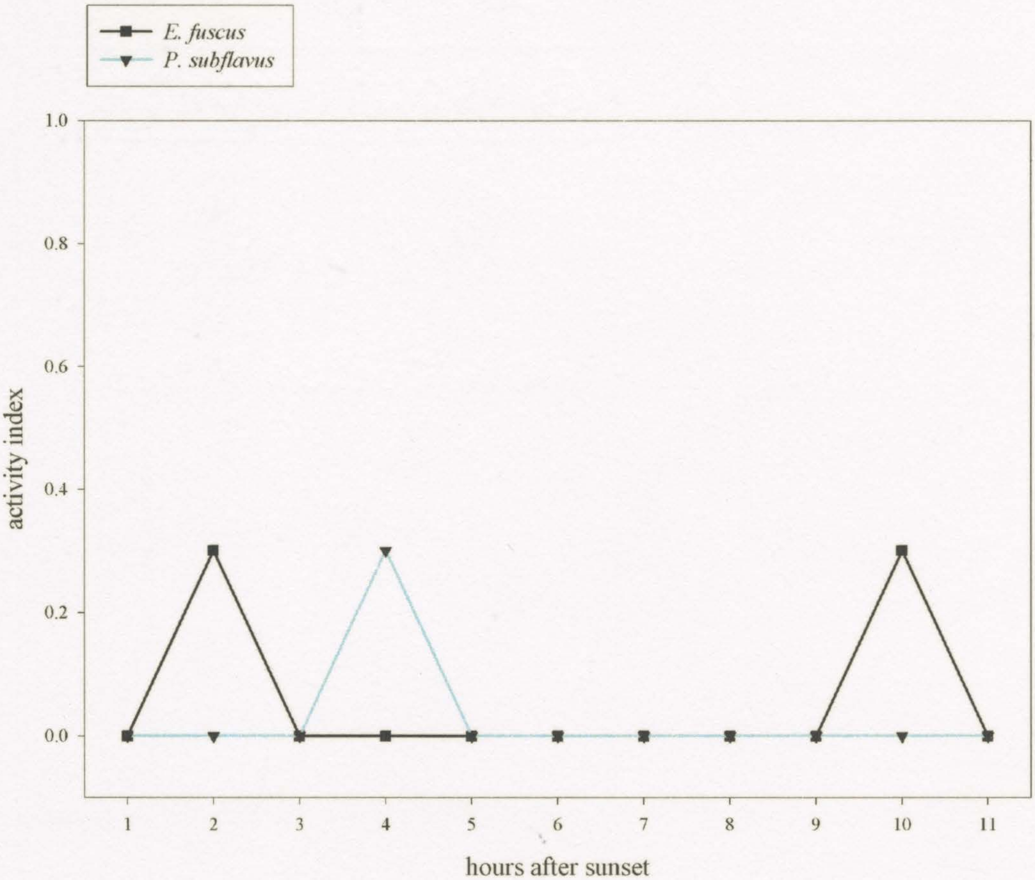


Figure 14. Urban bat activity over commercial areas.

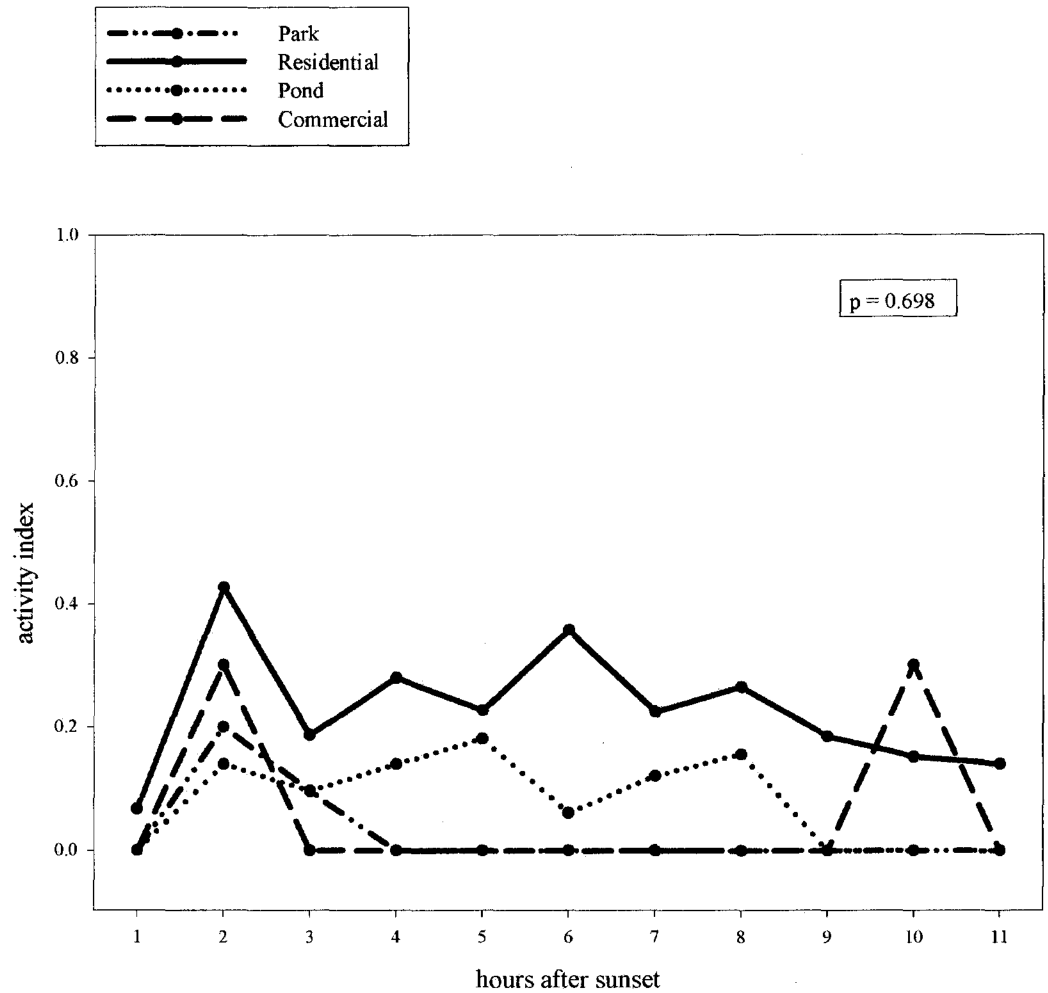


Figure 15. *Eptesicus fuscus* urban habitat usage.

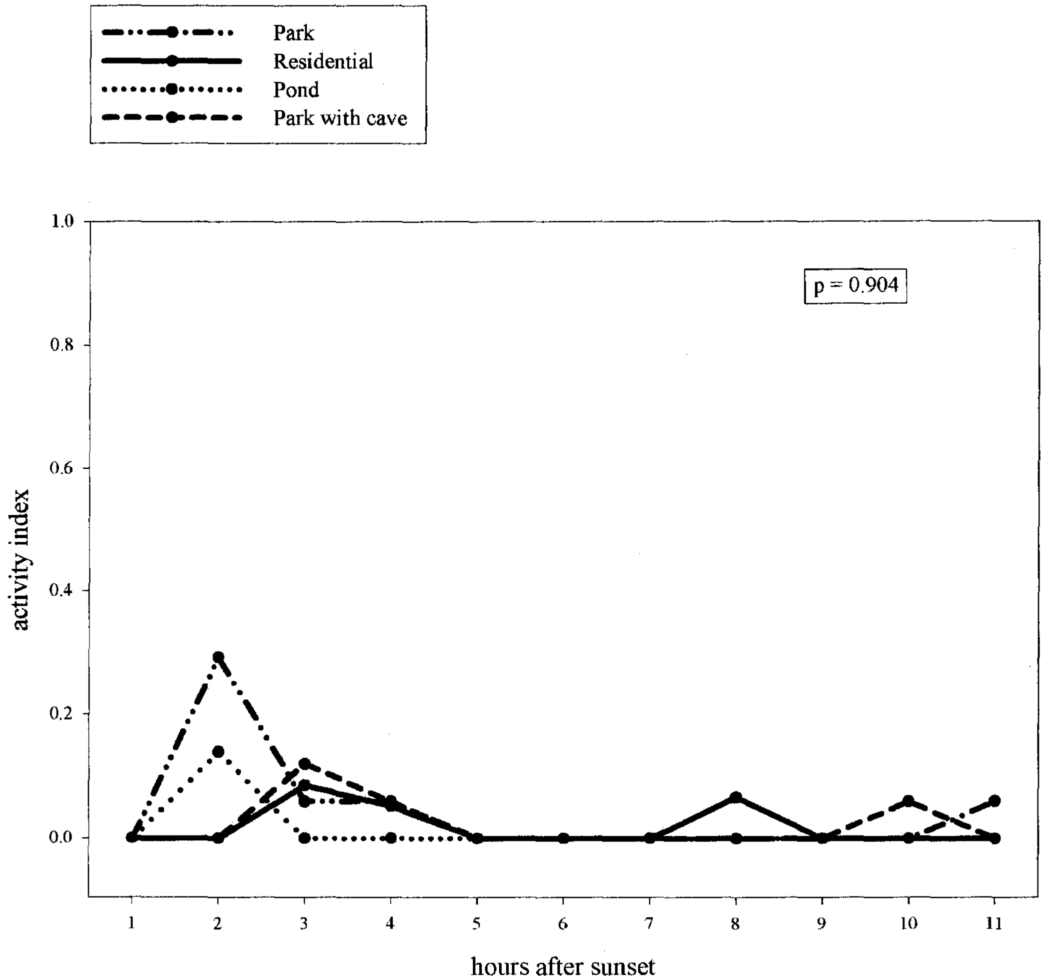


Figure 16. *Lasiurus borealis* urban habitat usage.

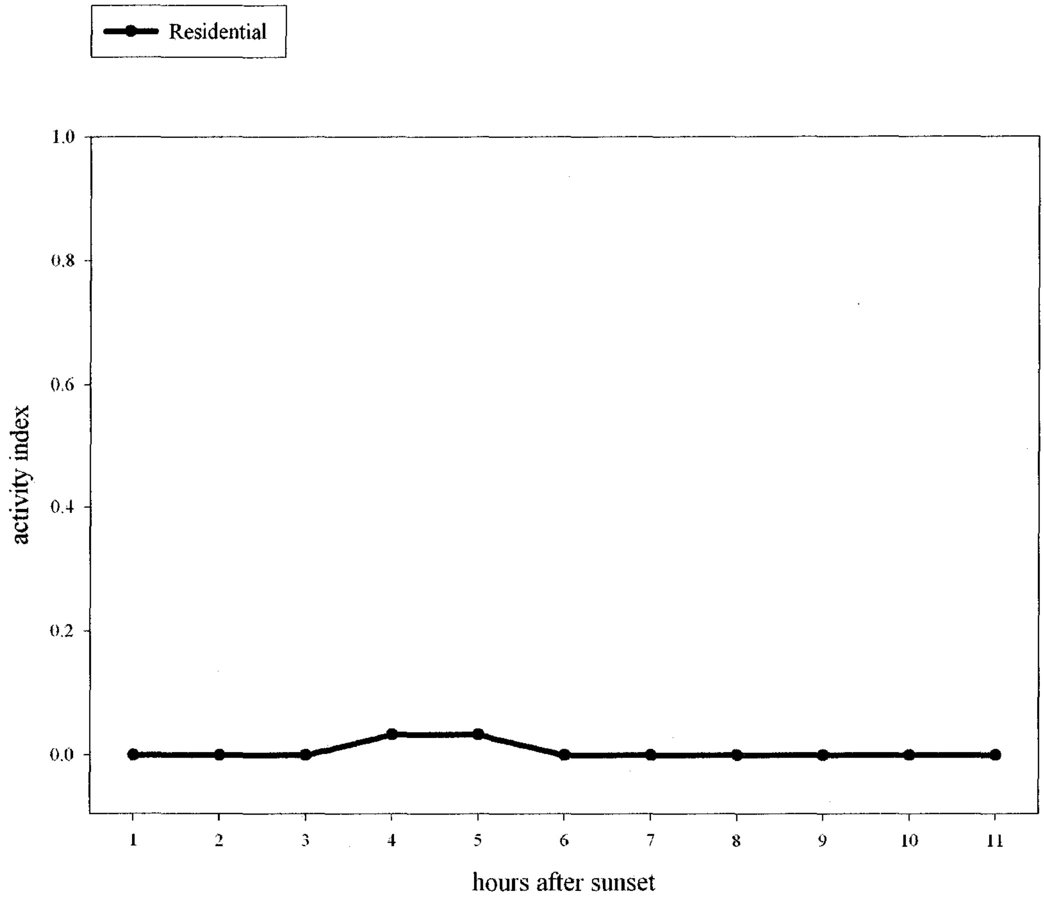


Figure 17. *Lasiurus cinereus* urban habitat usage.

