ROOST SELECTION AND LANDSCAPE MOVEMENTS OF FEMALE INDIANA BATS AT THE GREAT SWAMP NATIONAL WILDLIFE REFUGE, NEW JERSEY

By

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A Thesis

Presented to the Graduate School
Department of Biology
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In partial fulfillment of the requirements
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Written under the direction of
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ABSTRACT

Much effort has been expended studying the roosting ecology of the federally endangered Indiana bat *(Myotis sodalis)* during the maternity season; yet there is a paucity of studies on roosting behavior in the northeastern U.S., where populations have increased significantly over the last 40 years. The primary goals of this study were to identify and characterize roosts selected by reproductively active females in and around Great Swamp National Wildlife Refuge; to observe behavior such as colony size, roost fidelity, home range size and foraging activity; and to compare results to studies conducted elsewhere in the species' range and to randomly selected trees. Mist nets were placed across stream and forested corridors to capture bats from May 15-August 15, 2006-2007. Transmitters were placed on adult female *M. sodalis*, and bats were tracked daily to identify roosts and foraging areas. The characteristics of both roost trees and randomly selected trees, and their surrounding habitat (0.1 ha) were measured. Emergence counts were conducted during 2007 at all trees containing transmittered bats. Using all known locations (capture site, roosts, and estimated foraging points), home range estimates were produced using minimum convex polygons (MCP) and fixed kernel density estimates (KDE). Twenty-four females were tracked to 74 roosts representing 3 colonies during 2006-2007; only 2 roosts were re-used by different bats during the course of the study. Peak emergence counts at 4 primary trees were 252, 164, 52 and 55 bats. Selected roosts were largely similar to those documented elsewhere; however, several variables differed significantly between years, including dbh, height and canopy closure. Comparisons with randomly selected trees revealed that *M. sodalis* selected shagbark hickory (*Carya ovata*) and American elm (*Ulmus americana*) more often than would be expected; and that roost plots had fewer, larger trees and a greater proportion of suitable roost trees than random plots. Roost switching occurred on average once every 1.8 (± 0.27 se) days, and mean distance moved between consecutive roosts was 1003.4 (± 299.98) m. Mean home range size was 236.6 (± 136.45) ha for MCP estimates and 325.0 (± 33.10) ha for 50% KDE estimates. The variation in roost characteristics observed between years emphasizes that Indiana bats may be flexible in their roost requirements even within a study site. Furthermore, the number of colonies found, the number of roosts identified and the average distance moved between roosts suggest that Great Swamp NWR may represent ideal maternity habitat for Indiana bats. Lastly, the large home ranges identified suggest that bats may range widely across the habitats available to them, even if roosting and foraging habitat is not limiting.

ACKNOWLEDGEMENTS

This project would not have been possible without the invaluable support of volunteers and associates too numerous to mention. I must first thank my husband, Dave, for his immense patience and support as the first two years of our marriage succumbed to the demands of graduate school and field research. You managed to keep me grounded, reassured and well fed during this long process (a thankless task, I know) and you are the most amazing husband, partner and friend a girl could ask for.

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INTRODUCTION

The Indiana bat *(Myotis sodalis*, Miller and Allen 1928*)* (Chiroptera: Vespertilionidae) is a federally endangered species found throughout the midwestern and eastern United States. Despite the protection of all major known hibernation sites (hibernacula) since its listing in 1967, populations continued to decline through 2001 (U.S. Fish and Wildlife Service 2007). Suspected causes include changes in hibernacula microclimates, changes in land use in the bat's roosting and foraging habitats, and chemical contamination of the insect prey base; insufficient information exists however to substantiate the effects of these factors on the species' decline (Menzel et al. 2001, U.S. Fish and Wildlife Service 1999). Little is known about the species' summer habitat requirements in the eastern United States, and there is a documented research need for additional information from this part of the country (U.S. Fish and Wildlife Service 1999). In August 2005, a bat survey conducted at the Great Swamp National Wildlife Refuge (GSNWR) in northern New Jersey revealed juveniles and post-lactating females foraging within the refuge (Campbell 2005), confirming the existence of a maternity colony there. This was the second summer record of Indiana bats in New Jersey, and the first documentation of juveniles (Craddock 2006). Furthermore, GSNWR is the only National Wildlife Refuge in the northeast region in which Indiana bat maternity habitat has been documented (although the species was captured at Wallkill River NWR in August 2008; Wight 2008 pers. comm.).

Female Indiana bats are solely responsible for the rearing of young, and although little is known about the summer habits of males, they appear to be less selective in their choice of roost trees (Barclay and Kurta 2007, Kurta 2005). Thus, managing for the roost characteristics required by females is likely to also satisfy the needs of males. For this reason, the study of reproductively active female Indiana bats in New Jersey represents a major contribution to the understanding of the species' summer habitat use in the northeast. Only three other studies on Indiana bats have been conducted in this part of the country. One of these described 29 *M. sodalis* roosting among 20,000 little brown bats *(Myotis lucifugus)* in an abandoned church, and represents the only known maternity colony to reside in an abandoned building (Butchkoski and Hassinger 2002). This is not typical of Indiana bat maternity habitats. The other two studies were conducted in the Champlain Valley of Vermont: Palm (2003) identified and examined roost trees used by 3 female Indiana bats, and Watrous et al. (2006) used roost tree and foraging data to predict minimum habitat characteristics associated with reproductive females (but no summary of the roost trees or foraging ranges was published). While much information on summer habitat characteristics has been collected in the midwest, and while the data of Palm (2003) and Watrous et al. (2006) suggest that Indiana bat preferences in the northeast are similar to those in the midwest, insufficient information exists to justify the assumption that the species' habitat preferences are consistent throughout the species' range. Thus, the current study represents the most comprehensive and thorough study of Indiana bat summer habitat to be conducted in the northeast, and serves as a significant source of information that may help to illuminate whether habitat preferences vary across the species' range.

The primary goals of this study were to quantify the abundance and distribution of Indiana bats within GSNWR, to locate and characterize the roosts used by reproductively active females, and to compare roost preferences and behavior to that observed elsewhere in the species' range. A second goal was to identify the foraging habitats used by reproductively active females, and to quantify the size and location of their home ranges.

Indiana bat life history

The Indiana bat *(Myotis sodalis)* is a 6-9 g insectivorous bat belonging to the genus *Myotis* (family: Vespertilionidae). Similar to its congeners, it has a total body length of 41-49 mm, a forearm length of 35-41 mm and can be distinguished by a distinctly keeled calcar and few, short toe hairs on the hind feet (Barbour and Davis 1969, Bat Conservation International 2008, U.S. Fish and Wildlife Service 2007). Indiana bats range throughout the eastern and midwestern United States, with the core of their range in the midwestern states of Indiana, Missouri and Kentucky. The species hibernates in caves and mines from October through April, and migrates to summer areas where it roosts predominantly underneath the loose or peeling bark of dead and dying trees from mid-April through September. Humphrey and Cope (1977) documented females living as long as 14.8 years and males as long as 13.5 years after banding (age unknown when banded), while the very similar and better-studied *M. lucifugus* has been shown to live as long as 30 years (Keen and Hitchcock 1980).

Indiana bats hibernate from October through April in caves and mines with temperatures between 3-6° C (Hall 1962, Henshaw and Folk 1966, Tuttle and Kennedy 2002). Because few available caves provide the microclimates preferred by Indiana bats, 85% of the known population hibernates in 9 caves in Indiana, Kentucky and Missouri (U.S. Fish and Wildlife Service 1999). Upon arrival at the hibernacula in the fall, “swarming” occurs: this can be described as large numbers of bats flying in and out of the caves from dusk to dawn, without roosting in the caves (Cope and Humphrey 1977, U.S. Fish and Wildlife Service 2007). Mating occurs during this period, before bats enter hibernation; fertilization is delayed until shortly after spring emergence, when ovulation occurs. Females typically leave the hibernacula before males and may arrive in their summer habitats as early as April 15 (Cope and Humphrey 1977, Gardner et al. 1991, Hall 1962, U.S. Fish and Wildlife Service 1999).

Females may migrate up to 532 km (Kurta and Murray 2002) to form maternity colonies where they roost together to pup and raise young, typically in groups of less than 100. These colonies may be composed of individuals from several different hibernacula (Kurta and Murray 2002). Parturition of one young occurs in June or early July, and the young become volant in 3-5 weeks (Gardner et al. 1991, Humphrey et al. 1977, Kurta and Rice 2002). One or more primary roosts (those used throughout the summer by large numbers of females and their young) and multiple alternate roosts (used intermittently by small numbers of bats) may be utilized throughout the summer (Callahan et al. 1997). Females switch roost sites every 2-4 days presumably to maintain an awareness of suitable alternate roosts, but other benefits may include moving closer to foraging grounds, finding more desirable microclimates, reducing predation risk or disrupting parasite life cycles to minimize parasite load (Kunz 1982, Kurta et al. 2002, Lewis 1995). Occasionally the entire colony moves to a new tree, but more commonly individuals switch roosts such that at any one time the “colony” may be dispersed across multiple trees (Kurta 2005, Kurta et al. 2002). Lactating females switch roosts less frequently than pregnant or post-lactating females (Kurta et al. 2002). Less is known about the summer habits of males, which may summer near the hibernacula or disperse throughout the range to roost individually or in small numbers (Kurta and Rice 2002).

Indiana bats have been documented using 33 species of trees for roosts, the majority of which are snags (standing dead trees) or are nearly dead (Kurta 2005). Bats generally cluster together within roosts between the exfoliating bark and the bole of the tree but have also used vertical crevices, cavities, buildings and bat houses (Butchkoski and Hassinger 2002, Gardner et al. 1991, Kurta 2005). The naturally peeling bark of some species of live trees such as shagbark hickory *(Carya ovata)* may also provide shelter, especially during periods of extended cold or wet weather when living trees may provide improved thermal benefits and rainwater protection (Callahan et al. 1997, Humphrey et al. 1977, Miller et al. 2002, U.S. Fish and Wildlife Service 1999). The most important characteristic in roost trees is exfoliating bark, though exposure to sunlight, canopy closure and tree diameter also play important roles (Callahan et al. 1997, Humphrey et al. 1977, Kurta 2005, Menzel et al. 2001). Primary roosts typically have large diameters (greater than 22 cm and frequently much larger) and are found in open areas with high exposure to sunlight (Callahan et al. 1997, Kurta 2005, Menzel et al. 2001); alternate roosts are generally smaller in diameter and located in the forest interior.