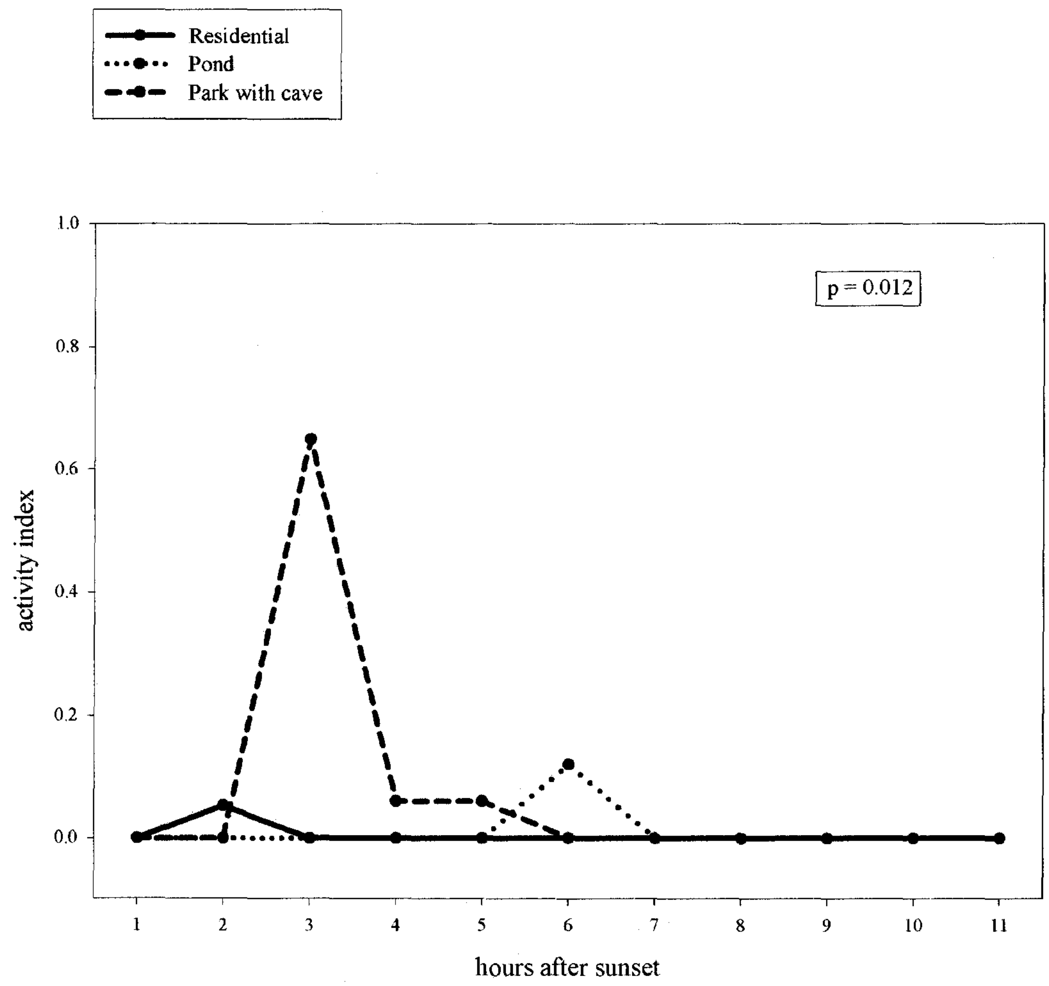


Figure 18. *Myotis grisescens* urban habitat usage.

the only area in which this species was captured. The sparse recordings of *Myotis lucifugus* placed its activity ($p = 0.875$) over residential ponds and parks with and without caves (Figure 19), though little brown bats have only been captured at one cave in southeastern Springfield. The few recordings of *Myotis sodalis* activity were over a park with a cave (Figure 20). The one echolocation call sequence recording of *M. septentrionalis* was over a residential neighborhood, and this lone data point was not graphically represented. Neither of these latter two *Myotis* species was captured in this study.

There was no significant difference in activity for *Pipistrellus subflavus* among different habitat variables ($p = 0.527$). Pipistrelle activity qualitatively was higher over parks with caves even though activity was recorded over parks without caves, residential areas, ponds, and commercial areas (Figure 21). Three parks without caves each had one call sequence recorded, and two ponds also had single sequences recorded, but these solitary data points were not represented graphically. Eastern pipistrelles have been captured at caves and hand collected on buildings.

A few *Nycticeius humeralis* have been hand collected from the sides of buildings, however, the recordings of this species were eliminated for statistical analysis as the p-values for presence versus absence were not significant. Due to a small sample size for *Lasiurus cinereus* and *M. septentrionalis*, these data were not sufficient for statistical analysis.

In addition to the aforementioned passive box locations, a detached bat detector was placed at 15 street lights for 606 minutes, and 28 call sequences were recorded.

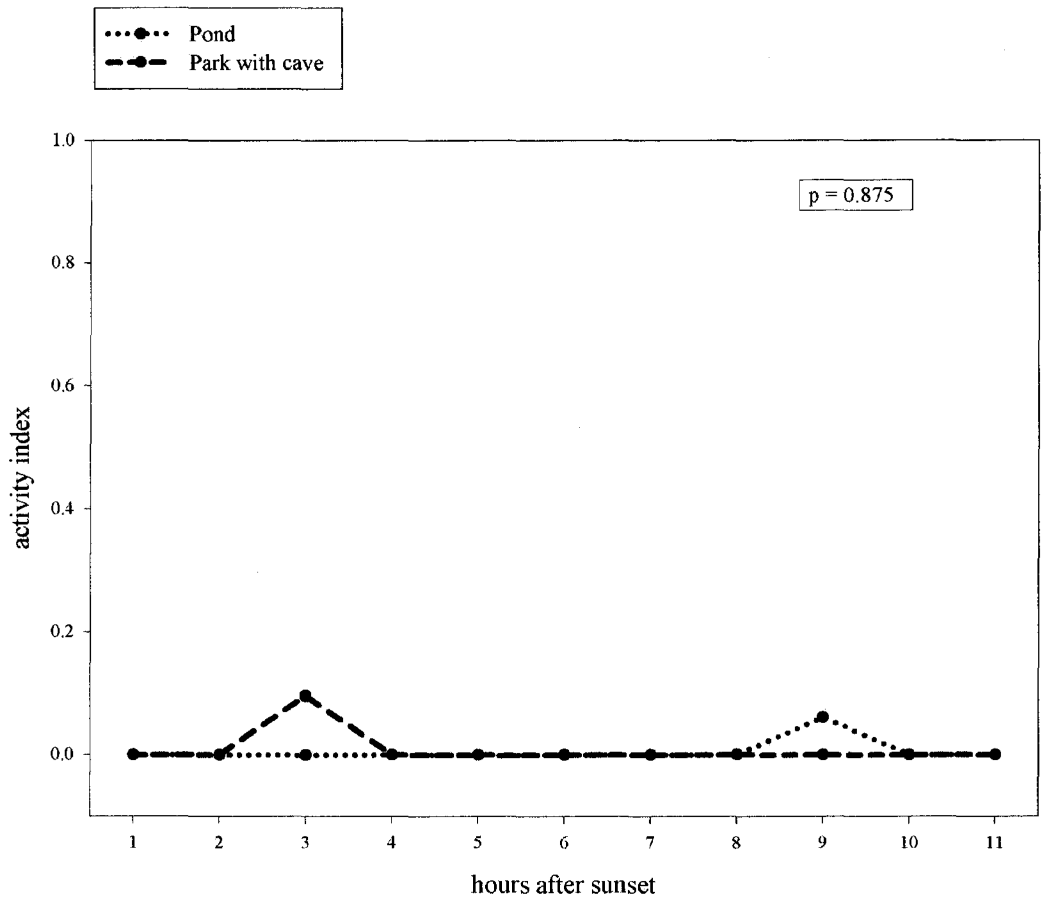


Figure 19. *Myotis lucifugus* urban habitat usage.

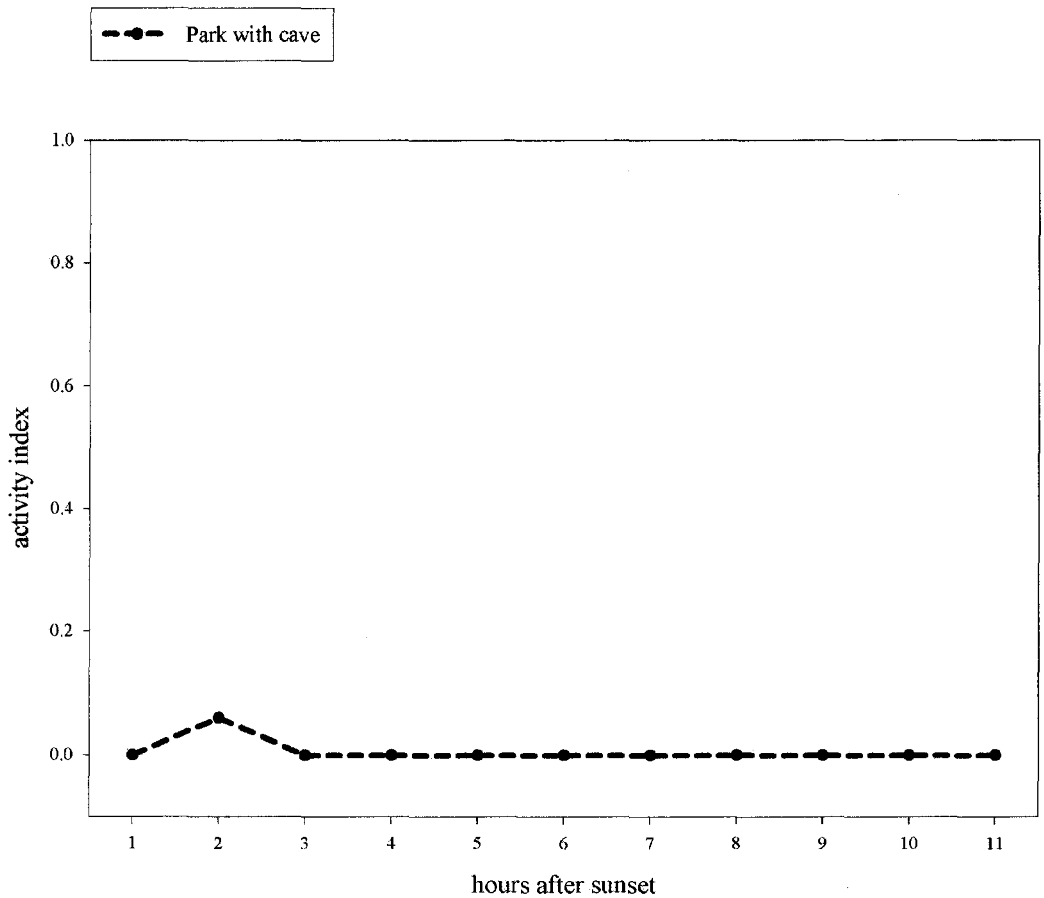


Figure 20. *Myotis sodalis* urban habitat usage.

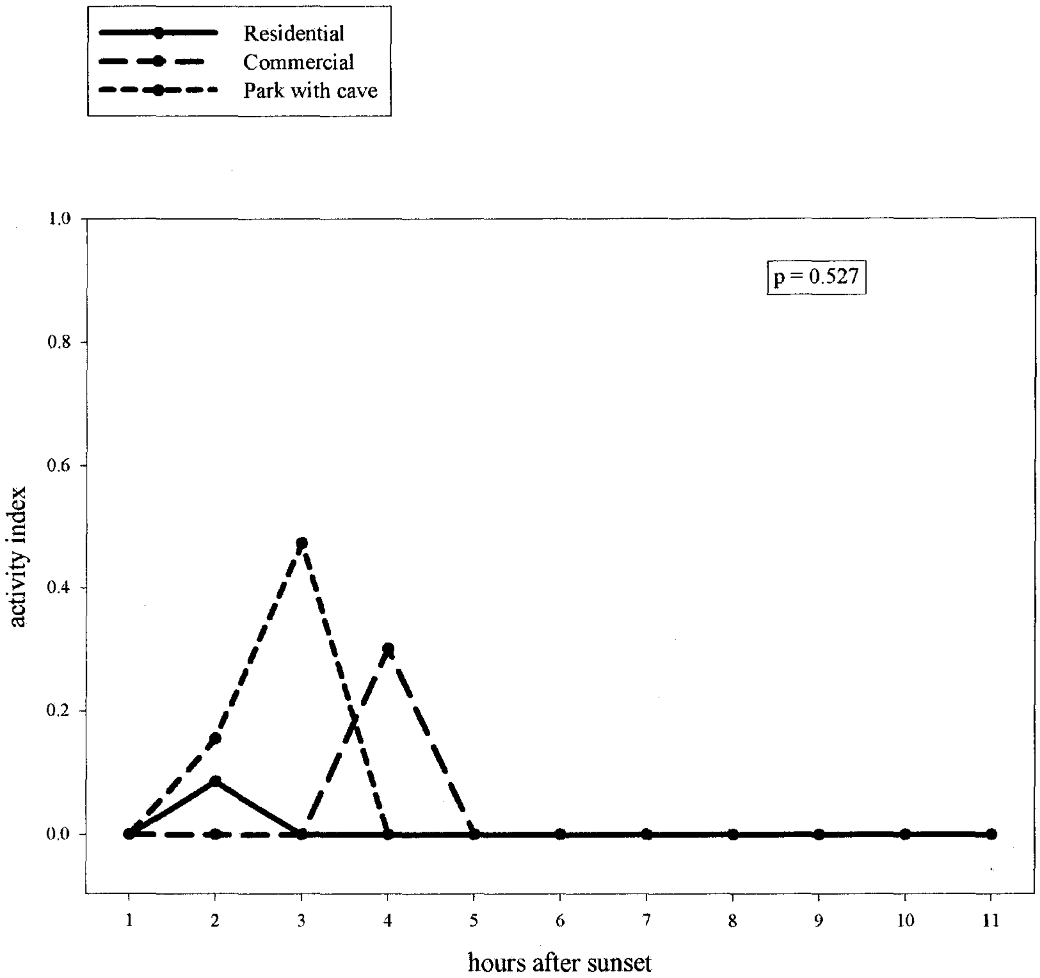


Figure 21. *Pipistrellus subflavus* urban habitat usage.

Eight of these sequences were around stadium lights, five from around a billboard, and the remainder from random lights within the city.

Telemetry

Home range is defined as the area in which an animal normally lives, excluding long migrations and random erratic movements (Brown and Orians, 1970). Generally, home ranges do not have fixed boundaries, and as is often the case, they can be continuous, compact or disjunct and broken into several areas connected by flyways. Prey items are normally not distributed evenly across the home range, thus certain areas are visited with more frequency than others; not every part of the home range is utilized on a daily basis (Smith, 1996). For bats, males and adults typically have larger home ranges than females and juveniles (Smith, 1996).

A total of 12 bats were successfully tracked via radio telemetry: 6 *Eptesicus fuscus*, 3 males and 3 females; 4 *Lasiurus borealis*, 2 males and 2 females; a female *Pipistrellus subflavus* and a male *Myotis grisescens* (Figure 22).

Eptesicus fuscus were captured at four different locations: a church, a residence, a cave, and a business. An established maternity colony of about 75 big brown bats inhabit Saint Joseph's Catholic Church, located just north of the center of Springfield. An adult lactating female and a newly volant, or flying, male were hand collected on 1 July 1999 from the steeple. At dusk, the female, shown in light blue (Figure 23), didn't forage far from the church. Her foraging bouts lasted about 30 minutes and comprised the areas over a college, a park, and the town square. Her home range area was 0.49 km^2 and her greatest distance from the roost was 1.3 km.

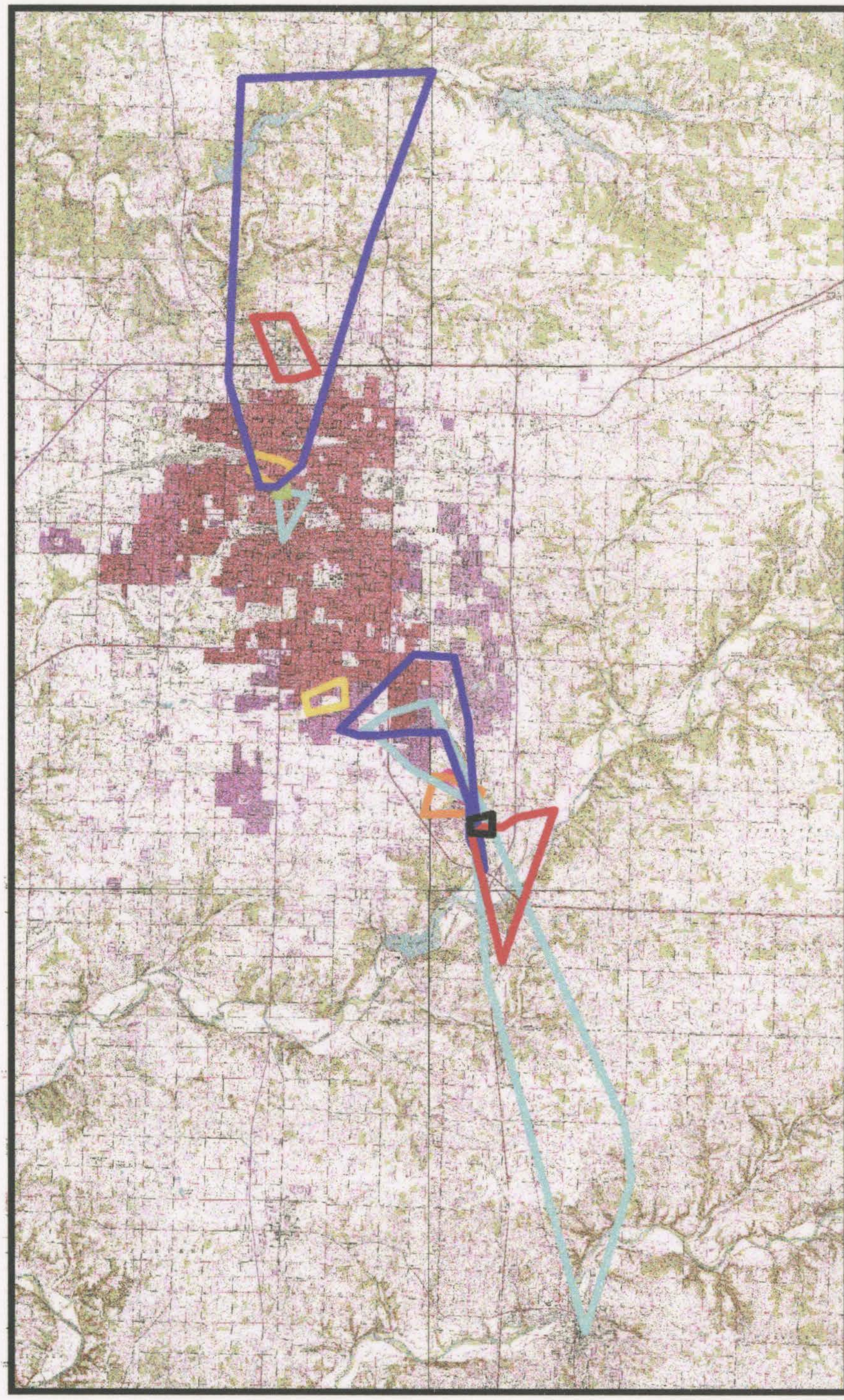
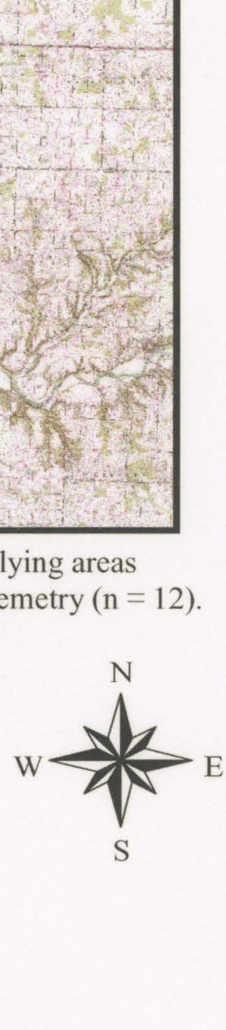


Figure 22. Topographic map of Springfield and outlying areas displaying home ranges of bats tracked via radio telemetry (n = 12). Each lineation depicts a different bat tracked



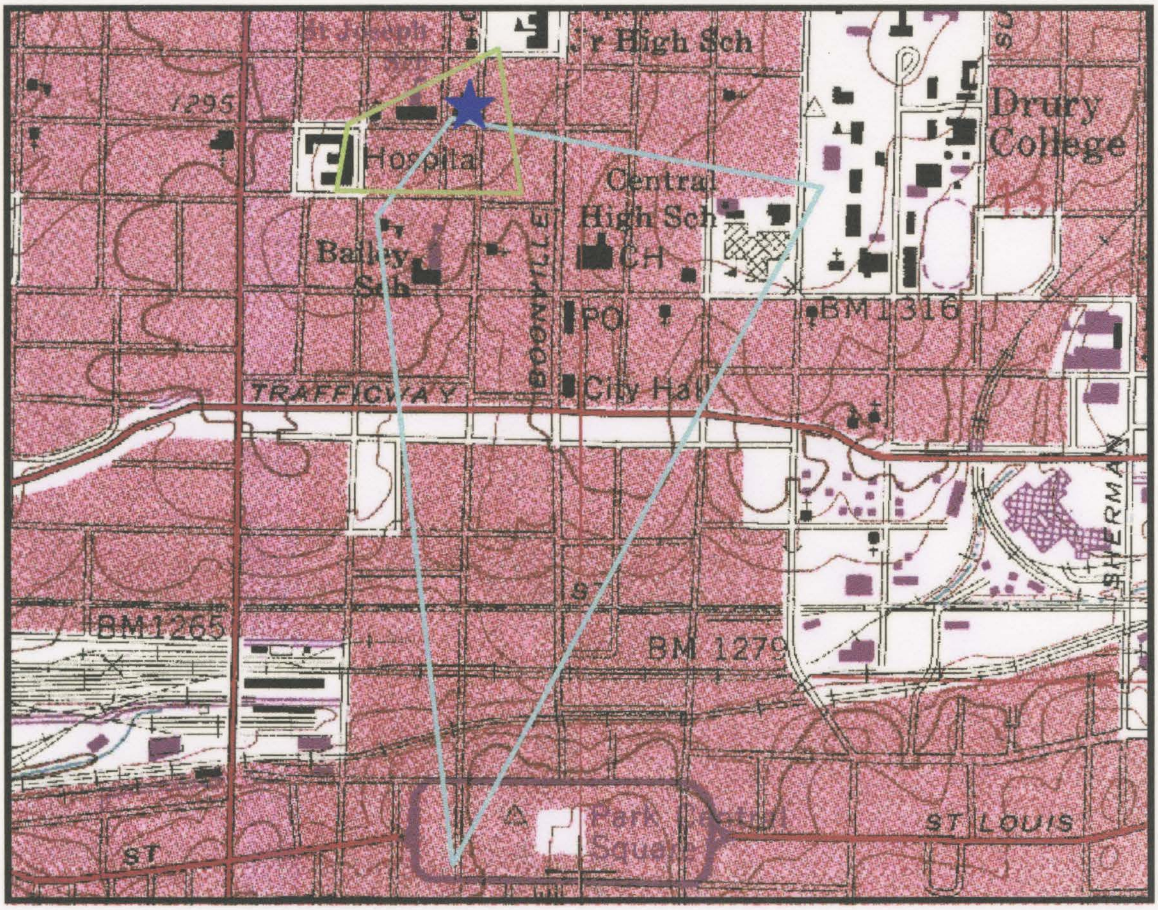


Figure 23. Home ranges of lactating female (light blue) and newly volant male (light green) *Eptesicus fuscus*. Church roost depicted as star. Both bats had a total of four tracking nights.

The behavior of the newly volant male, shown in light green (Figure 23), indicated he was probably an inexperienced flyer. His foraging bouts were about 20 minutes long, and he flew no farther than one block away from the church at any time. His home range was 0.05 km^2, and his greatest distance from the roost was 0.25 km.

An adult male and lactating female were hand-collected on 20 July 1999 from a colony of several dozen within the attic of a residence in the north-central part of town. The male, shown in dark blue (Figure 24), foraged briefly over a park, a railroad yard, and lights at a school but then mainly foraged over farmland, small creeks and more rural areas. His mean foraging time was 2.5 hours, and his home range encompassed 11.44 km^2 with a greatest distance from the roost being 35.43 km.

The female, shown in yellow (Figure 24), stayed within close proximity to the roost, as is displayed by her home range area of 0.59 km^2 and her greatest distance from the roost being 0.9 km. She essentially circled the residence, and her foraging bouts were no more than one hour in duration.