Indiana bats emerge from their day roosts shortly after sunset and have been found to travel up to 2.4 km to reach foraging areas (Gardner et al. 1991). Flying insects including moths (Lepidoptera), beetles (Coleoptera), caddis flies (Trichoptera) and flies (Diptera) seem to be the most important prey species, while wasps and ants (Hymenoptera), mosquitoes and midges (Diptera) may also be consumed (Brack and LaVal 1985, Kurta and Whitaker 1998, Murray and Kurta 2004). Lactating females return to the day roost multiple times during the night (presumably to nurse pups), while most non-reproductive bats remain within the foraging area throughout the night and return to the roost shortly before dawn (Murray and Kurta 2004, Sparks et al. 2005).

Roost trees may be found in a variety of forested habitats but are generally associated with wetlands or riparian areas, suitable densities of large and medium trees, and edge habitats appropriate for foraging. Amount of forest cover is not a useful predictor of Indiana bat presence (as determined by mist-netting, Kurta 2005); bats tolerate a wide range of land cover types near maternity roosts, including agricultural lands, wetlands, forests, urban development and water bodies such as lakes, ponds and rivers (Gardner et al. 1991, Kurta 2005, Kurta et al. 2002). Roost trees used by a maternity colony are not widely dispersed, with distances between roosts ranging from a few meters to several kilometers (Callahan et al. 1997, Kurta et al. 2002, Miller et al. 2002, U.S. Fish and Wildlife Service 1999). A review of the literature shows that Indiana bats typically establish maternity colonies in agricultural areas with fragmented forests, rather than in areas of extensive forest (Carter et al. 2002, Gardner and Cook 2002, Gardner et al. 1991, Kurta 2005). Although this may be a result of the prevalence of studies in the Midwest, studies in the Northeast have also shown association with agricultural areas (Watrous et al. 2006).

Indiana bats forage mostly in and around forested habitats, although the type of woodlands used may vary throughout the species' range and include pole-stage mixed-oak forest, floodplain forest, upland forest and forested wetlands (Butchkoski and Hassinger 2002, Gardner et al. 1991, Humphrey et al. 1977, Murray and Kurta 2004, Rommé et al. 2002, Sparks et al. 2005). Preferred foraging habitats for pregnant and lactating Indiana bats include wooded corridors, streams, associated floodplain forests and impounded bodies of water, although they may also forage within the canopy of upland forests, over clearings of early successional habitats, along borders of croplands and wooded fencerows and over farm ponds in pastures (Gardner et al. 1991, Humphrey et al. 1977, Kurta et al. 1996, Murray and Kurta 2004, Menzel et al. 2001, Sparks et al. 2005). Foraging areas range from linear distances of 0.8 km to areas over 3000 ha (Humphrey et al. 1977, Rommé et al. 2002); bats usually fly in the airspace 2 to 30 m above ground level while foraging (Humphrey et al. 1977).

Population status of Indiana bats

Indiana bats were first systematically censused in the late 1950's, with population estimates exceeding 800,000 individuals (U.S. Fish and Wildlife Service 2007). Subsequent population declines resulted in the species being listed as in danger of extinction under the Endangered Species Preservation Act of 1966 (now "endangered" under the Endangered Species Act of 1973, U.S. Fish and Wildlife Service 2007). The protection of most major known hibernacula did not stop this decline, which continued through 2001 (U.S. Fish and Wildlife Service 2007). Since 1983, standardized survey methods have been used to biennially estimate winter bat populations within hibernacula. Estimates from the three survey periods since 2001 have shown an increase in the population, suggesting that the long-term decline may have halted (although causes of population change are unknown; U.S. Fish and Wildlife Service 2007). Winter hibernacula surveys in 2006-2007 estimated over 468,000 individuals range-wide (U.S. Fish and Wildlife Service 2008), which represents a decrease of about 47% since the initiation of regular surveys in the 1960's (U.S. Fish and Wildlife Service 2007). This decline is not uniform across the range of the species; populations in the midwest and northeast have increased by about 30% while populations in the southeast have decreased by 80% (Clawson 2002, Hicks and Novak 2002). Methods for these estimates included representing newly discovered hibernating populations in all earlier estimates, such that the addition of new sites did not falsely imply population growth, Clawson 2002.

Low genetic diversity within populations wintering in the northeast seems to indicate a relatively recent colonization of this portion of the species' range (estimated at 150 years ago) by a small number of individuals (U.S. Fish and Wildlife Service 2007). This colonization event may explain the population increase observed in the northeast, as the species expands to occupy suitable habitats. Winter hibernacula surveys have revealed that the vast majority of Indiana bats in the northeast hibernate in New York; since 1980, estimates of wintering populations there have increased from 22 individuals to over 41,000, representing approximately 12% of the range wide population (Hicks and Novak 2002, Hicks et al. 2005, U.S. Fish and Wildlife Service 2007).

In the winter of 2006-2007 (in the middle of this study), an estimated 8,000-11,000 bats from four hibernacula in eastern NY succumbed to a mysterious die-off called "white-nose syndrome" (WNS) due to the presence of a powdery white substance (later identified as a fungus phylogenetically related to *Geomyces spp.*) concentrated around the nose and mouth of affected bats (Veilleux 2008, Blehert et al. 2008). By the winter of 2007-2008, WNS had spread to 24 hibernacula in four states including 15 in NY, 4 in VT, 4 in MA and 1 in CT, and had been shown to affect every species known to hibernate in the Northeast (Veilleux 2008); resulting mortality exceeding 90% has been reported in affected hibernacula (Kelley 2008, Stilwell 2008). The little brown bat *(M. lucifugus)* has sustained the greatest mortality, with the northern long-eared bat *(M. septentrionalis)* and Indiana bat *(M. sodalis)* also suffering high losses (Veilleux 2008). Mortality estimates vary widely, due in part to the wide range of the syndrome, the existence of undocumented hibernacula, and the consumption of carcasses by scavengers and predators. Biologists fear that anywhere between 250,000 and 500,000 bats may have died in 2007-2008 alone (Kelley 2008; Murray 2008). Winter 2007-2008 estimates of *M. sodalis* in NY's largest hibernacula (last known to harbor over 38,000 individuals) indicate as many as 13,717 individuals (19.5% of the northeast population) are unaccounted for (Herzog 2008 pers. comm.; Hicks and Newman 2007).

The proximity of Great Swamp NWR to affected hibernacula in NY (135 km) and the overlap between WNS's emergence and this study make this research increasingly important to the understanding of Indiana bat habitat in the northeast, but also pertinent to understanding the effects of WNS on all species of bats. As mentioned previously, this study is the most comprehensive yet to be conducted on Indiana bat maternity habitat in the northeast, and it may come to serve as baseline information for pre-WNS concentrations and behavior of the species in the northeast. Similarly, the mist netting data gathered during this study may also serve as baseline information for comparisons of bat diversity and abundance between pre- and post-WNS bat populations in NJ.

The history of Indiana bats in New Jersey

Indiana bats were first discovered in Morris County during a 1992 winter survey of Hibernia Mine, when nineteen *M. sodalis* were observed hibernating in a tight cluster (Valent 2008 pers. comm.). The presence of the species was officially confirmed in 1993 (Chenger 2006; Dutko 2008 pers. comm.; Van De Venter 2007) and recent surveys have documented as many as 122 *M. sodalis* hibernating here (Valent 2008 pers. comm.). Indiana bats were discovered nearby at Mount Hope mine during fall swarming surveys in October of 1994 and 1996 (Valent 2008 pers. comm.; Van De Venter 2007). Though fall swarming behavior is presumed to occur at hibernacula, no winter surveys were conducted to confirm Mount Hope as a hibernation site until February 2004, when over 500 Indiana bats were observed roosting within the cave (Van De Venter 2007).

The first summer occurrence of an Indiana bat in NJ was recorded in 1995, when a post-lactating female was captured during mist-net surveys on Picatinny Arsenal (PICA) near the town of Dover, less than 2 miles from Hibernia and Mount Hope mines (Craddock 2006, Van De Venter 2007). In subsequent survey efforts from 1997-1998, five males and three females were transmittered on or near PICA. Summer mist netting in 1997 resulted in the capture of two males on PICA property, and in April of 1998 harp traps were used during to capture three males and three females during their spring emergence from the Mount Hope shafts. Radiotracking of these bats revealed the use of abandoned buildings, roost trees and ponds on PICA property; two bats captured during spring emergence left the area shortly after release, presumably on migration to other summer areas (Van De Venter 2007).

In summer 2005, a suspicion that GSNWR might host summering populations of *M. sodalis* prompted managers to initiate bat surveys there. Following visual and acoustic surveys, mist-netting efforts were initiated over 5 sampling nights at two sites for a total of 20 net nights. Seven species of bats were captured, including 11 *M. sodalis*; of these, 8 were juveniles, 1 was an adult male, and 2 were post-lactating females (Campbell 2005). The presence of juveniles and post-lactating females confirmed the presence of a maternity colony of Indiana bats on or near GSNWR and prompted further research resulting in this study.