An adult male *Eptesicus fuscus* was captured 21 June 1999 via mist net at the mouth of Doling Park Cave in the extreme north-central part of town. As with the other male tracked, this big brown bat (Figure 25) also spent a minimal amount of time foraging over street lights at a school and then fed over rural areas the duration of his foraging bout. As his transmission was lost shortly after leaving the city limits, I speculate his home range area and greatest distance from the roost are very conservative at 1.72 km^2 and 1.96 km respectively.

A newly postpartum female (Figure 26), was hand collected from a business in the center of town on 11 July 2000. As with the other female big brown bats tracked, she

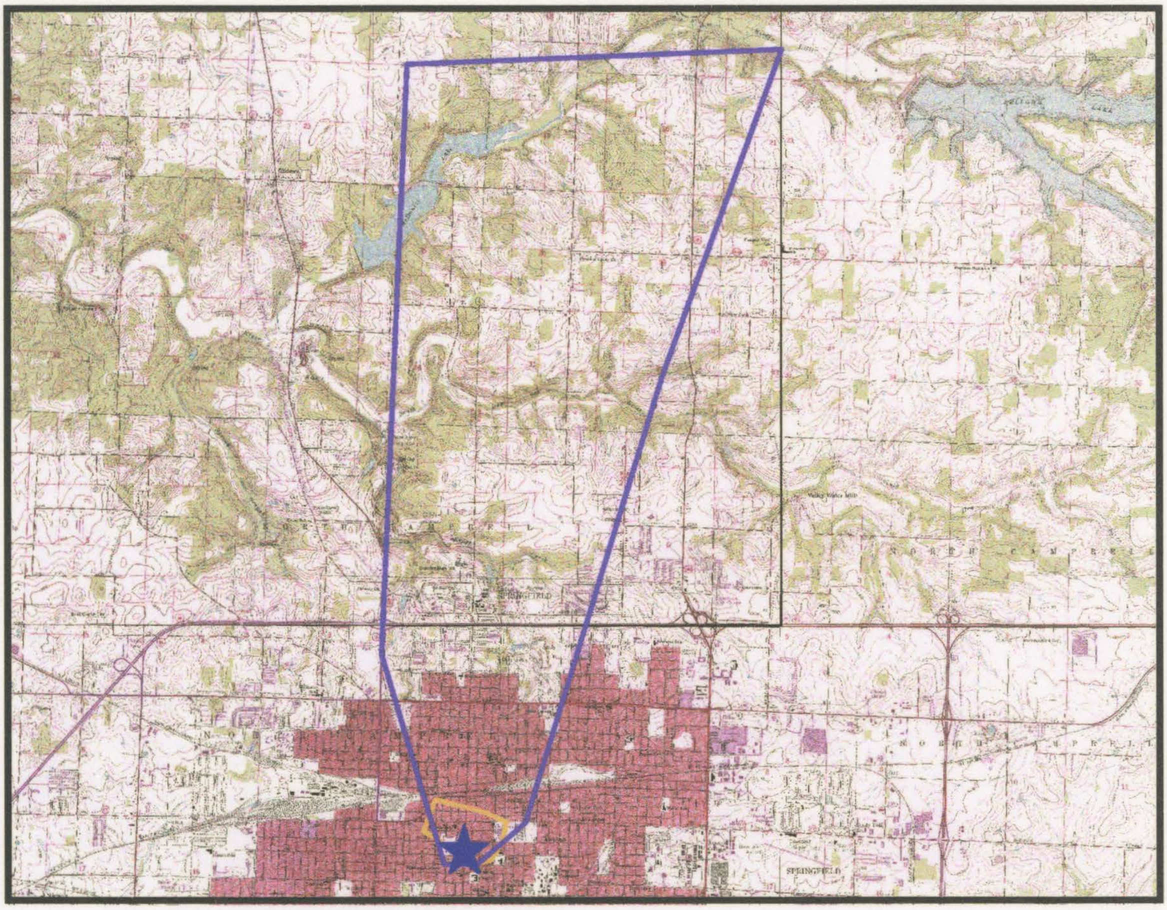
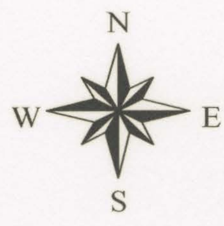


Figure 24. Home ranges of lactating female (yellow) and adult male (dark blue) *Eptesicus fuscus*. Residence roost depicted as star. Both bats had a total of six tracking nights.



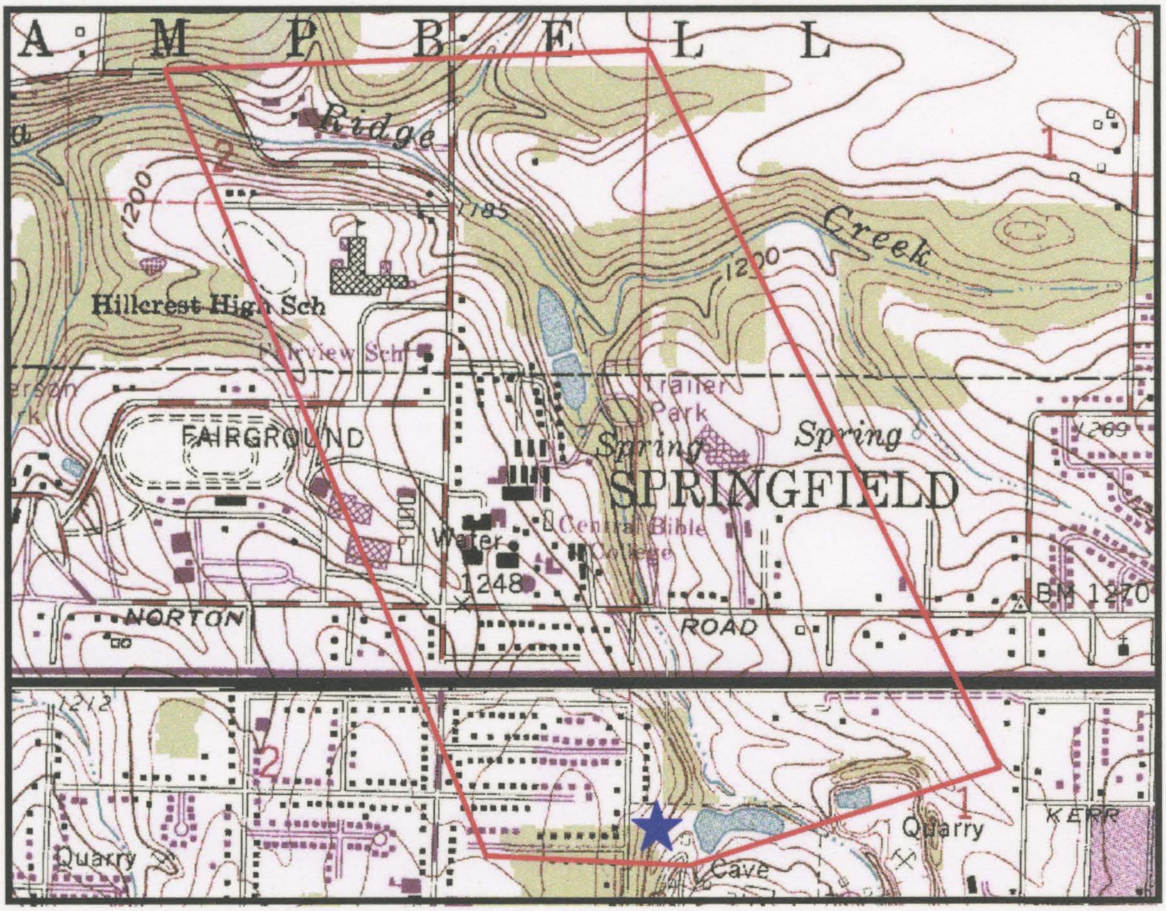
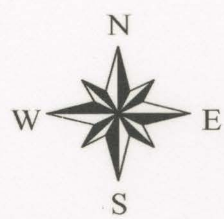


Figure 25. Home range of adult male *Eptesicus fuscus*. Star indicates roost cave. Tracked for a total of three nights.



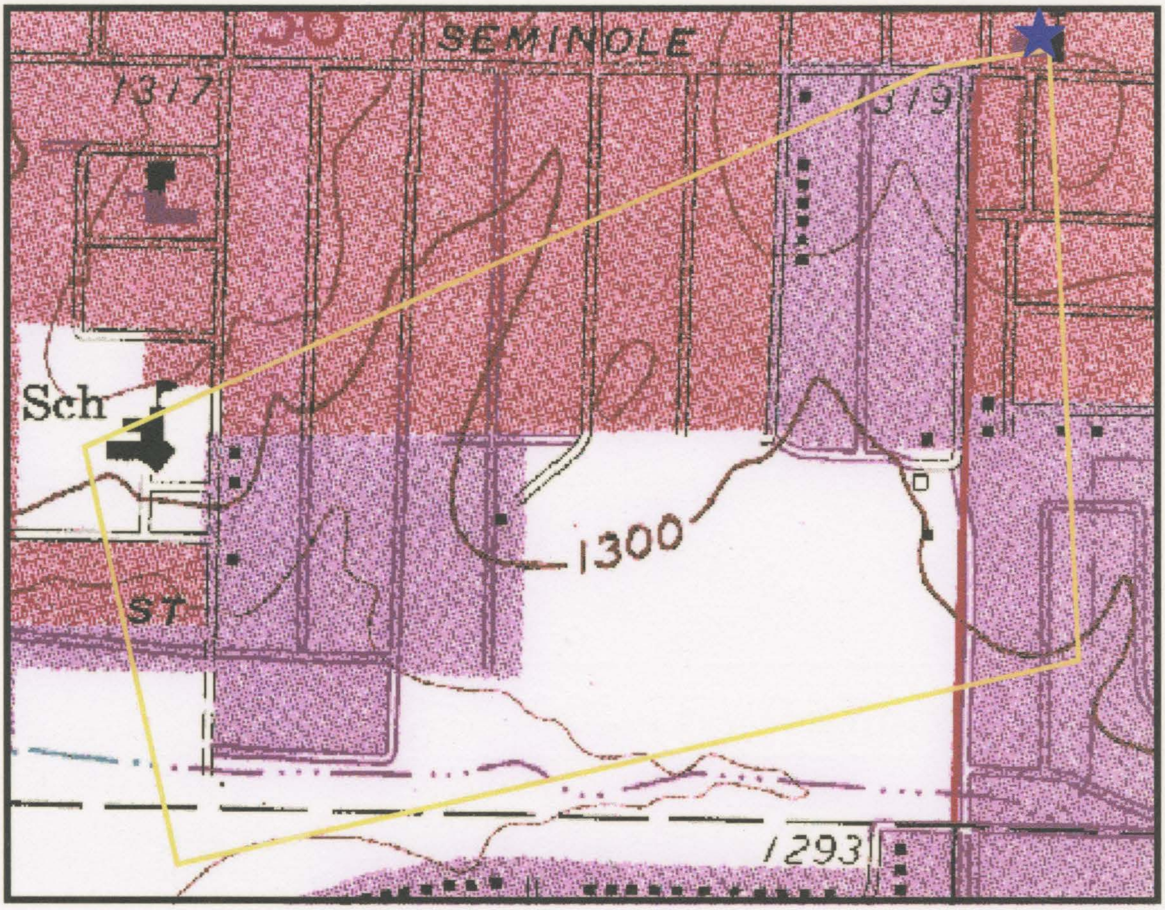
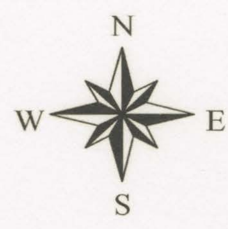


Figure 26. Home range of postpartum female *Eptesicus fuscus*. Star indicates business roost. Tracked for a total of five nights.



fed within close proximity to her roost and incorporated residential and commercial areas into her foraging bout. Her home range area totaled 0.50km^2 with the greatest distance from roost being 1.29 km.

Four *Lasiurus borealis* were tracked. Two pregnant females were captured 8 June 1999 with a mist net placed at a cave mouth in the southeastern corner of Springfield, and two males were trapped in a mist net erected upon the roof of a home in a residential neighborhood in southeastern Springfield. The two females were not residents of the cave, rather, they roosted in trees depicted with a pink and orange star (Figure 27). The smaller home range of 0.26 km^2 belonged to the female who was much further along in gestation. The greatest distance she flew from her roost tree was 0.87 km. The female in earlier stages of gestation had a home range of 1.12 km^2 with a greatest distance from her roost tree being almost twice that of her conspecific's at 1.52 km. Neither female foraged for more than 45 minutes per bout, but both went out to feed many times throughout the course of each night over low-density residential areas and a park. Both also focused the majority of their foraging over the residential sinkholes adjacent to the roost trees.