In spring 2006 (immediately prior to the start of this study), a study funded by PICA tracked the spring migration patterns of 5 female *M. sodalis* exiting Mount Hope Mine and 5 exiting Hibernia Mine (Chenger 2006). Two of the bats exiting the Mount Hope Mine migrated to GSNWR (distance 24 km), and a third was tracked to private property adjacent to refuge lands and within the approved acquisition boundary. Although none of the Hibernia bats roosted on the refuge (distance 24 km), two were tracked to an area less than 7 km west of GSNWR. This confirmed that at least some members of the Great Swamp maternity colonies hibernate in Mount Hope Mine, and possibly in Hibernia Mine. (The two remaining Mount Hope bats roosted about 5.5 km northwest and 14 km west-northwest of the refuge, respectively; two Hibernia bats were not recovered and the last roosted 21 km northwest of the mine, or 37.5 km north-northwest of the refuge).

STUDY AREA

The GSNWR is located in north-central New Jersey (Morris County; Fig. 1) in the Piedmont Plateau of the Appalachian Province, and lies in a basin 11.3 km long by 4.8 km wide. Till deposited by a receding glacier 15,000 years ago blocked the outlet of this basin and created ancient Lake Passaic (roughly 77,280 ha); extensive marshes and swamps were created when the lake eventually drained, creating what is now known as the Great Swamp Basin (Parrish and Walmsley 1997, Stanford 2007). The basin is characterized by a series of low wooded ridges (79 to 122m in elevation) interspersed with wooded swamp and open marsh. The GSNWR comprises the largest land ownership (54%) and is located at the heart of the Great Swamp Basin (Fig. 2); remaining lands are predominantly held in private ownership with the exception of Somerset County Park and Environmental Education Center (384 ha) and Morris County Outdoor Education Center (16 ha), both of which border GSNWR.

The area was inhabited by the Lenni Lenape (Native Americans) until 1708, when approximately 12,140 ha were purchased by British investors. Development was slow through the mid-1800's, and although villages surrounding the swamp were settled (including Green Village, New Vernon, Meyersville, and Basking Ridge), the swamp itself remained lightly settled with widely scattered farms. By the late nineteenth century, the woodlands of the Great Swamp were in great demand and were utilized to provide lumber for homes and ships, railroad ties, fuel for mills and iron forges and other commodities. As forests were cut back, excess water became more of a problem. Ditches and canals were dug to drain the swamp and create more suitable farmland; in the 1930's the Works Projects Administration (WPA) continued this work, with little success. Throughout the 1900's, attempts to farm the wetter portions of the swamp

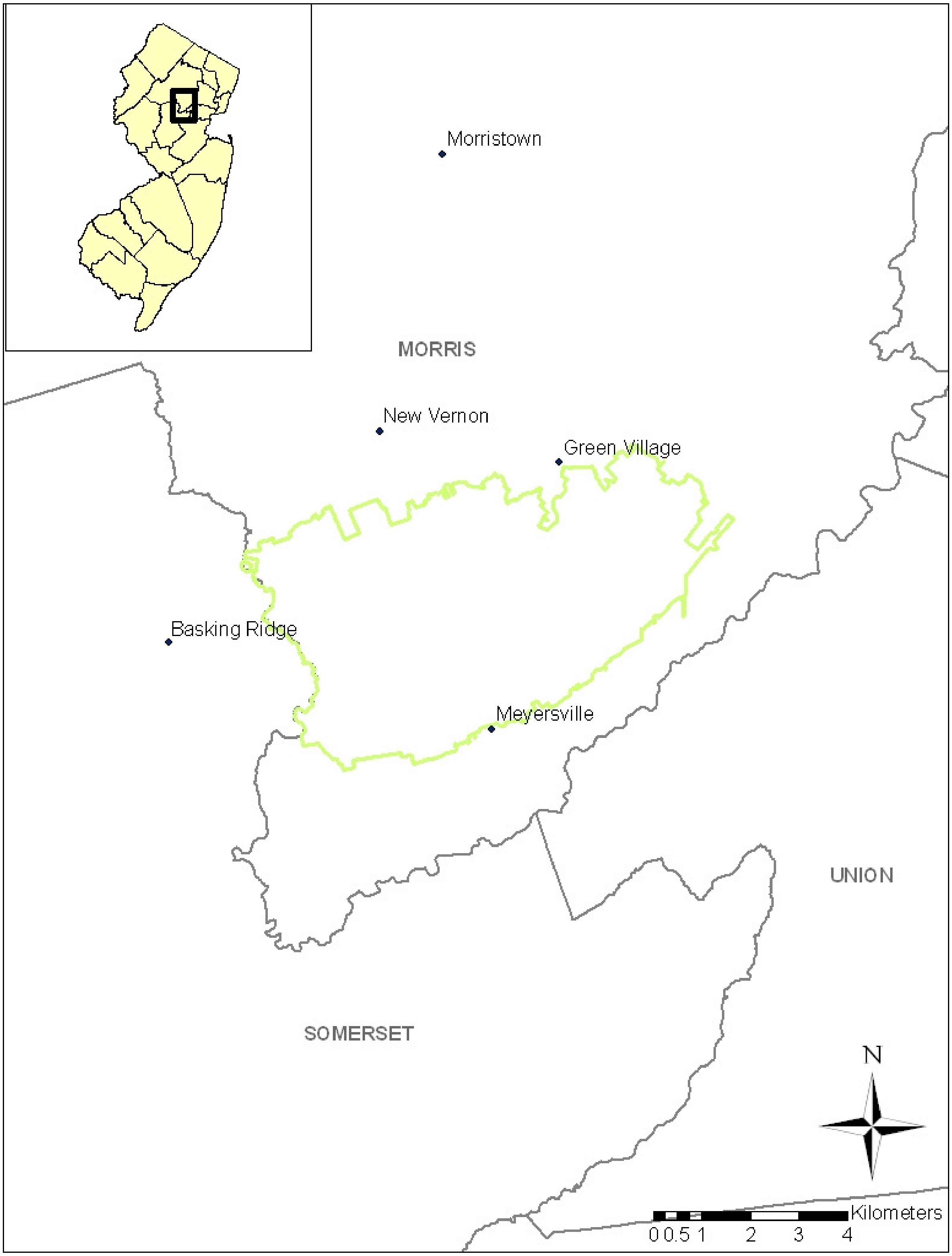

Figure 1. Site map showing Great Swamp National Wildlife Refuge and surrounding towns.

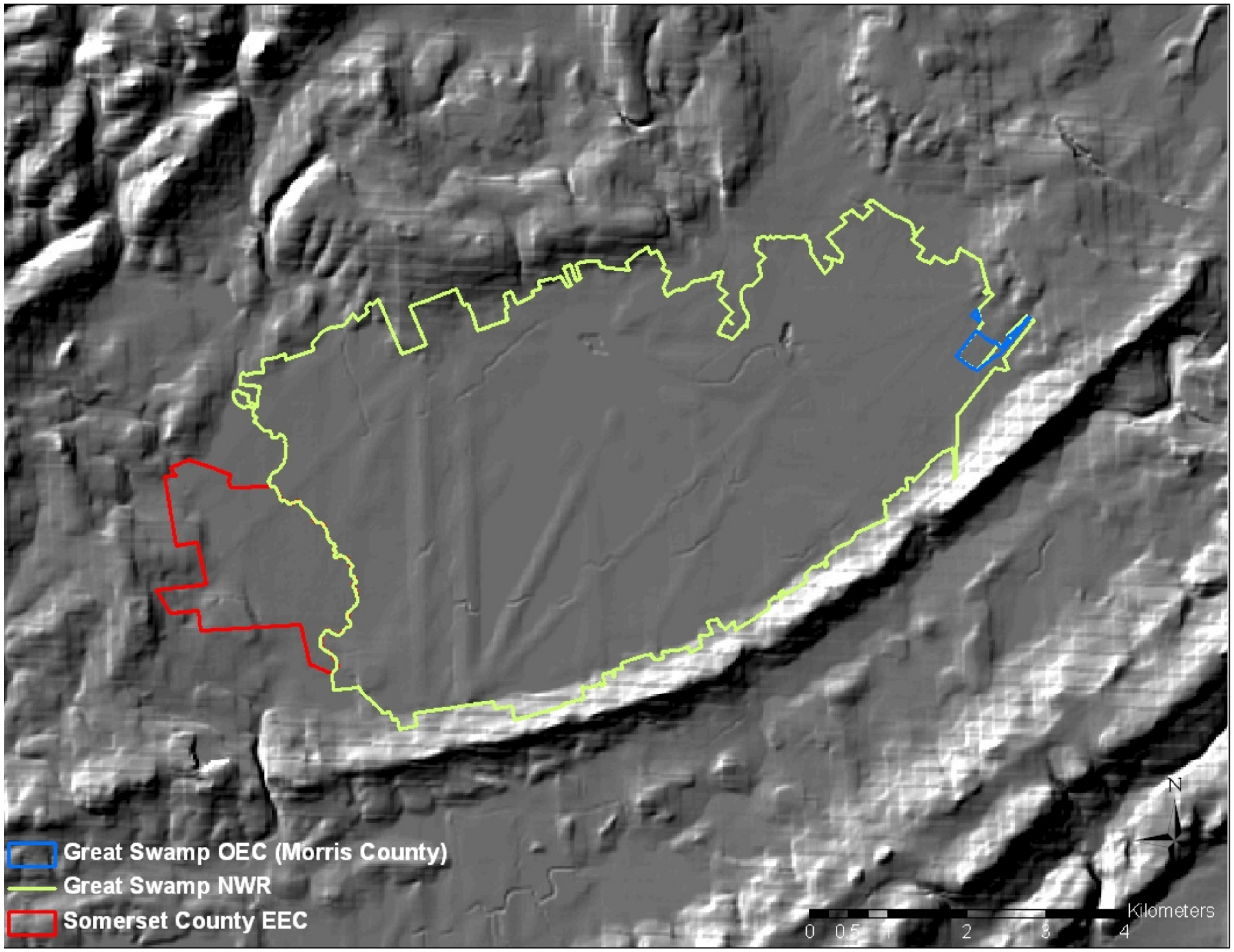

Figure 2. Topography surrounding and including the Great Swamp Basin, elevation 79-122m. Maximum elevation shown (northwest corner) is 183m. The Refuge acquisition boundary, adjoining Somerset County Environmental Education Center (EEC) and Great Swamp Outdoor Education Center (OEC) are shown.

were gradually abandoned and, tract by tract, portions of the area began to revert to forest. In 1959 the New York Port Authority proposed a jetport in the Great Swamp (Cavanaugh 1978). It was the local community's fight against this jetport that resulted in designation of Great Swamp National Wildlife Refuge in 1964 (Cavanaugh 1978). Today the refuge protects 3,075 ha of palustrine swamplands, floodplain forests and bottomland hardwoods. Although portions of the area are maintained in early seral stages such as grasslands and brush, forests dominate much of the refuge. Dominant species include American beech *(Fagus grandifolia)*, oaks *(Quercus spp.)*, hickories *(Carya spp.)* and red maple *(Acer rubrum).* The Passaic River and five other major streams run through the refuge, including the Black, Great, Loantaka, Middle and Primrose Brooks (Fig. 3). These waterways and their associated tributaries provide plentiful and suitable foraging habitat for the Indiana bat, while forested portions of the refuge provide roosting habitat.

The original collection of lands (1,481 ha) donated to the Refuge were federally designated as Wilderness in 1968 (Public Law 90-532, 1968). As a result of this, structures and artificial road surfaces have been removed from the area and mechanized vehicles and tools are prohibited. No habitat management has taken place on this portion of the refuge since its wilderness designation. The Black Brook, Loantaka Brook and Great Brook and their associated tributaries run through the area, which also contains about 12.9 km of hiking trails (foot traffic only). In a restoration effort and to comply with the Wilderness Act, many of the ditches were plugged to restore wetlands, and water levels here were left to natural processes. The majority of the area is characterized as bottomland floodplain forest, with approximately 100 ha of open water. This part of the refuge is bordered on the west by the managed portion of the refuge, on

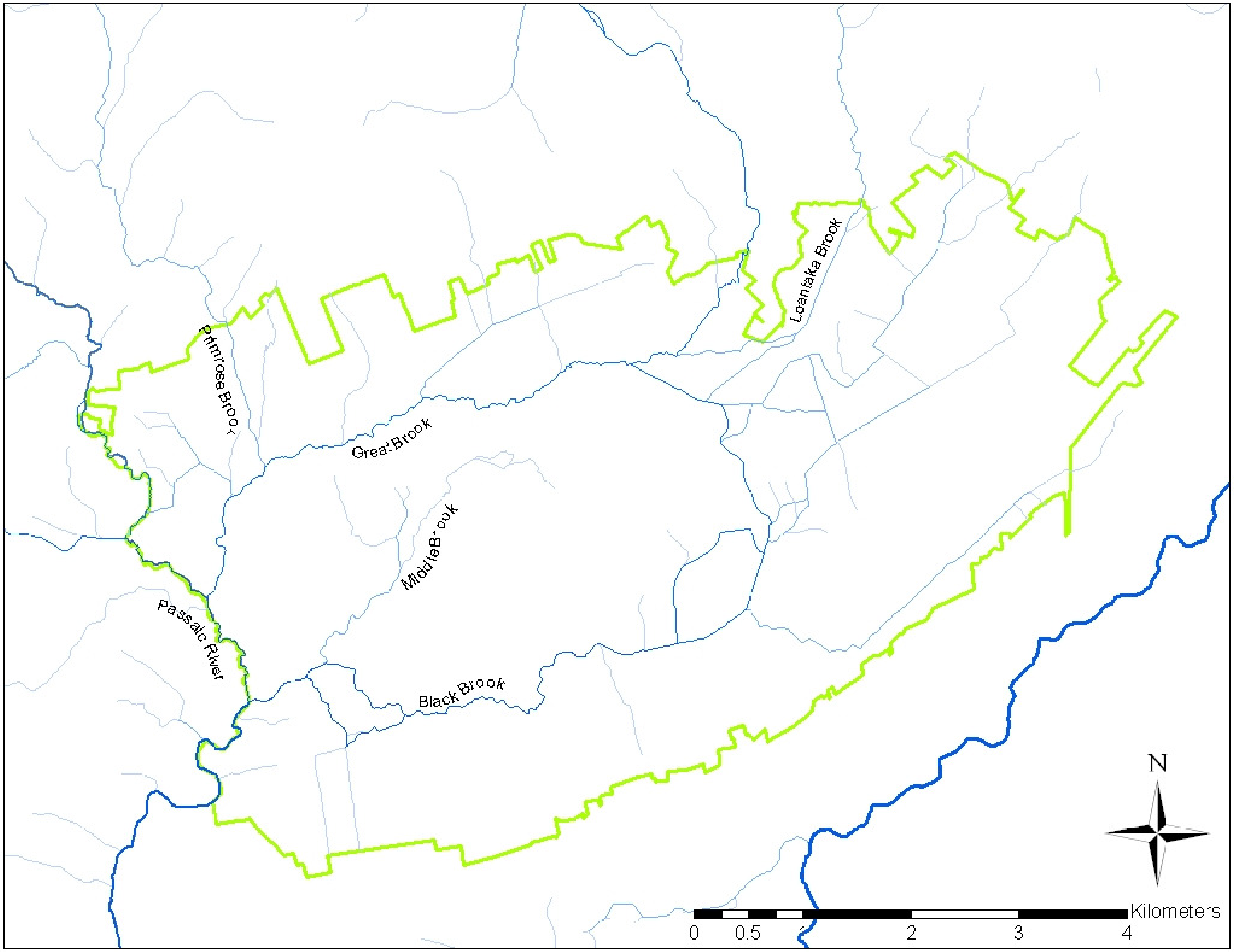

Figure 3. Waterways running through the Great Swamp NWR.

the north and south by low-density development, and on the east by high-density development and the Morris County Outdoor Education Center (16 ha; Fig. 4).

The managed portion of the refuge is situated directly to the west of the wilderness area and contains 1,594 ha of early successional habitat, impoundments and floodplain forest. The Middle, Primrose and Great Brooks run through this part of the refuge, which is bordered on the west by the Passaic River. The refuge's five impoundments are also located here and include Pool 1 (47 ha), Pool 2 (103 ha), Pool 3A (22 ha), Pool 3B (35 ha) and Middle Brook Pool (7 ha), together comprising 15% of the management area (214 ha). Impoundments are managed for shallow water depths to allow for maximum feeding, breeding and brooding habitat for waterfowl, wading birds and shorebirds. An additional 182 ha are maintained in grasslands and shrublands to provide habitat for woodcock, songbirds and other wildlife species. The rest of the management area (1,198 ha) is dominated by forests. Habitat management conducted in the management area includes mowing, stand thinning and occasional stream clearing. The management area is bordered on the east by the wilderness area, on the north and south by low density development, and on the west by the Somerset County Environmental Education Center (384 ha) and the Basking Ridge Country Club.

The refuge lies along the boundary between the state's North and Central climate zones. Annual precipitation averages about 120 cm, and is fairly evenly distributed throughout the year (GSNWR unpublished data). The growing season averages about 155 days a year, and the average dates for the last spring frost and first fall frost are May 4 and October 7, respectively. Average temperatures range from a low of -1.9º C in January to a high of 22.8º in July (Office of the NJ State Climatologist 2008 a,b).

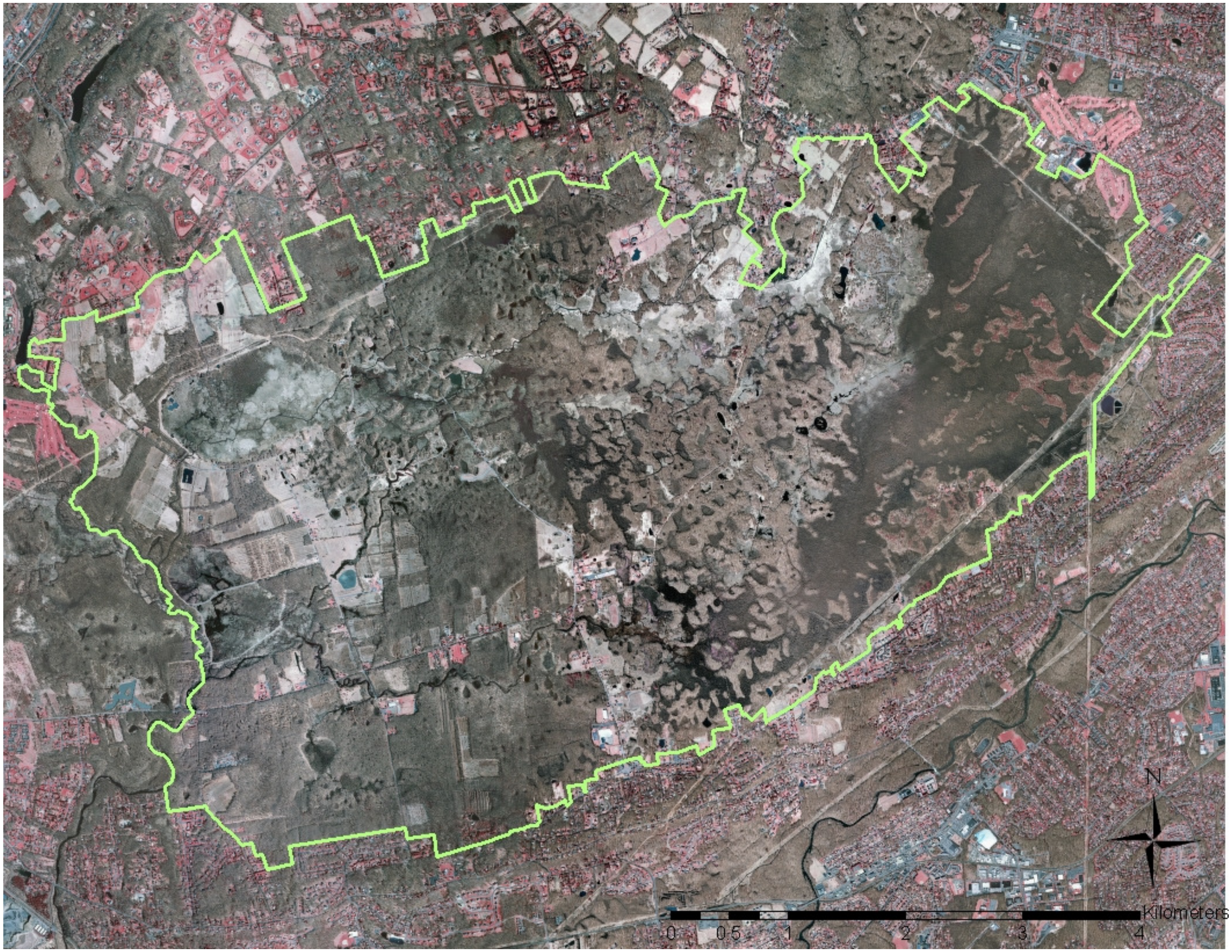

Figure 4. Aerial photography showing landcover and land use in and around Great Swamp NWR.