The male red bats were captured 1 October 2000. One male, shown in black (Figure 28), remained consistent in his foraging in that he never ventured further than 0.42 km from his roost tree. His home range area encompassed low-density residential sites and totaled 0.27 km^2. The other male, shown in red (Figure 28) foraged briefly over the same low-density residential sites but then flew to an agricultural area where he spent the duration of his foraging time. His furthest distance from his roost tree was 3.57 km and his home range totaled 3.89 km^2.

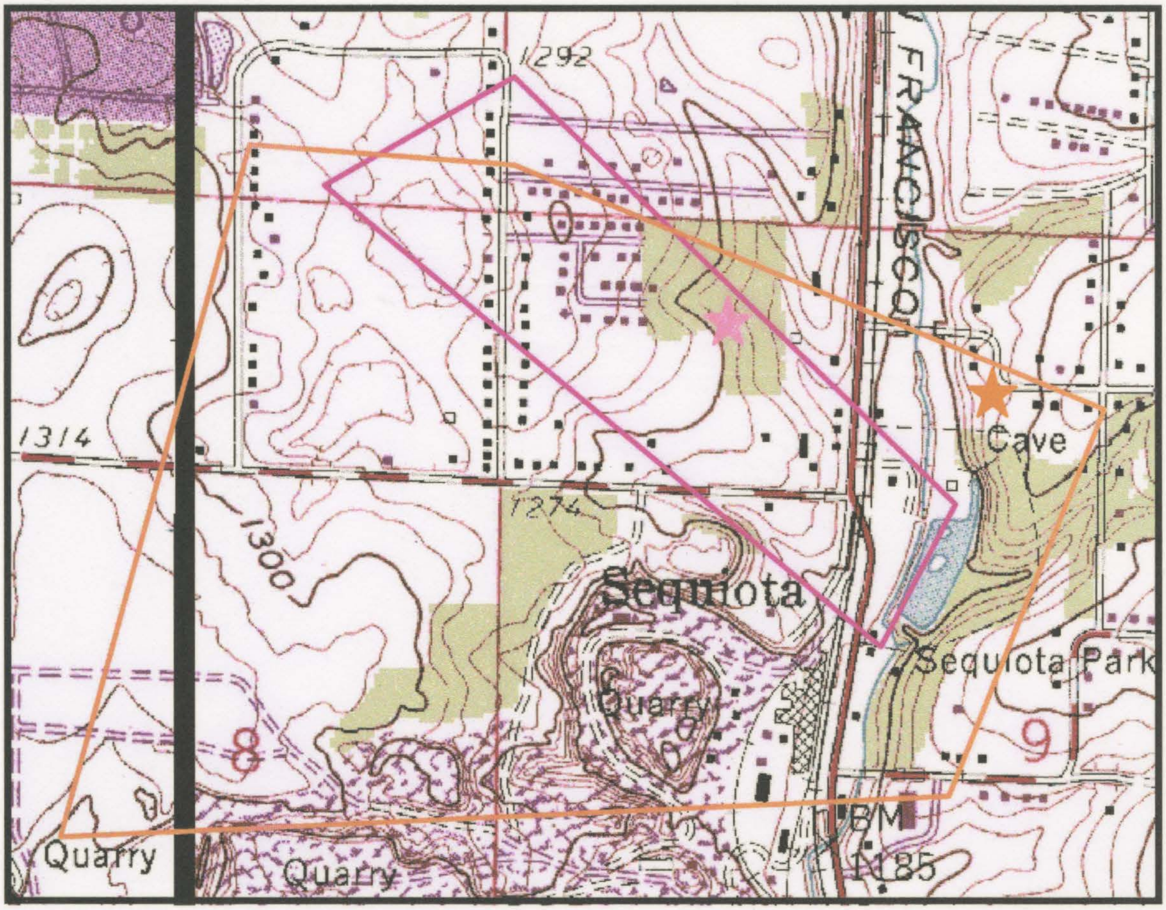


Figure 27. Home ranges of gestating *Lasiurus borealis*. Roost trees depicted as stars of corresponding color. Both were tracked for a total of two nights.

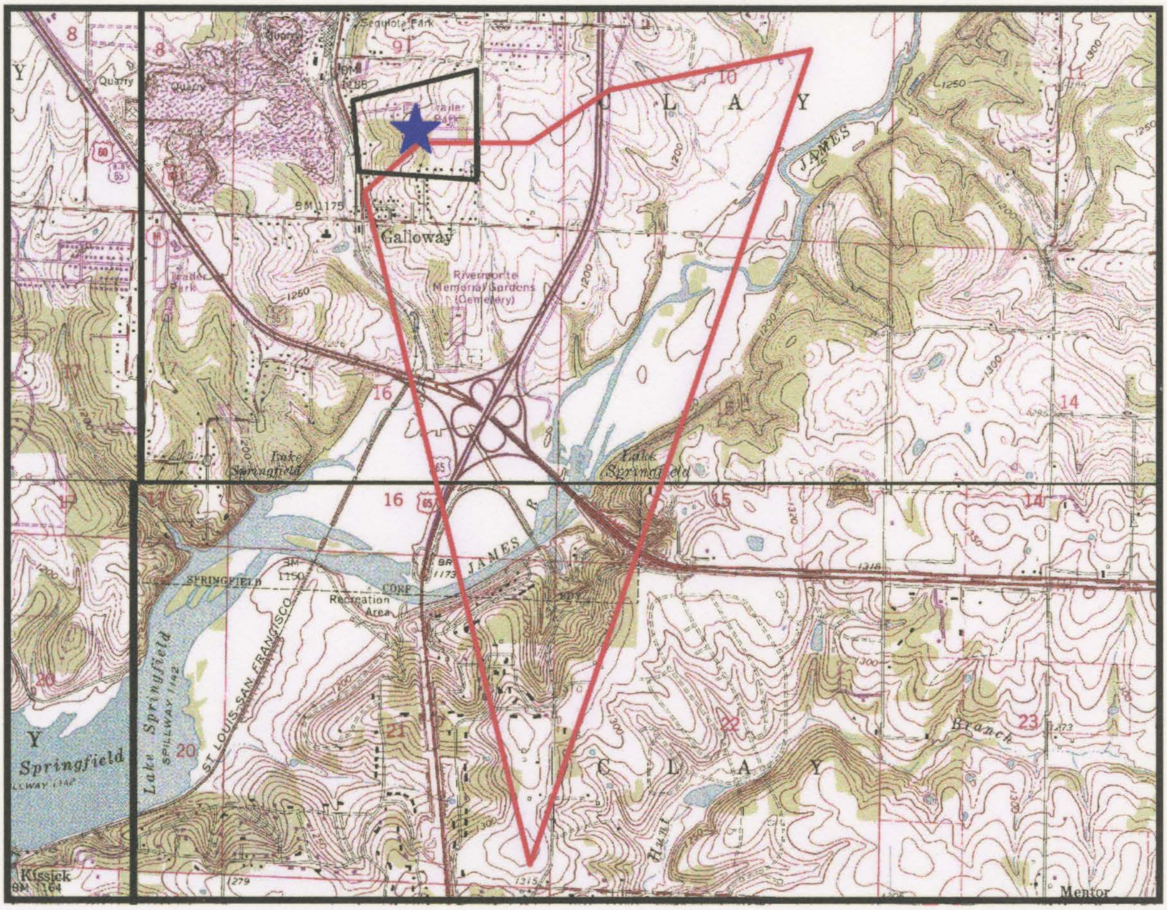
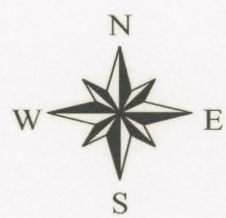


Figure 28. Home ranges of adult male *Lasiurus borealis*. Capture site depicted by star. Bat shown in black was tracked for four nights, bat in red was tracked for three nights.



One adult male *Myotis grisescens* and one juvenile female *Pipistrellus subflavus* were captured at the same cave as the female red bats. The gray bat (Figure 29) was captured 28 May 1999 and flew a very consistent course night after night; he started with foraging over a lake just north of his roost cave and then fed over medium-density residential and commercial areas for the remainder of his 2.5-3 hour foraging bout. One night however, an impending thunderstorm changed the distance and direction of his normal route. Instead of foraging over populated areas, he flew back and forth repeatedly in a stream corridor adjacent to his roost cave. His home range area was 5.88 km^2, and his greatest distance from the roost was 4.03 km.

The young pipistrelle (Figure 30) captured 19 August 1999 began her foraging the first few nights of tracking by spending an hour in town over commercial and medium-density residential areas. The next nights of tracking, she ventured farther and farther south from her roost until she reached the small town of Ozark, Missouri. She foraged in Ozark shortly over a school and church, but then returned to her Springfield roost, briefly feeding over the many small ponds and streams that dissect the area. Even though her rural foraging route was very different from her urban route, her foraging time was still about 1 hour. Her home range area was computed at 25.5 km^2, and her greatest distance from her roost was 14.57 km.

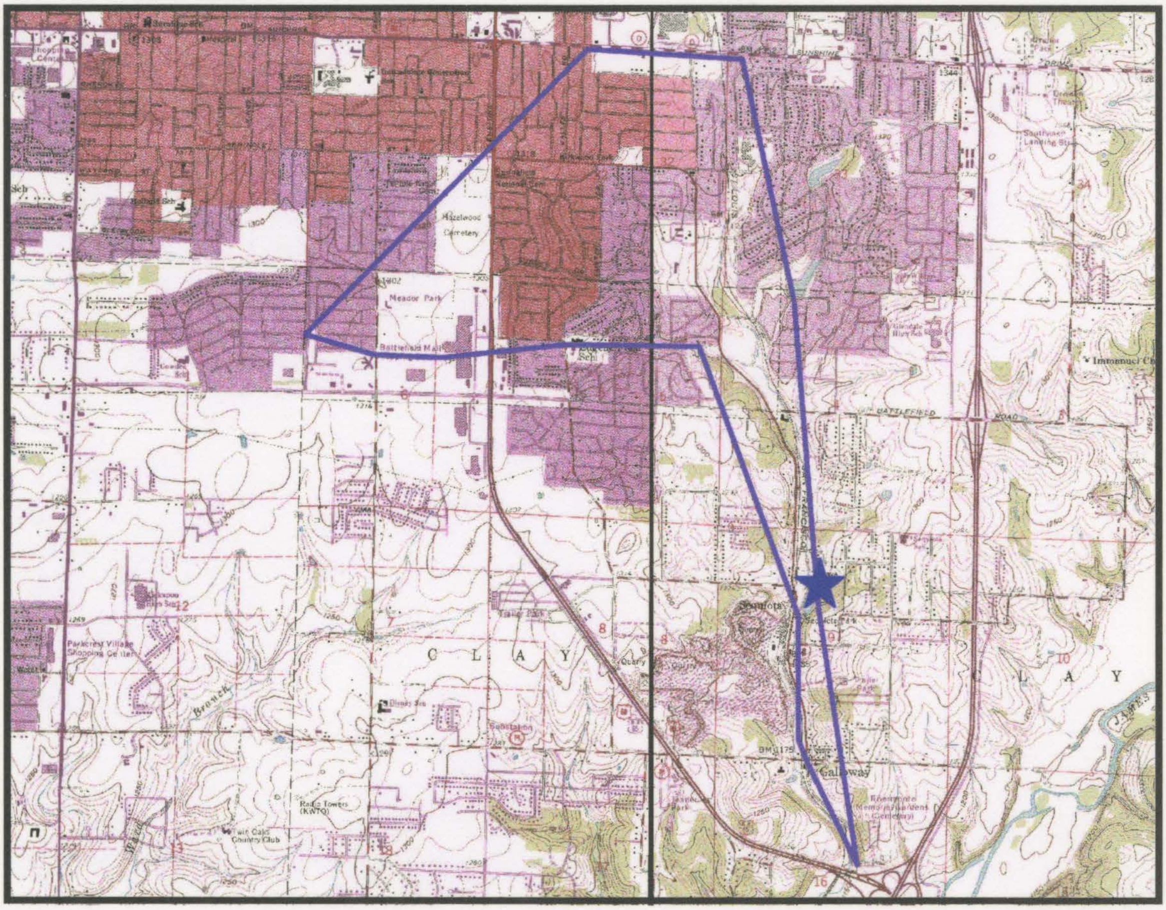
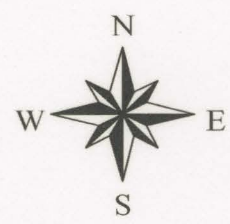


Figure 29. Home range of adult male *Myotis grisescens*. Roost cave depicted by star. Tracked for total of five nights.



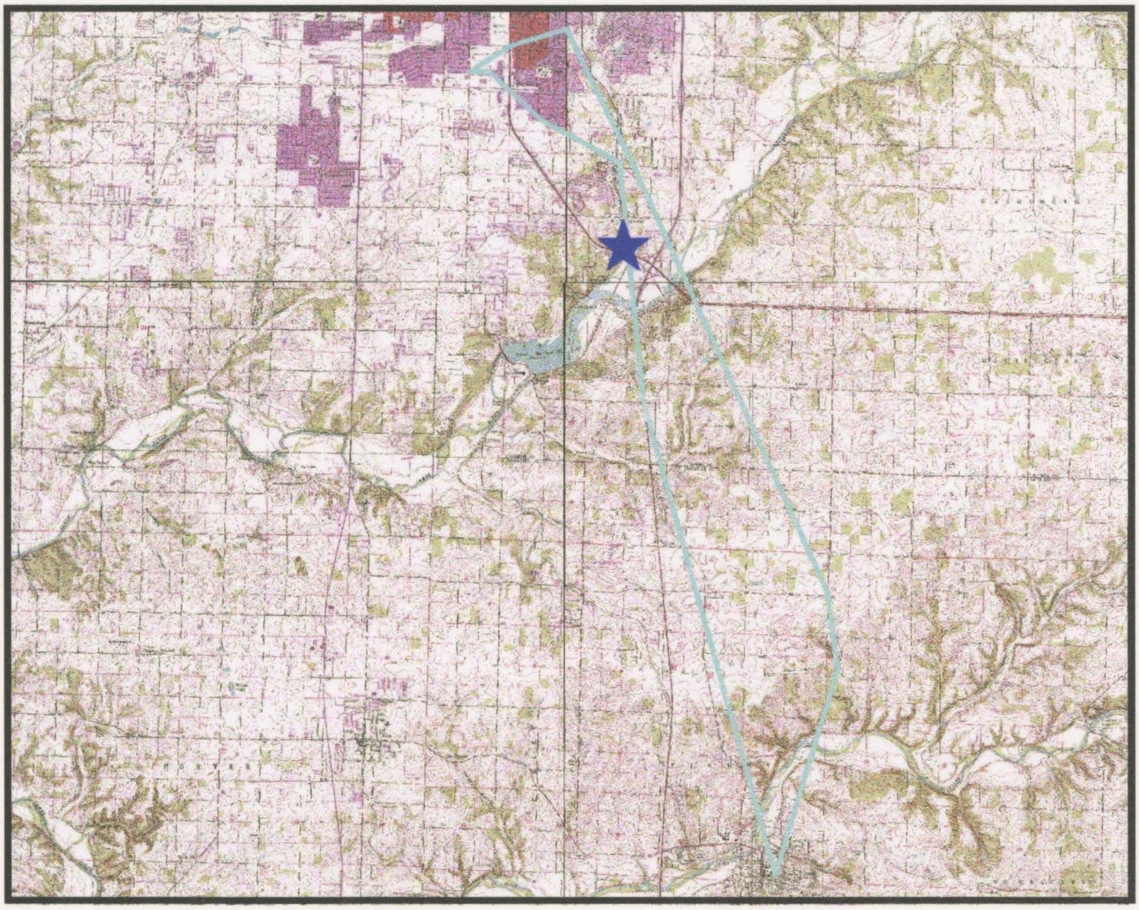
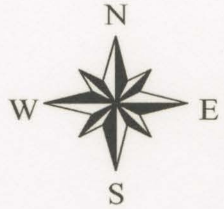


Figure 30. Home range of juvenile female *Pipistrellus subflavus*. Roost cave depicted by star. Tracked for a total of six nights.



DISCUSSION

The significant difference in the mean levels of *Eptesicus fuscus* activity between urban and rural environments may be due to the plethora of available roosting sites, such as buildings and residences, within Springfield. The data showing that residential areas have more big brown bat activity than other habitats within Springfield further supports this hypothesis. Of the big brown bats tracked by radio telemetry, the females all foraged in town in close proximity to their roosts while the males all flew to the outlying rural areas to feed. When not lactating, the females may also forage outside of urbanized environments as there is greater insect biomass in rural areas (Furlonger et al., 1987), but during the time of year the females were tracked, these locations are farther from the roost and from nursing young. Geggie and Fenton's study (1985) on *Eptesicus fuscus* in urban and rural environments did not find a significant difference in the mean level of activity between urban and rural sites, or in relative activity between habitat types in the urban setting. They did find that the likelihood of encountering a foraging big brown bat in rural areas was more than twice that in the urban environment. Perhaps the ideal environment for *E. fuscus* is at the periphery of urban and rural settings, thus exploiting anthropogenic structures and the greater rural insect biomass.

If insect density is higher in rural settings than urban areas, foliage roosting bats such as *Lasiurus borealis* and *L. cinereus* should be less active in urban areas because of prey rather than roost density (Geggie and Fenton, 1985). However, there was no significant difference in amount of red bat or hoary bat activity between rural and urban environments, and three of the four *L. borealis* tracked foraged tightly around their urban roost tree. This could be directly related to patchiness in insect abundance. Parks and

greenways serve as "islands" surrounded by urban "ocean" to insects such as Diptera and Coleoptera. Within these urban islands, the species richness and abundance are higher than the surrounding urban setting, and suggest that these insects are as isolated as many species which occur on true oceanic islands (Faeth and Kane, 1978). The higher level of bat activity in greenways and parks in the present study further supports this hypothesis.

The occurrence of the forest dwelling *Myotis sodalis* and *M. septentrionalis* within the urban environment is probably incidental, as these species were only recorded at the urban and rural interface. The abundance of studies that depict *Myotis lucifugus* (Pearl and Fenton, 1996) and *Nycticeius humeralis* (Harvey et al., 1991) as species that willingly utilize urban environments and anthropogenic structures for roosting, and the relative lack of occurrences of these species in this study is not readily explicable. The low amount of recorded activity of these bats negates the idea that little brown bat and evening bat roosts were simply not located, and further supports the results that indicate that these two species are not abundant in Springfield.

Pipistrellus subflavus have also been documented forming maternity colonies in man-made structures, however the only colonies of the eastern pipistrelle encountered were those in caves. While parks with caves did display the most activity for this species, they were not significant in regards to the other urban habitat types where eastern pipistrelles were recorded. Urbanization did not affect the emergence times and peaks of activity in the foraging of *P. subflavus* when compared to rural settings, but the decrease in amount of activity was substantial. Loss of suitable roosting habitat may account for this, as may favored prey density; the female eastern pipistrelle radio tracked foraged a considerable distance outside of town over rural areas dotted with sinkholes and small

ponds and streams. It is this type of riparian habitat that Tuttle (1975, 1976) and Choate and Decher (1996) would have predicted the radio-tagged gray bat would have foraged. On the contrary, the male *Myotis grisescens* fed over highly urbanized locations including residential and commercial areas. *M. grisescens* did not seem adversely affected by urbanization in Springfield, as the activity levels for this species are comparable in urban and rural environments. The fact that the gray bat was encountered in Springfield is undoubtedly due to the presence of multiple small caves within the city limits. This, coupled with the many streams and the open drainage system that acts as a river, serve as the riparian habitat and roost sites required by this endangered species. If these caves and waterways did not exist, it is probable that the gray bat would not inhabit this urban environment.

Street lights

Many studies have documented the exploitation of insects around street lights by foraging bats (Geggie and Fenton, 1985; Furlonger et al., 1987; Hickey and Fenton, 1990; Rydell and Racey, 1995; Catto et al., 1996; Hickey et al., 1996; Fenton, 1997). As lights attract aggregations of insects, thereby altering their spatial distribution, some species of aerial hawking insectivorous bats have learned to take advantage of concentrations of food at these predictable locations. However, insect density around street lamps is dependent on the type of lamp. Mercury-vapor street lights emit a bluish-white light, and these are shown to attract insects. In contrast, the monochromatic orange light emitted by low-pressure sodium lamps do not attract insects, and the high-pressure sodium lights, which include some mercury-vapor lamps, are intermediate in attracting insects (Rydell and Racey, 1995).

Springfield's 16,646 street lights comprise a combination of mercury-vapor and high-pressure sodium, with the older lamps being the former. As these lights burn out, they are replaced by the high-pressure sodium, and are thus downgraded in terms of insect attraction. Eventually, all of Springfield will only be intermediate in drawing concentrations of insects around street lamps. In this study, comparatively few bats were seen or recorded foraging around street lamps. I surmise this may be due to a dilution effect of many lights in the area and therefore relatively low bat activity for any individual lamp.

CONCLUSION

Alterations in natural habitat caused by expansions in human populations or resource use remains to be the underlying theme in all conservation issues faced by North American bats (Pierson, 1998). With the exceptions of generalists who thrive in anthropogenic structures, such as *Eptesicus fuscus*, and tree dwelling species such as *Lasiurus borealis*, urban and suburban sprawl has eliminated or severely limited roosting and foraging habitat, resulting in dramatic declines in species richness, diversity and overall abundance (Geggie and Fenton, 1985; Kurta and Teramino, 1992).

The largest obstacle faced by bats in urban environments is that of human ignorance. Once people are educated about the relatively harmless nature of these beneficial insectivores, their unwarranted fears bred by popular misconceptions, exaggerated rabies scares and supposed health risks may be ameliorated. This should substantially decrease the number of senseless eradications of these animals from anthropogenic structures and thereby limit harmful pesticide use. Greenways with water sources incorporated into city planning would also be of great value, as the bats could then have flight corridors and greater roosting and foraging habitat. Commercially available bat houses are becoming more popular with the efforts of Bat Conservation International. With these steps, conservation is slowly taking a foothold for these invaluable aerial mammals.

"Our urban centers can be viewed as bellwethers of our global environmental fate. Our success at meeting the challenges of protecting biological diversity in urban areas is a good measure of our commitment to protect functioning ecosystems worldwide. If we cannot act as responsible

stewards in our own backyards, the long-term prospects for biological diversity in the rest of this planet are grim indeed" (Murphy, 1988).

LITERATURE CITED

Adams, L.W. and L.E. Dove. 1989. Wildlife Reserves and Corridors in the Urban Environment: A Guide to Ecological Landscape Planning and Resource Conservation. National Institute for Urban Wildlife, Maryland, 81pp.

Aldridge, H.D.J.N. and R.M. Brigham. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% "rule" of radio-telemetry. Journal of Mammalogy, 69: 379-382.

Altringham, J.D. 1998. BATS Biology and Behaviour. Oxford University Press Inc., New York, 262pp.

Anthony, E.L.P. 1988. Age determination in bats. *In* Ecological and Behavioral Methods for the Study of Bats, (T.H. Kunz ed.), Smithsonian Institution Press, Washington D.C., London, 47-57pp.

Balcombe, J.P. and M.B. Fenton. 1988. Eavesdropping by bats: the influence of echolocation call design and foraging strategy. Ethology, 79: 158-166.

Barbour, R.W. and W.H. Davis. 1969. Bats of America. The University Press of Kentucky, 286pp.

Barclay, R.M.R. 1985. Long- versus short-range foraging strategies of hoary (*Lasiurus cinereus*) and silver-haired *(Lasionycteris noctivagans)* bats and the consequences for prey selection. Canadian Journal of Zoology, 63: 2507-2515.

______ and G.P. Bell. 1988. Marking and observational techniques. *In* Ecological and Behavioral Methods for the Study of Bats, (T.H. Kunz ed.), Smithsonian Institution Press, Washington D.C., London, 59-76pp.

______ 1991. Population structure of temperate zone insectivorous bats in relation to foraging behaviour and energy demand. Journal of Animal Ecology, 60: 165-178.

______ and R.M. Brigham. 1991. Prey detection, dietary niche breadth and body size in bats: why are aerial insectivorous bats so small? American Naturalist, 137: 693-703.

Bell, G.P. 1980. Habitat use and response to patches of prey by desert insectivorous bats. Canadian Journal of Zoology, 58: 1876-1883.

Betts, B.J. 1998. Effects of interindividual variation in echolocation calls on identification of big brown and silver-haired bats. Journal of Wildlife Management, 62: 1003-1010.

Bradbury, J., D. Morrison, E. Stashko, and R. Heithaus. 1979. Radio-tracking methods for bats. Bat Research News, 20: 9-17.

Brigham, R.M., J.E. Cebek, and M.B.C. Hickey. 1989. Intraspecific variation in the echolocation calls of two species of insectivorous bats. Journal of Mammalogy, 70: 426-428.

Britzke, E.R., K.L. Murray, B.M. Hadley, and L.W. Robbins. 1999. Measuring bat activity with the Anabat II system. Bat Research News, 40: 1-3.

Britzke, E.R., K.L. Murray, J.S. Heywood, and L.W. Robbins. In press. Acoustic identification of the Indiana bat, *Myotis sodalis*.