METHODS AND MATERIALS

Abundance and Distribution

Acoustic monitoring

Ultrasonic detectors including AnaBat SD1 (Titley Electronics) and Pettersson D-230 (Pettersson Elektronik) were used to quantify bat vocalizations in areas of suitable habitat. These surveys were conducted once or twice a week to identify areas of high bat use and to select locations appropriate for mist netting. Generally 1-3 teams surveyed 2-3 sites each, beginning a half-hour after sunset and ending by 2300 at the latest. Each site was observed for a 15-minute period. Using the ultrasonic detectors, the number of passes (indicative of prey searching), feeding buzzes (indicative of successful captures), and visual sightings were recorded. The site with the most activity was chosen for mist-netting the following night. Acoustic data were not analyzed to determine which species had been detected at potential net sites.

Mist netting

Mist nets (Avinet, Inc.) were used to capture bats throughout this study. Following USFWS guidelines for the capture of *M. sodalis*, mist net surveys were conducted between May 15 and August 15, 2006-7 (U.S. Fish and Wildlife Service 2007). Bats were captured in mist nets 2.6m tall and varying in width from 4m to 12m (38mm nylon mesh). Nets were placed across potential flight corridors such as streams, roads and trails in accordance with USFWS guidelines. Varying widths, heights and configurations were used depending on site conditions, but in the majority of cases three nets were stacked vertically such that total net height was 8m;

this is the same method described by Gardner et al. (1989) and recommended for the capture of *M. sodalis*. Net sites were located at least 500m from each other; attempts were made to sample as much of the refuge as possible, including several sites in both the Wilderness and managed portions of the refuge (Fig. 5). Netting was conducted between 2100 and 0200 hours for at least 2 consecutive nights per site in fair weather, and occurred 2-4 nights per week. Usually one site was netted each night, but occasionally staffing permitted the simultaneous sampling of 2 or more sites. Netting was not attempted in rain and/or winds exceeding 16-24 km/h; nets were closed during passing showers and netting resumed once precipitation ceased. The location of each net was recorded with an e-Trex or Rino 530 GPS unit (Garmin International, Inc.; accuracy <15 m) and was assigned a unique ID that identified its location, survey date, and size.

Date, site, personnel and time of first bat sighting were recorded at each survey. The time of net opening and closure were recorded, as was starting and ending temperature, relative humidity, wind speed, sky and moon conditions. Temperature and humidity were measured with a NIST-certified digital hygrometer (model 11-661-7B, Thermo Fisher Scientific Inc., accuracy ± 0.2º C, ± 1.5% RH). Wind speed, sky and moon conditions were recorded as a visual description.

Nets were checked at 10-15 min intervals throughout the sampling period. Captured bats were removed and time of capture, net of capture and height in net were recorded. Bats were placed in cloth bags to await processing. Species were identified using morphological characteristics according to Bat Conservation International 2008; photo documentation for *M. sodalis* was also used. Age was determined by backlighting the wing; bats with cartilaginous epiphyseal growth plates in the finger bones (appearing lighter than the surrounding ossified bone) were categorized as juveniles (Anthony 1988). Females that were pregnant, lactating or

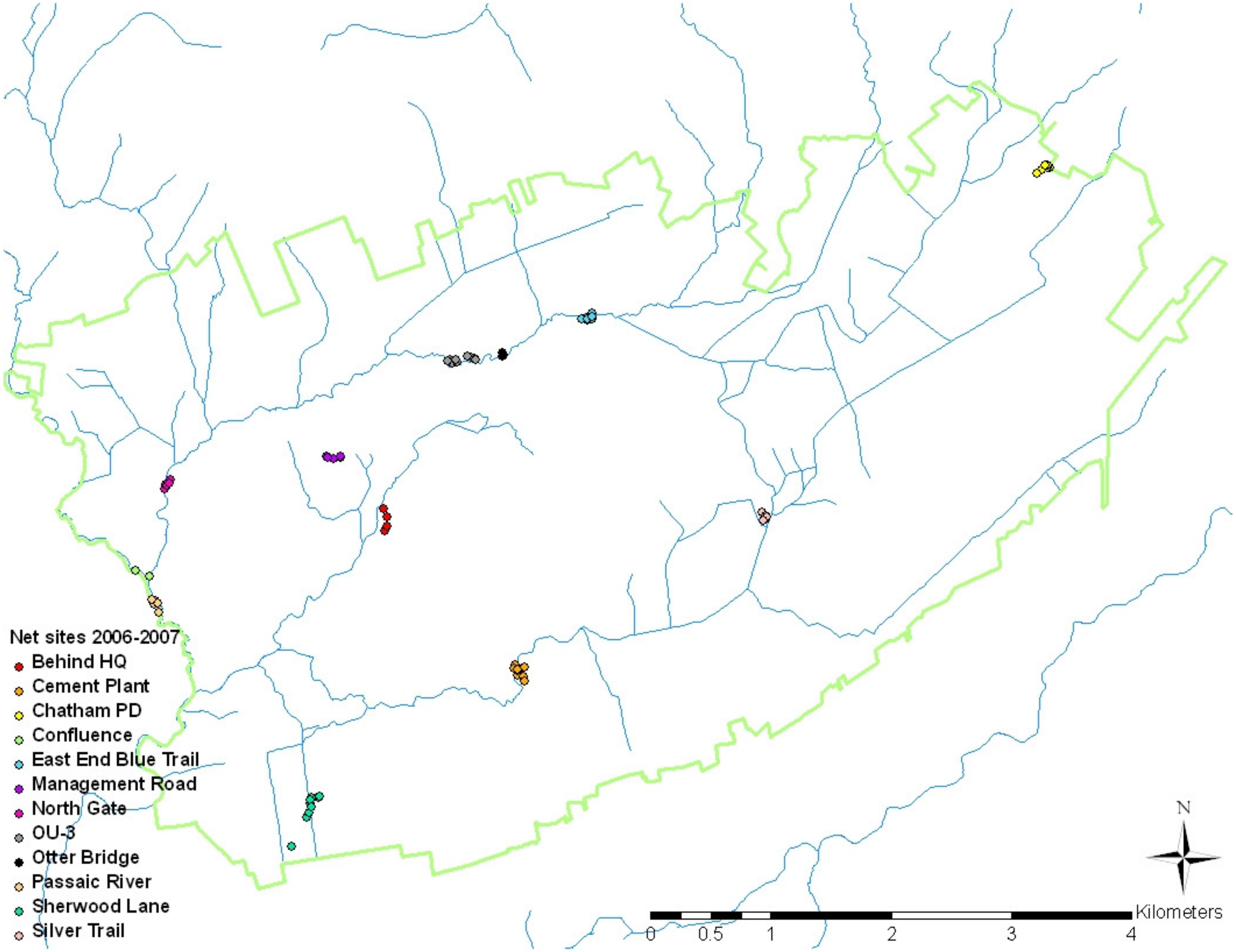

Figure 5. Map of Great Swamp NWR showing locations of net sites, 2006-2007. Streams and the Refuge acquisition boundary are shown.

post-lactating were considered reproductively active. Pregnancy was determined by palpation of the abdomen; lactation was determined by the extrusion of milk from nipples that had been suckled (appearing extended, with little to no fur surrounding them); and post-lactation was determined by the failure to extrude milk from nipples that had obviously been suckled. Males were considered reproductively active if the penis was noticeably distended (Racey 1988*)*. Bats were placed in lightweight mesh bags and weighed using 30g (accuracy ± 0.9 g) or 60g (± 0.18 g) spring scales (Pesola AG); forearm length was measured with digital calipers (± 0.2mm, Mitutoyo Corp.). Each bat received a uniquely numbered aluminum band placed on the right forearm of males and the left forearm of females. All *M. sodalis* and 16 bats of other species received 2.9mm-diameter lipped aluminum bands (Porzana Ltd.) obtained from the New Jersey Division of Fish and Wildlife (NJDFW), whose numbering system is coordinated with those of other northeastern states. All other bats received either 2.5mm or 4.0mm diameter butt-lipped aluminum bands (Gey Band & Tag Co.). Bats were examined for external parasites, scarring, frostbite damage and other injuries in order to determine general health. Bats not used for further radiotelemetry studies were released at the site of capture after processing was complete.

Adult female Indiana bats weighing more than 6.0 g were selected for radiotelemetry and were fitted with radiotransmitters. When multiple bats were available, preference was given to the heaviest reproductively active individuals, such that radiotransmitters would not exceed 5% of the animal's body mass (Animal Care and Use Committee, American Society of Mammalogists 1998). The fur was parted midway between the scapulae and a 0.4-gram transmitter (model LB-2N, Holohil Systems Ltd.) was glued in place using a non-harmful latex surgical adhesive (Torbot Bonding Cement, Torbot Group Inc.). The surrounding fur was glued over the transmitter to better secure it. Bats were immobilized and held for approximately 30 min while the glue set; during this time, transmitters were checked for functionality and the frequency of strongest signal was confirmed. All bats were released at the site of capture. Limited personnel allowed a maximum of three bats to be radiotracked at any given time.