Brown, J.L. and G.H. Orians. 1970. Spacing Patterns in Mobile Animals, Annual Review of Ecology and Systematics Vol. 1, 239-262pp.

Buchler, E.R. 1976. A chemiluminescent tag for tracking bats and other small nocturnal animals. Journal of Mammalogy, 57: 173-176.

Cahalane, V.H. 1964. Mammals of North America, Macmillan Company, New York, 682pp.

Catto, C.M.C., A.M. Hutson, P.A. Racey, and P.J. Stephenson. 1996. Foraging behavior and habitat use of the serotine bat (*Eptesicus serotinus*) in southern England. The Zoological Society of London, 238: 623-633.

Choate, J.R. and J. Decher. 1996. Critical habitat of the gray bat (*Myotis grisescens*) in Kansas. Kansas Department of Wildlife and Parks, Pratt, Kansas, 26pp.

Constantine, D.G. 1970. Bats in relation to the health, welfare and economy of man. *In* Biology of Bats, Vol. II (W. A. Wimsatt, ed.), Academic Press, New York, 319-449pp.

Cousins, S.H. 1982. Species size distributions of birds and snails in an urban area. *In* Urban Ecology (R. Bornkamm, J.A. Lee and M.R.D. Seaward, eds.), Blackwell Scientific Publications, Oxford, 99-109pp.

Cross, S.P. 1986. Bats. *In* Inventory and monitoring of wildlife habitat, (A.Y. Cooperrider, R.J. Boyd, and H.R. Stuart, eds.), U.S. Department of the Interior, Bureau of Land Management Service Center, Denver, Colorado, 497-517pp.

Cox, B.C. and P.D. Moore. 1995. Biogeography: An Ecological and Evolutionary Approach, Blackwell Science Ltd., London, 140-150pp.

Davis, A.M. and T.F. Glick. 1978. Urban ecosystems and island biogeography. Environmental Conservation, 5: 299-304.

Davis, B.N.K. 1982. Habitat diversity and invertebrates in urban areas. *In* Urban Ecology, (R. Bornkamm, J.A. Lee and M.R.D. Seaward, eds.), Blackwell Scientific Publications, Oxford, 49-63pp.

Dickman, C.R. 1987. Habitat fragmentation and vertebrate species richness in an urban environment. Journal of Applied Ecology, 24: 337-351.

Ekman, M. and J. De Jong, 1996. Local patterns of distribution and resource utilization of four bat species *(Myotis brandti, Eptesicus nilssoni, Plecotis auritus* and *Pipistrellus pipistrellus)* in patchy and continuous environments. The Zoological Society of London, 238: 571-580

Erickson, J.L. and S.D. West. 1996. Managed forest in the Western Cascades: the effects of seral stage on bat habitat use patterns. *In* Bats and Forest Symposium (R.M.R. Barclay and R.M. Brigham, eds.), British Columbia Ministry of Forests, Victoria, British Columbia, Canada, 215-227pp.

Faeth, S.H. and T.C. Kane. 1978. Urban Biogeography: city parks as islands for Diptera and Coleoptera. Oecologia, 32: 127-133.

Feldhamer, G.A., L.C. Drickamer, S.H. Vessey, and J.F. Merritt. 1999. Mammalogy: Adaption, Diversity and Ecology, McGraw – Hill Companies, Inc., United States of America, 206-225pp.

Fenton, M.B., S.L. Jacobson, and R.N. Stone. 1973. An automatic ultrasonic sensing system for monitoring the activity of some bats. Canadian Journal of. Zoology. 51: 291-299.

Fenton, M.B. and G.P. Bell. 1981. Recognition of species of insectivorous bats by their echolocation calls. Journal of Mammalogy, 62: 233-243.

Fenton, M.B. 1982. Echolocation, insect hearing, and feeding ecology of insectivorous bats. *In* Ecology of bats, (T.H. Kunz ed.), Plenum Press, New York and London, 261-285pp.

______ and H.G. Merriam. 1983. Bats of Kootenay, Glacier, and Mount Revelstoke National parks in Canada: Identification by echolocation calls, distribution, and biology. Canadian Journal of Zoology, 61: 2503-2508.

______ 1997. Science and the conservation of bats. Journal of Mammalogy, 78: 1-14.

______ 1998. The Bat: Wings in the Night Sky. Firefly Books Inc., United States, 144pp.

Findley, J.S. 1993. Bats a community perspective. Cambridge University Press, Great Britain, 167pp.

Forbes, B. and E.M. Newhook. 1990. A comparison of the performance of three models of bat detectors. Journal of Mammalogy, 71: 108-110.

Furlonger, C.L., H.J. Dewer, and M.B. Fenton. 1987. Habitat use by foraging insectivorous bats. Canadian Journal of Zoology, 65: 284-288.

Gardener, J.E., J.E. Garner, and J.E. Hofmann. 1989. A portable mist netting system for capturing bats with emphasis on *Myotis sodalis* (Indiana bat). Bat Research News, 30: 1-8.

Geggie J.F. and M.B. Fenton. 1985. A comparison of foraging by *Eptesicus fuscus* (Chiroptera: Vespertilionidae) in urban and rural environments. Canadian Journal of Zoology, 63: 263-266.

Hall, E.R. 1981. The Mammals of North America. John Wiley and Sons. New York, 2: 182-227.

Harvey, M.J., J.R. MacGregor, and R.R. Currie. 1991. Distribution and status of Chiroptera in Kentucky and Tennessee. Journal of the Tennessee Academy of Science, 66: 191-193.

Hayes, J.P. 1997. Temporal variation in activity of bats and the design of echolocation – monitoring studies. Journal of Mammalogy, 78: 514-524.

Hayes, J.P. and M.D. Adam. 1996. The influence of logging riparian areas on habitat utilization by bats in western Oregon. *In* Bats and Forest Symposium, (R.M.R. Barclay and R.M. Brigham, eds.), British Columbia Ministry of Forests, Victoria, British Columbia, Canada, 228-292pp.

______ and P. Hounihan. 1994. Field use of the Anabat II bat-detector system to monitor bat activity. Bat Research News, 35: 1-3.

Hickey, M.B.C. and M.B. Fenton. 1990. Foraging by red bats (*Lasiurus borealis*): do intraspecific chases mean territoriality? Canadian Journal of Zoology, 68: 2477-2482.

Hickey, M.B.C, L. Acharya, and S. Pennington. 1996. Resource partitioning by two species of vespertilionid bat (*Lasiurus cinereus* and *Lasiurus borealis*) feeding around street lights. Journal of Mammalogy, 77: 325-334.

Hill, J.E. and J.D. Smith. 1984. Bats a natural history. University of Texas Press, Austin, 243pp.

Humphrey S.R., A.R. Richter, and J.B. Cope. 1977. Summer habitat and ecology of the endangered Indiana bat, *Myotis sodalis*. Journal of Mammalogy, 58: 334-346.

Johnsen, A.M. and L.W. VanDruff. 1987. Summer and winter distribution of introduced bird species and native bird species richness within a complex urban environment. Integrating Man and Nature in the Metroplitan Environment, Proc. National Symposium on Urban Wildlife, 123-127.

Koch, E.R. 2000. Population characteristics of urban white-tailed deer (*Odocoileus virginianus*) in southern Springfield, Missouri. Unpublished thesis. Southwest Missouri State University, Springfield, Missouri.

Krusic, R.A. and C.D. Neefus. 1996. Habitat associations of bat species in the White Mountain National Forest. *In* Bats and Forest Symposium (R.M. Barclay and R.M. Brigham, eds.), British Columbia Ministry of Forests, Victoria, British Columbia, 185-198pp.

Kuenzi, A.J. and M.L. Morrison. 1998. Detection of bats by mist nets and ultrasonic sensors. Wildlife Society Bulletin, 26: 307-311.

Kunick, W. 1982. Comparison of the flora of some cities of the Central European Lowlands. Urban Ecology, (R. Bornkamm, J.A. Lee, and M.R.D. Seaward eds.), Blackwell Scientific Publications, Oxford, 13-22pp.

Kunz, T.H. 1973. Resource utilization: temporal and spatial components of bat activity in central Iowa. Journal of Mammalogy, 54: 14-32.

______ and C. Brock. 1975. A comparison of mist nets and ultrasonic detectors for monitoring flight activity of bats. Journal of Mammalogy, 56: 907-911.

______ and A. Kurta. 1988. Capture methods and holding devices. *In* Ecological and Behavioral Methods for the Study of Bats, (T.H. Kunz ed.), Smithsonian Institution Press, Washington D.C., London, 1-28pp.

Kurta, A. and J.A. Teramino. 1992. Bat community structure in an urban park. Ecography, 15: 257-261.

Lance, R.F., B. Bollich, C.L. Callahan, and P.L. Leberg. 1996. Surveying forest-bat communities with Anabat detectors. *In* Bats and Forest Symposium, (R.M.R. Barclay and R.M. Brigham, eds.), British Columbia Ministry of Forests, Victoria, British Columbia, Canada, 175-184pp.

LaVal, R.K. 1970. Banding returns and activity patterns of some Costa Rican bats. Southwestern Naturalist, 15: 1-10.

Leedy, D.L. and L.W. Adams. 1986. Wildlife in urban and developing areas: an overview and historical perspective. *In* Wildlife Conservation and New Residential Developments: Proc. National Symposium on Urban Wildlife, 8-20.

Margules C. and M.B. Usher. 1981. Criteria used in assessing wildlife conservation potential: a review. Biological Conservation, 21: 79-109.

Murphy, D.D. 1988. Challenges to biological diversity in urban areas. *In* Biodiversity, (E.O. Wilson ed.), National Academy Press, Washington D.C., 71-76pp.

Murray, K.L., E.R. Britzke, B.M. Hadley, and L.W. Robbins. 1999. Surveying bat communities: a comparison between mist nets and the Anabat II bat detector system. Acta Chiroperologica, 1: 105-122.

Murray, K.L., E.R. Britzke, and L.W. Robbins. 2001. Variation in search-phase calls of bats. Journal of Mammalogy, 82: 728-737.

Nagorsen, D.W. and R.M. Brigham. 1993. The Bats of British Columbia. UBC Press, Vancouver, 164pp.

O'Farrell, M.J. 1997. Use of echolocation calls for the identification of free-flying bats. Transactions of the Western Section of the Wildlife Society, 33: 1-8.

O'Farrell, M.J. and W.L. Gannon. 1999. A comparison of acoustic versus capture techniques for the inventory of bats. Journal of Mammalogy, 80: 24-30.

O'Farrell, M.J., C. Corben, W.L. Gannon, and B.W. Miller. 1999a. Confronting the dogma: a reply. Journal of Mammalogy, 80: 297-302.

O'Farrell, M.J., B.W. Miller, and W.L. Gannon. 1999b. Qualitative identification of free-flying bats using the Anabat detector. Journal of Mammalogy, 80: 11-23.

Pearl, D.L. and M.B. Fenton. 1996. Can echolocation calls provide information about group identity in the little brown bat (*Myotis lucifugus*)? Canadian Journal of Zoology, 14: 2184-2192.

Pierson, E.D. 1998. Tall trees, deep holes and scarred landscapes: Conservation biology of North American Bats. *In* Bat biology and conservation, (T.H. Kunz and P.A. Racey eds.), Smithsonian Institution Press, Washington and London, 309-325pp.

Pye, J.D. 1992. Equipment and techniques for the study of ultrasound in air. Bioacoustics, International Journal of Animal Sound and its Recording, 4: 77-88.

Richards, G.C. 1989. Nocturnal activity of insectivorous bats relative to temperature and prey availability in tropical Queensland. Australian Wildlife Research, 16: 151-158.

Rosatte, R.C., P.M. Kelly-Ward, and C.D. MacInnes. 1987. A strategy for controlling rabies in urban skunks and raccoons. Integrating Man and Nature in the Metroplitan Environment, Proc. National Symposium on Urban Wildlife, 161-167.

Rydell, J. and P.A. Racey. 1995. Street lamps and the feeding ecology of insectivorous bats. Zoological Society of London, 67: 291-307.

Salwasser, H. 1987. Greenways for Americans. Integrating Man and Nature in the Metroplitan Environment, Proc. National Symposium on Urban Wildlife, 119-121.

Schwartz C.W. and E.R. Schwartz. 1981. The Wild Mammals of Missouri, revised edition, University of Missouri Press, Missouri, 51-98pp.

Smith, R.L. 1996. Ecology and Field Biology, fifth edition. HarperCollins Publishers Inc., United States, 424-425pp.

Stearns F. and J.E. Ross. 1978. The Pressures of Urbanization and Technology. *In* Wildlife and America, (H.P. Brokaw, ed.), Council on Environmental Quality, Washington, D.C., 199-217pp.