Identification, characterization, and use of roost trees

Day roosts of radiotransmittered bats were located with the use of R-1000 receivers (Communication Specialists) and 3-element collapsible Yagi antennas (Wildlife Materials, Inc.) tuned to 160-164 mHz. Roost trees were identified every day that a signal was detected. A stationary signal at the same roost on two consecutive nights, combined with the associated emergence of bats, was interpreted as a detached transmitter. Searches were suspended after transmitters had been undetected for 4 consecutive days.

Geographic coordinates of roost trees were determined with an e-Trex or Rino 530 GPS unit (Garmin International Inc., accuracy <15m); these coordinates were entered into ArcMap 9.2 (Environmental Systems Research Institute) for later determination of spatial relationships of roosts. With few exceptions, roost trees were verified in 2007 by emergence counts conducted every night at roosts containing transmittered bats; due to limited staff, no such verification was possible in 2006.

In order to describe the roosts utilized by Indiana bat females, roost tree characteristics suspected to influence roost selection were measured. In addition, characteristics of surrounding 0.1 ha circular plots were measured to give some indication of the habitat in which roosts occurred. Because these techniques are frequently used to characterize tree roosts, data from this study can be compared to literature values.

Characteristics of roost trees

Characteristics of roost trees were measured from mid to late summer. Except for trees in late stages of decomposition, species was determined via characteristics of the tree's form and remaining bark (Petrides and Peterson 1972). Diameter at breast height (dbh) was measured using tree calipers (Haglof Inc.); if the trunk was asymmetrical in circumference, two perpendicular measurements were taken and averaged. Tree height was measured with a clinometer (Suunto), and canopy closure in 4 cardinal directions at the base of the tree was measured with a convex spherical densiometer (Forest Densiometers). Status of the roost tree was characterized as living, declining, or dead (hereafter termed a snag); and decay stage was assigned using a 5-class system for log decomposition published by Triska and Cromack (1980). According to this system, a decay stage of 1 corresponded with a roost tree for which bark was intact and twigs were present; stage 2 was characterized by intact bark and an absence of twigs; stage 3 had sloughing bark and sound heartwood; stage 4 had detached or absent bark and rotten heartwood; and stage 5 had detached or absent bark and no heartwood. The percent bark remaining on the roost tree, and percent of remaining bark that was exfoliating, were estimated visually. (Shagbark hickories have naturally peeling bark, and bark was only recorded as exfoliating if it was falling off of the tree and exposing the trunk). If the specific emergence point had been identified through emergence counts, the presumed roost space (under bark, cavity or split), directional exposure and emergence height (by clinometer) were recorded.

Characteristics of roost tree plots

Characteristics of the vegetation and habitat surrounding the roost were measured within a 0.1 ha circular plot centered on each roost tree. For each tree ≥10cm dbh occurring within the plots, species, dbh, status, and direction and distance from the roost (measured by measuring tape or laser range-finder, model TLM 100, The Stanley Works) were measured. Height was also recorded for the tree nearest the roost. If a tree was dead or declining, its decay stage was recorded as loose bark, no bark, broken top, or decomposed (stump); more than one stage could apply to a given tree. The amount of loose bark was further classified using the following system developed by Gardner et al. (1991) for ranking the suitability of a tree in providing roosting structures for *M. sodalis*: a tree was ranked “high” if it had ≥25% loose bark; “medium” if ≥10% but <25% loose bark; and “low” if it had >0% but <10% loose bark. Separate ranking criteria were established for *C. ovata*, since the naturally peeling bark of this species was not considered exfoliating. For this species only, suitability was considered “high” at dbh’s of ≥30 cm; “medium” at dbh’s of 18-30 cm; and “low” at dbh’s of 12-18 cm (see discussion). The presence of splits, cavities and/or exfoliating bark was recorded. Saplings (defined as tree species ≥1m in height and ≤5cm dbh) crossing the cardinal transects radiating out from the roost tree within the plot were counted, and the numerically dominant sapling species was recorded. The plot was divided into 4 quadrants separated by cardinal bearings, and percent shrub coverage within each quadrant was estimated visually. Lastly, canopy closure at each cardinal point along the plot edge was measured using the spherical densiometer. Distance to water (defined as a body of water, or stream, that retains water even during the driest parts of the summer; this is not necessarily open water) was measured in the field with measuring tape or laser range-finder. In some cases, these distances were determined within ArcMap 9.2 using the distance measuring tool.

Roost occupancy

Emergence counts were conducted to determine the number of bats roosting in a given tree each night that a roost was identified. Observers arrived at the roost tree 15 minutes prior to sunset, positioned themselves so that the bole of the tree was best silhouetted against the sky, and then counted the number of bats exiting the roost. The number of bats exiting minus the number that returned to the roost during the count provided the final number; this avoided double-counting bats that may have left the roost twice. If multiple observers were present, each recorded an independent observation and these were averaged. Observers remained at the roost until a) it was too dark to see bats emerging, or b) 10 minutes after the last bat had emerged, whichever occurred last. If a transmittered bat was located in the tree, the observer carried with them a receiver and antenna to detect its emergence.

Time of sunset, transmitter frequency (if applicable), date, temperature in degrees Centigrade (EnviroSafe Thermometer, Forestry Suppliers), sky code and wind code (Tables 1 and 2) and time of observer arrival were recorded at the start of the survey. During the emergence count, the times at which the first bat was seen flying, the last bat emerged, and (if applicable) the transmittered bat emerged were recorded. Lastly, the observer's time of departure was recorded.

During 2006, limited staff resulted in only 5 emergence counts being conducted as opportunity allowed. During 2007, counts were performed each night at roosts containing transmittered bats, weather and access permitting. Counts were also performed weekly throughout the summer on a small number of trees with initial counts of 20 or more bats.

In 9 cases a transmittered bat emerged prior to observer arrival, and the ensuing emergence count revealed 0 bats exiting the tree. These counts were deemed unreliable and were excluded from analysis.

Both the date of the emergence count and a subset of the characteristics measured during roost tree characterization (species, dbh, tree height, canopy closure, percent bark remaining and

Table 1. Sky codes used during emergence counts performed at Great Swamp NWR.

Code	Indicators
0	Clear or scattered clouds
1	Partly cloudy/variable sky
2	Cloudy or overcast
3	Fog or smoke
4	Drizzle
5	Rain
6	Thunderstorms
7	Hazy, humid

Table 2. Beaufort wind scale, used during emergence counts performed at Great Swamp NWR.

Code	MPH	Indicators
0	<1	Smoke rises vertically
1	1-3	Smoke drift shows wind direction
2	4-7	Wind felt on face/leaves rustle
3	8-12	Leaves and small twigs in constant motion
4	13-18	Raises dust and loose paper
5	19-24	Small trees sway

percent bark exfoliating) were analyzed to determine whether counts alone could serve as indicators of roost quality (i.e., did any of these factors significantly affect emergence counts). Data were compiled in order to pair characteristics with emergence counts for each roost, and the data for each characteristic were lumped into categories to increase the power of analysis. A repeated measures analysis was run to determine associations between roost characteristics and emergence counts; this dealt with the lack of independence in the data. The roost tree was used as the repeated measure. The analysis was first run to examine the by-date association; the resulting asymmetry in the emergence count residuals was resolved by adding 1 to each count (to address 0 data) and log-transforming the data. The analysis produced estimates (means) and standard errors for each date and roost characteristic. In the repeated measures analysis, log(count) was the dependent variable and the classes included RoostID and date, plus the characteristic of interest (species, dbh, canopy closure, bark remaining, bark exfoliating, or height). Theses classes were also included as independent variables in the model. The characteristic of interest was used as the effect, RoostID was used as the subject and Date was used as the repeated variable.

Roost fidelity

Roost fidelity estimates were established using 3 different methods. Following Kurta et al. (1996, 2002), the number of days for which a roost was identified was divided by the number of switches that occurred for each individual bat. Since no information for the previous day was available, the first day's information was excluded. A second estimate was obtained following a slight modification of the Kurta et al. method, in which 1 was added to the number of observed switches prior to calculation of the estimate. The last estimate was created following Britzke et al. (2006), where the number of consecutive days that a bat spent in each roost was averaged. In all cases, bats with only 1 day of information were excluded from analysis.

Landscape patterns

Distance and direction to the nearest roost previously used by each bat were measured in the field with measuring tape or laser range-finder. In some cases, inter-roost distances were determined within ArcMap 9.2 using Hawth's Analysis Tools v. 3.27 (Beyer 2006). Two additional distances were measured: distance to the nearest neighboring roost (as used by any other transmittered bat) and the distance between consecutive roosts. These were determined using Hawth's Analysis Tools.

Random trees and plots

Thirty random trees (and plots centered on those trees) were measured to provide comparisons to roost trees and plots used by *M. sodalis.* Hawth's Analysis Tools v. 3.27 (Beyer 2006) was used to generate 200 random points within lands owned by the refuge, and the calculate geometry tool within ArcMap 9.2 was used to assign geographic coordinates to each of these points. National Land Cover Database (NLCD) data from 2001 were used to classify habitat for each point; however, further classification was necessary due to low resolution of the NLCD data. This was achieved by examining 2002 Orthophotography tiles for New Jersey (available at http://njgin.nj.gov/OIT_IW/index.jsp) and defining habitat type as forest, edge, marsh, swamp, grassland, brush, open water, residential, or a combination of these (such as edge forest/swamp). Random points were restricted to the three habitat types represented among known *M. sodalis* roost trees (forest, forest edge, and swamp). The thirty random points were selected using a list of randomly generated numbers (1-200) and accessible, suitable points were selected one-by-one until 10 of each had been chosen. (A point was defined as inaccessible if it would take more than 1 hour to reach from the nearest access point, or if attempts to access it were unsuccessful). Garmin Rino 530 GPS units were used to navigate to each point and verify that the correct habitat type had been assigned. Once a point was confirmed, the nearest tree ≥10cm dbh was selected as the random tree, and the plot was laid out with this tree at its center. Data collection proceeded using the methodology outlined above for roost trees and plots.

Foraging and home range estimation

Following the daily identification of roost trees, a focal bat was chosen to be the subject of night telemetry; this occurred most nights that a bat was available to be followed. Telemetry generally began 15 minutes prior to sunset and lasted until 2 a.m. (weather permitting); on a few occasions bats were followed until 5 a.m. Telemetry efforts were suspended only in heavy rain or thunderstorms; three or occasionally four observers were used.

The location of each observer was recorded with a Rino 530 GPS unit (Garmin International, Inc.; accuracy <15m) and compass bearings were taken in the direction of the strongest signal every 5-10 minutes. These 'timepoints' were coordinated using the alarm clock feature of the Rino 530 GPS unit such that readings by observers occurred simultaneously; observers relocated as necessary to follow animal movements throughout the night. In addition to observer location and compass bearing, the apparent activity of the bat (moving/stationary), relative strength of the signal, and minimum receiver gain necessary to detect a signal at full volume was recorded at each timepoint; this provided a frame of reference for the distance between each observer and the focal bat. Attempts were made to position observers as close to the bat as possible (but not closer than 25 meters) and space them equilaterally around the animal; however, this was not always possible. Inter-bearing angles were generally 60-160º (not exceeding 180º) and observers were usually positioned more than 300m from the bat.

LOAS v. 4.0.2.9 (Ecological Software Solutions) was used to estimate bat locations from telemetry data (i.e., observer locations and their azimuth of strongest signal). A declination of -12.8º was used to align readings with true north. Maximum Likelihood Estimates were used to estimate bat locations, and error ellipses were created using the adjusted-F distribution with 75% confidence. Only bearings with intersections were used; all others were excluded from analysis. Locations with error ellipses under 2 ha were considered highly reliable, and those with ellipses 2-10 ha were deemed somewhat reliable. All other estimated locations were removed from analysis.

Home ranges were estimated using ArcMap 9.2 and Hawth's Analysis Tools v. 3.27 (Beyer 2006). Home range estimates were produced by two different methods – minimum convex polygons (MCP's) and fixed kernel density estimates (KDE's). The former (MCP) method identifies the most outlying locations and uses them to create a polygon, which results in a minimum estimate of home range size that encloses any and all travel corridors used. Kernel estimates generate contour lines enclosing the x (here, 50, 90 and 95) percent by volume contours; in other words, the resulting output encloses 50% (or other set amount) of the locations (Beyer 2006). All known locations (site of capture, roost trees, and triangulated foraging points with errors less than 10 ha) were used to create MCP's and 50, 90 and 95% KDE's for bats with 5 or more known locations. The process was repeated to estimate colony home ranges.

Statistical analysis

All analyses were conducted using SAS v. 9.1 (SAS Institute, Inc., Cary, NC, c. 2002-2003), and an alpha value of 0.05 was used throughout. Zar (1999) was used as the reference for all statistical methods.

Chi-square analysis was used to test for differences in categorical data, and ANOVA was used to test for differences in continuous data following examination of residual plots for equal variance. The Tukey adjustment was used for all pairwise comparisons within ANOVA. When independence was violated, Mixed models ANOVA (mm-ANOVA) was used in place of ANOVA; the repeated characteristic (such as RoostID or frequency) was set as the random variable and fixed variables included year, tree species, dbh, canopy closure, bark remaining, bark exfoliating, and roost tree height. In addition to correcting for non-independence, this method is also more powerful than a two-sample t-test.

In random-roost comparisons, ANOVA was used to test for differences when characteristics differed between years; and two-sample t-tests were used when no difference was detected. One roost (W77006MK1) was used in both years, and trees within its plot were measured twice. To correct for this, the distance of each tree was averaged prior to random-roost comparisons (distance did not differ statistically between years). Trees within this plot were deleted prior to random-roost comparisons of dbh (since plot tree dbh differed between years).

ABUNDANCE AND DISTRIBUTION

Results

Acoustic monitoring

In 2006, 12 echolocation surveys were conducted at 13 sites; 4 of those sites were eventually netted (acoustic monitoring was not conducted at all net sites). In 2007, 41 echolocation surveys were conducted at 21 sites, 11 of which were netted (Fig. 5). Activity varied from week to week (and sometimes from night to night) at any given location, such that one could not assume that an active site would remain so for any period of time.

Mist netting

In 2006, netting began on June 3 and was conducted every other week through June; surveys were then conducted weekly through mid-August. Throughout 2006 netting occurred 1-2 times per week, weather permitting. In 2007, additional staff permitted more frequent and earlier netting, which occurred from May 22-August 14 and was conducted 2-4 times per week. Seven sites were netted during 20 nights in 2006, and eleven sites were netted during 36 nights in 2007 (including the 7 netted the first year) for a total of 56 net nights between 2006-2007 (Table 3). Four of the capture sites (Sherwood Lane, Management Road, Behind HQ and Chatham PD) utilized nets set across trails in the woods that represented potential flight corridors. Each of these sites was less than 300 m from a stream. The remaining 7 sites had some, if not all, of the nets set across streams including the Great Brook, Passaic River and Black Brook (Fig. 5).

A total of 530 captures resulted in the identification of 520 bats during 2006-2007 (235 captures on 20 nights in 2006; 299 captures on 36 nights in 2007). Six species were captured:

Table 3. Net effort by site, 2006-2007. Nights refers to the number of individual nights a site was visited. One net night is equivalent to one net being open for one night. One net hour is equivalent to $1 m^2$ of net being open for one hour. The presumed colony associated with each net site is indicated; SL = Sherwood Lane.

		2006			2007			TOTAL		
	Site	nights	net nights	net hours	nights	net nights	net hours	nights	net nights	net hours
SL	Sherwood Lane	2	6	2119.62	4	12	3800.98	6	18	5920.6
OU-3	OU-3, Otter Bridge	5	11	3392.53	10	20	5097.03	15	31	8489.56
	East end Blue Trail	4	11	2192.50	5	13	2687.86	9	24	4880.36
	Silver Trail	0	0	0.00	3	15	2177.41	3	15	2177.41
	Chatham PD	0	0	0.00	3	16	1958.57	3	16	1958.57
Passaic River	Passaic River	2	9	2063.19	2	8	2433.68	4	17	4496.87
	Great Brook/Passaic River Confluence	0	0	0.00	4	8	3103.31	4	8	3103.31
	North Gate	8	20	5058.37	3	9	3036.22	11	29	8094.59
	Behind HQ	0	0	0.00	3	15	1488.84	3	15	1488.84
	Management Road	2	8	2032.52	3	3	1357.2	5	11	3389.72
	Cement Plant	2	10	2431.00	4	12	3115.62	6	22	5546.62
	TOTAL	25	75	19289.7	44	131	30256.7	69	206	49546.4

228 little brown *(M. lucifugus;* 43.8%), 130 big brown *(Eptesicus fuscus*; 25.0%), 85 Indiana *(M. sodalis*; 16.3%), 46 northern long-eared *(M. septentrionalis*; 8.8%), 18 red *(Lasiurus borealis*; 3.5%), and 13 eastern pipistrelle *(Perimyotis subflavus*; 2.5%) bats. (Four bats escaped before species could be confirmed, and three *E. fuscus* discovered in a building were banded; these bats were excluded from this analysis). Each species was caught in approximately the same proportion each year (± 2%).

Males, females and juveniles of all 6 species were captured (although no juvenile *P. subflavus* were caught in 2007). Juvenile sex ratios were approximately equal for *M. lucifugus*, *E. fuscus*, *and M. sodalis* (see Table 4). Juvenile sex ratios in *M. septentrionalis*, *L. borealis*, and *P. subflavus* were skewed towards females, although sample size was small. Adult sex ratios were skewed towards females for all species except *L. borealis*. Among the adult females, reproductive individuals represented 81.5% of *Eptesicus*, 66.7% of *Lasiurus*, 100% of *Perimyotis,* 77.2% of *M. lucifugus*, 83.3% of *M. septentrionalis*, and 85.7% of *M. sodalis* captures.

Among all species, pregnant bats were caught up to three weeks later in 2007 compared to 2006, and post-lactating bats first appeared 12 days later in 2007; however, the appearance of lactating bats and of juveniles were similar (occurring within a six and four-day span, respectively). Among all species, pregnant females were first detected on June 3, 2006 and May 22, 2007 and were caught through June 22 and July 16, respectively. The first post-lactating females were caught July 5 2006 and July 17 2007, and the first juveniles were caught June 22 and June 26 respectively.

Nine individual bats were recaptured during mist net surveys (although none were *M. sodalis*); all but one of these occurred within the same year and one bat was recaptured twice

Table 4. Total number of captured bats by age and reproductive status, 2006-2007. J = juvenile; A = adult; N = non-reproductive; P = pregnant; L = lactating; PL = post-lactating. Recaptured bats are included once for each capture.

		Males		**Females**		**Adult Females**			
Species	**Total**	**J**	**A**	**J**	**A**	**N**	**P**	**L**	**PL**
Myotis lucifugus[1]	231	18	76	22	114	26	42	39	7
Eptesicus fuscus	134	12	28	13	81	15	34	15	17
Myotis sodalis	86	15	9	13	49	7	4	30	8
Myotis septentrionalis[2]	48	4	11	8	24	4	8	8	4
Lasiurus borealis	18	2	6	7	3	1	0	1	1
Perimyotis subflavus	13	0	2	2	9	0	4	1	4
species unknown[3]	4								
Total	534	51	132	65	280	53	92	94	41

[1] one male escaped before age could be determined

[2] one female escaped before age could be determined

[3] Includes 1 adult and 1 female; others escaped before age, sex, repro condition could be confirmed.

(Table 5). Time between same-year captures ranged from two hours to 53 days, and seven of the recaptures occurred at the site of initial capture.