Thomas, D.W., G.P. Bell, and M.B. Fenton. 1987. Variation in ecolocation call frequencies recorded from North American Vespertilionid bats: a cautionary note. Journal of Mammalogy, 68: 842-847.

______ 1988. The distribution of bats in different ages of douglas-fir forests. Journal of Wildlife Management, 52: 619-626.

Tuttle, M.D. 1975. Population ecology of the gray bat (*Myotis grisescens*): Factors influencing early growth and development. Occasional Papers of the Museum of Natural History, the University of Kansas, Lawrence, Kansas, 36: 1-24.

______1976. Population ecology of the gray bat (*Myotis grisescens*): Philopatry, timing and patterns of movement, weight loss during migration, and seasonal adaptive strategies. Occasional Papers of the Museum of Natural History, the University of Kansas, Lawrence, Kansas, 54: 1-38.

______ 1986. Endangered gray bat benefits from protection. Bats: Newsletter of Bat Conservation International, 4: 1-3.

______ 1988. America's Neighborhood Bats: Understanding and Learning to Live in Harmony with Them. University of Texas Press, Austin, 96pp.

______ and D.L. Hensley. 1993. The Bat House Builder's Handbook. University of Texas Press, Austin, 34pp.

Vaughan, T.A. 1986. Mammalogy. Harcourt Brace Jovanovich College Publishers, Florida, 96-137pp.

Whitaker, J.O. Jr. 1995. Food of the big brown bat *Eptesicus fuscus* from maternity colonies in Indiana and Illinois. American Midland Naturalist, 134: 346-360.

Whitham J.H. and J.M. Jones. 1987. Deer-human interactions and research in the Chicago metropolitan area. Integrating Man and Nature in the Metroplitan Environment, Proc. National Symposium on Urban Wildlife, 155-159.

Wilkinson G.S. and J.W. Bradbury. 1988. Radiotelemetry: Techniques and Analysis. *In* Ecological and Behavioral Methods for the Study of Bats, (T.H. Kunz ed.), Smithsonian Institution Press, Washington D.C., London, 105-120pp.

Williams, T.C., L.C. Ireland, and J.M.Williams. 1973. High altitude lights of the free-tailed bat, *Tadarida brasiliensis*, observed with radar. Journal of Mammalogy, 54: 807-821.

Woodside, D.P. and K.J. Taylor. 1985. Echolocation calls of fourteen bats from eastern New South Wales. Australian Mammalogy, 8: 279-297.

Appendix

Sites the Anabat II bat detector system recorded echolocation sequences and the number of call sequences identified for each bat species at each location. $\alpha = 0.05$

County	Year	Location	Description	Species	No. of calls	P-value
Greene	1998	Springfield	Park at perimeter of city - at lake with cave within 50 meters	*Eptesicus fuscus*	2	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	1	0.06
				Myotis grisescens	15	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Park at perimeter of city - at lake with cave within 50 meters	*Eptesicus fuscus*	10	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	64	<.001
				Myotis grisescens	16	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Church in commercial area	*Eptesicus fuscus*	5	<.001
				Lasiurus borealis	2	0.194
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	4	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Church in residential area	*Eptesicus fuscus*	14	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Residential pond	*Eptesicus fuscus*	1	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	2	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Greene	1998	Springfield	Residence in center of city	*Eptesicus fuscus*	9	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Residence in center of city	*Eptesicus fuscus*	5	<.001
				Lasiurus borealis	3	0.103
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Park in light commercial area	*Eptesicus fuscus*	10	<.001
				Lasiurus borealis	4	0.34
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	1	0.033
				Myotis grisescens	1	0.012
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Light residential	*Eptesicus fuscus*	0	1
				Lasiurus borealis	1	0.409
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	0.999
				Pipistrellus subflavus	6	<.001
				Myotis grisescens	2	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	Springfield	Light residential on city perimeter	*Eptesicus fuscus*	6	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Greene	1999	Springfield	Billboard in commercial area	*Eptesicus fuscus*	3	<.001
				Lasiurus borealis	1	0.346
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Residential pond	*Eptesicus fuscus*	15	<.001
				Lasiurus borealis	5	0.031
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	4	<.001
				Myotis lucifugus	4	<.001
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Residential pond	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	0.823
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	2	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Residential pond	*Eptesicus fuscus*	23	<.001
				Lasiurus borealis	1	0.352
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	2	0.002
				Myotis grisescens	5	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Commercial pond at Cox South Hospital	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	0.823
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	2	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Greene	1999	Springfield	Park in center of city	*Eptesicus fuscus*	7	N/A
				Lasiurus borealis	0	N/A
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	N/A
				Pipistrellus subflavus	0	N/A
				Myotis grisescens	3	N/A
				Myotis lucifugus	0	N/A
				Myotis septentrionalis	0	N/A
				Myotis sodalis	0	N/A
Greene	1999	Springfield	Park on perimeter of city - parking lot and lake within 100 meters	*Eptesicus fuscus*	39	<.001
				Lasiurus borealis	10	0.041
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	3	0.842
				Pipistrellus subflavus	2	0.053
				Myotis grisescens	0	1
				Myotis lucifugus	3	<.001
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Park on perimeter of city - few trees and several small ponds	*Eptesicus fuscus*	2	<.001
				Lasiurus borealis	37	<.001
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	4	0.998
				Pipistrellus subflavus	3	0.122
				Myotis grisescens	0	0.998
				Myotis lucifugus	2	0.098
				Myotis septentrionalis	1	<.001
				Myotis sodalis	0	0.098
Greene	1999	Springfield	Park adjacent to university	*Eptesicus fuscus*	0	1
				Lasiurus borealis	1	0.371
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	3	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Light residential: on city perimeter	*Eptesicus fuscus*	12	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	3	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	1	<.001
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Greene	1999	Springfield	Light residential: sinkhole nearby	*Eptesicus fuscus*	1	<.001
				Lasiurus borealis	2	0.177
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	1	0.053
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Residence in center of city	*Eptesicus fuscus*	5	<.001
				Lasiurus borealis	14	0.003
				Lasiurus cinereus	6	N/A
				Nycticeious humeralis	2	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Residence with big brown bat roost	*Eptesicus fuscus*	667	<.001
				Lasiurus borealis	1	0.103
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	0.996
				Pipistrellus subflavus	0	0.993
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1999	Springfield	Ewing Park stream under bridge	*Eptesicus fuscus*	6	<.001
				Lasiurus borealis	0	0.999
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	2	<.001
				Myotis grisescens	2	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	1	0.023
Vernon	1998	Camp Clark	Wooded with pond	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	0.999
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	33	<.001
				Pipistrellus subflavus	1	0.012
				Myotis grisescens	0	0.999
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Vernon	1998	Camp Clark	Wooded with pond	*Eptesicus fuscus*	0	N/A
				Lasiurus borealis	0	N/A
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	N/A
				Pipistrellus subflavus	1	N/A
				Myotis grisescens	0	N/A
				Myotis lucifugus	1	N/A
				Myotis septentrionalis	0	N/A
				Myotis sodalis	0	N/A
Vernon	1998	Camp Clark	Lake	*Eptesicus fuscus*	3	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	1	0.179
				Pipistrellus subflavus	12	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Newton	1998	Fort Crowder	Intermediate creek, several ponds	*Eptesicus fuscus*	0	1
				Lasiurus borealis	5	0.713
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	4	0.078
				Pipistrellus subflavus	26	<.001
				Myotis grisescens	6	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Greene	1998	North of Springfield	Wooded with lake: cave nearby	*Eptesicus fuscus*	31	<.001
				Lasiurus borealis	5	0.048
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	19	<.001
				Myotis grisescens	14	<.001
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Texas	1998	Paddy Creek sites 18 and 19	Various habitats; ponds, intermediate streams, road ruts, forested flyways	*Eptesicus fuscus*	4	<.001
				Lasiurus borealis	2	0.194
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	5	<.001
				Myotis grisescens	1	0.02
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Texas	1998	Paddy Creek Pond, Paddy Creek Road	Forested pond, road rut	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	1	<.001
				Myotis sodalis	0	1
Texas	1998	Paddy Creek	Forested creek	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	23	<.001
				Myotis grisescens	3	<.001
				Myotis lucifugus	1	0.027
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Texas	1998	Paddy Creek Houston - Rolla	Forested creek	*Eptesicus fuscus*	0	1
				Lasiurus borealis	3	0.327
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	1	0.802
				Pipistrellus subflavus	3	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	0	0.999
				Myotis septentrionalis	0	0.999
				Myotis sodalis	1	0.023
Texas	1998	Paddy Creek Houston - Rolla	Forested creek	*Eptesicus fuscus*	1	<.001
				Lasiurus borealis	5	0.031
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	3	0.001
				Myotis grisescens	2	0.002
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	1	0.023
Pulaski	1998	Houston - Rolla Dist. Rd. 1792	Pocket Eddy lodge pond	*Eptesicus fuscus*	0	1
				Lasiurus borealis	4	0.247
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	0.998
				Pipistrellus subflavus	54	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	2	0.001
				Myotis septentrionalis	1	<.001
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Phelps	1998	Houston - Rolla Dist. Rd. 1771	Trout Cemetery pond	*Eptesicus fuscus*	12	<.001
				Lasiurus borealis	5	0.336
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	1	0.897
				Pipistrellus subflavus	66	<.001
				Myotis grisescens	3	<.001
				Myotis lucifugus	2	0.014
				Myotis septentrionalis	8	<.001
				Myotis sodalis	2	0.226
Oregon	1998	Riverton quad.	Forested area	*Eptesicus fuscus*	1	<.001
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	7	<.001
				Myotis grisescens	9	<.001
				Myotis lucifugus	4	<.001
				Myotis septentrionalis	3	<.001
				Myotis sodalis	2	0.09
Texas	1998	Eldridge Spring	Pond	*Eptesicus fuscus*	3	<.001
				Lasiurus borealis	5	0.998
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	8	0.001
				Pipistrellus subflavus	62	<.001
				Myotis grisescens	1	0.012
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Phelps	1998	Houston - Rolla Dist. Rd. 1734	Kaintuck Hollow Pond	*Eptesicus fuscus*	0	1
				Lasiurus borealis	14	0.005
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	0.997
				Pipistrellus subflavus	127	<.001
				Myotis grisescens	10	<.001
				Myotis lucifugus	3	0.001
				Myotis septentrionalis	0	1
				Myotis sodalis	0	0.999
Phelps	1998	Houston - Rolla Dist. Rd. 1503	CCC Camp Pond	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	0.998
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	1	0.182
				Pipistrellus subflavus	3	<.001
				Myotis grisescens	2	<.001
				Myotis lucifugus	0	0.999
				Myotis septentrionalis	2	<.001
				Myotis sodalis	22	<.001

County	Year	Location	Description	Species	No. of calls	P-value
Oregon	1998	Ozark Trail	Forested area	*Eptesicus fuscus*	0	1
				Lasiurus borealis	1	0.365
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	3	<.001
				Myotis grisescens	0	1
				Myotis lucifugus	1	0.018
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Phelps	1998	Houston - Rolla Dist. Rd. 1708	Pond	*Eptesicus fuscus*	0	1
				Lasiurus borealis	5	0.526
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	2	0.389
				Pipistrellus subflavus	55	<.001
				Myotis grisescens	1	0.04
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	0	1
Texas	1998	Paddy Creek	Campground	*Eptesicus fuscus*	0	1
				Lasiurus borealis	11	0.003
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	1	1
				Pipistrellus subflavus	11	<.001
				Myotis grisescens	1	0.128
				Myotis lucifugus	1	0.196
				Myotis septentrionalis	0	1
				Myotis sodalis	1	0.052
Oregon	1998	Turner's Mill	Spring flowing down to Eleven Point River	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	1
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	0	1
				Myotis sodalis	3	<.001
Oregon	1998	Many Springs quadrangle	Buggy Pond	*Eptesicus fuscus*	1	<.001
				Lasiurus borealis	4	0.052
				Lasiurus cinereus	0	N/A
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	3	<.001
				Myotis grisescens	3	<.001
				Myotis lucifugus	3	<.001
				Myotis septentrionalis	2	<.001
				Myotis sodalis	0	1

County	Year	Location	Description	Species	No. of calls	P-value
Oregon	1998	FS Rd. 4030	Pond just past clear cutting	*Eptesicus fuscus*	0	1
				Lasiurus borealis	0	1
				Lasiurus cinereus	0	1
				Nycticeious humeralis	0	1
				Pipistrellus subflavus	0	1
				Myotis grisescens	0	1
				Myotis lucifugus	0	1
				Myotis septentrionalis	26	<.001
				Myotis sodalis	0	1