Peak captures occurred for most species between 2100 and 2200, with a noticeable decline in capture rates after 2230 (Fig. 6). Only *L. borealis* captures peaked outside of this timeframe, between 2300 and 2330. Capture rates remained relatively steady after 2230 for most species.

Myotis sodalis captures

The 85 *M. sodalis* caught included 48 adult females, 9 adult males and 28 juveniles. These were captured at 6 of 7 sites in 2006 and 10 of 11 sites in 2007. The site at which no *M. sodalis* were caught was the same in both years, although there is reason to believe they are present there (see discussion). Most *M. sodalis* were caught between 2100 and 2230 at relatively constant rates (as was the case with the other species, see Fig. 6), though capture continued throughout the night at lower rates.

Of the 82 captures where a height was recorded, 14 (17.1%) occurred 0-2 m off the ground or water; 27 (32.9%) occurred 2-4 m; 23 (28.1%) occurred 4-6 m; and 18 (22.0%) occurred 6-8 m. As 68 of 82 captures (82.9%) occurred above 2 m, it's clear that the triple-high setups as recommended by Gardner et al. (1989) were most efficient.

Juveniles showed a relatively even sex ratio, though the adult sex ratio was heavily skewed towards females (48:9, more so than with any other species; Tables 4 and 6). The 48 adult females included 7 non-reproductive, 4 pregnant, 30 lactating, and 8 post-lactating individuals (one recaptured bat is here included twice, once as pregnant and once as post-lactating). Pregnant *M. sodalis* were caught between May 30 and June 22; the first juveniles were caught on July 5 (most were caught after July 20). Post-lactating females were also caught

Table 5. Recapture data, 2006-2007. Data from original and subsequent captures shown.

			Original Capture				Subsequent Capture(s)							
Band ID	Species	Sex	Date	Age	Repro Status	Weight	Date	Age	Repro Status	Weight	Date	Age	Repro status	Weight
258	Eptesicus fuscus	M	6/7/2007	A	N	13.5	7/24/2007	A	N	16.75				
809	Myotis lucifugus	F	6/21/2006	A	L	7.5	7/13/2006	A	L	7.75				
845	Myotis septentrionalis	M	7/25/2006	A	N	6.75	7/26/2006	A	N	6.5				
1101	Eptesicus fuscus	M	6/7/2007	A	N	16.5	7/24/2007	A	N	18.25	7/30/2007	A	N	19.0
1131	Eptesicus fuscus[1]	F	6/26/2007	A	L	19.5	7/12/2007	A	P	21.75				
1139	Myotis lucifugus	M	7/3/2007	J	N	6	7/3/2007	J	N	6				
1169	Myotis septentrionalis	M	7/17/2007	A	N	6.5	7/20/2007	A	N	5.25				
AC1701	Myotis lucifugus[2]	F	8/3/2005	A	PL		6/6/2006	A	P	8.5				
NJDFW 25169	Myotis sodalis	F	6/7/2007	A	P	9.5	7/24/2007	A	PL	8.25				

[1] Although this bat was first recorded as lactating, subsequent recapture reveals she was probably not-palpably pregnant.

[2] First captured during preliminary surveys in 2005; no initial weight reported.

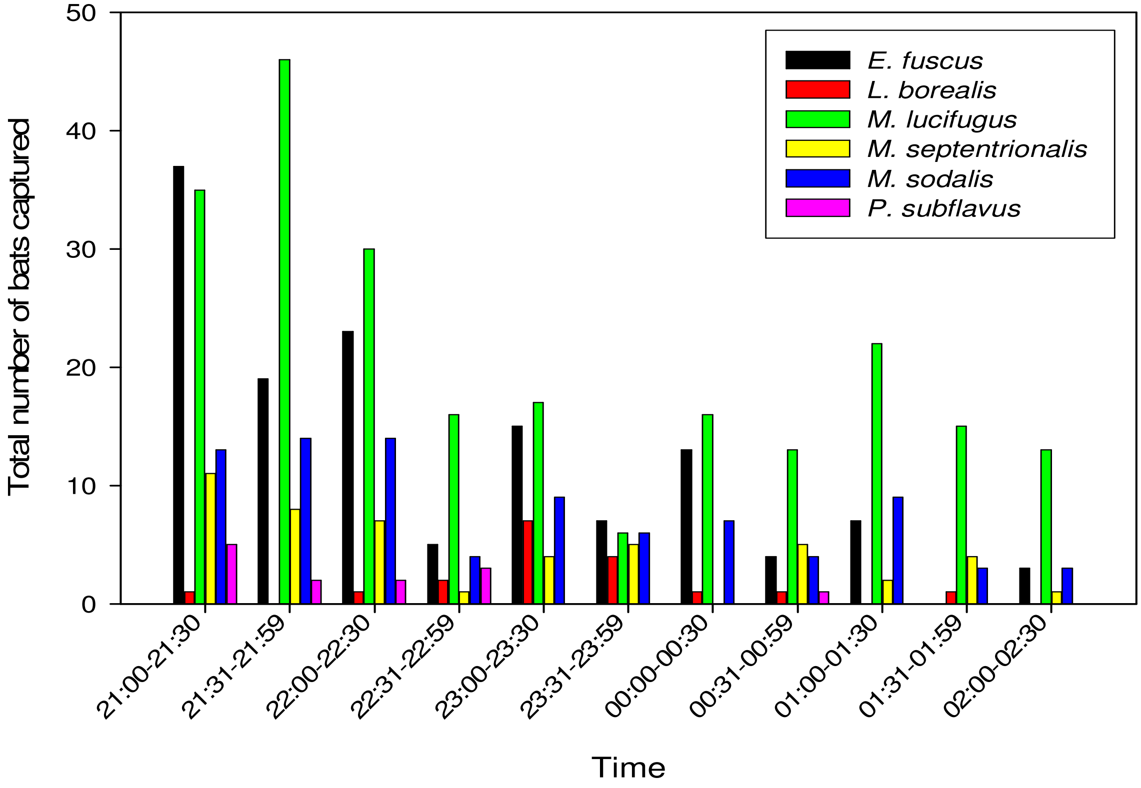

Figure 6. Total bat captures per species during 2006 and 2007.

Table 6. Sex ratios for bat species captured at Great Swamp, 2006-2007. Recaptured bats are included once for each capture.

		JUV			ADULT		
Species	Total	n	M	F	n	M	F
Myotis lucifugus	230	40	0.45	0.55	190	0.40	0.60
Eptesicus fuscus	134	25	0.48	0.52	109	0.26	0.74
Myotis sodalis	86	28	0.54	0.46	58	0.16	0.84
Myotis septentrionalis	47	12	0.33	0.67	35	0.31	0.69
Lasiurus borealis	18	9	0.22	0.78	9	0.67	0.33
Perimyotis subflavus	13	2	0.00	1.00	11	0.18	0.82
Total	528	116			412		

as early as July 5, though the majority were captured after July 26. Adult males were captured throughout the months of June and August, and though none were caught in July, this is probably the result of small sample size (n=9 for both years combined).

The average weight of *M. sodalis* caught in this study varied by sex, age and reproductive status, but largely fell within the 6-9g range typical of the species. Mean weight was least for juveniles (6.2 g ± 0.12 se, n = 28) followed by adult males (7.1 g ± 0.14 se, n = 9), post-lactating females (7.5 g ± 0.19 se, n = 8), non-reproductive females (7.6 g ± 0.44 se, n = 7; probably influenced by the heavier weights of pregnant females that were not yet detectable by palpation), lactating females (7.8 g ± 0.09 se, n = 30) and pregnant females (9.81 g ± 0.24 se, n = 4). Pregnant females were significantly heavier in weight, and juveniles significantly lighter, than all other classes ($p < 0.0001$, ANOVA, $\alpha = 0.05$). Forearm length fell largely within the 35-41 mm range expected for this species (Barbour and Davis 1969), with a few exceptions: a 34.1 mm length was observed in a juvenile male, and 3 adults had forearms exceeding 41.0 mm, with a maximum of 42.4 mm. Fleas or mites were recorded in 12 of 86 captures (13.95%), and judging from the amount and frequency of excrement that accumulated in bags while bats awaited processing, bats appeared healthy and well-fed (pers. obs.).

Adult females and juveniles comprised 89.5% *M. sodalis* captures; nearly half (42 of 86, or 48.8%) of the captures represented reproductively active females. Furthermore, 6 of the 7 non-reproductive females were captured prior to June 4th and may have been pregnant, as palpation cannot reliably detect an embryo during the first half of pregnancy (Kurta and Rice 2002; Racey 1988). Two of these (including one that was transmittered) had weights equal to or exceeding 9.0 grams, which may indicate pregnancy even though no fetus was detected. (Excluding pregnant and lactating females, no other *M. sodalis* exceeded 8.25g). In an effort to exclude not-palpably-pregnant females from analysis, Kurta and Rice (2002) examined *M. sodalis* captured after June 15 and found that 89% of the remaining adult females in Michigan were reproductive, though no other studies have provided such a comparison for *M. sodalis*. Using the same method, 97.5% of adult females caught at Great Swamp were reproductive.

Only one *M. sodalis* was recaptured during this study. This bat (band number NWDFW 25169, a pregnant female weighing 9.5g) was initially fitted with a radiotransmitter on June 7, 2007 at Sherwood Lane. Upon her recapture 47 days later she weighed 8.25g and was in a state of post-lactation; examination revealed a bare patch of fur at the site of transmitter attachment. A second transmitter was placed on this bat, but it became detached less than 24 hours later.

Temperature at the start of mist net surveys ranged from 11.9 – 27.1° C; ending temperatures ranged from 9.2 - 25.1° C. Beginning relative humidity ranged from 43.9 – 100% and usually rose throughout the survey period; ending humidity ranged from 71.3-100%. Usually little to no wind prevailed during surveys. Wind, sky, moon, relative humidity or temperature conditions appeared to have little effect on the number of captured bats of all species. The same was true with regard to the capture of *M. sodalis*. However, on two nights where the opening of nets was delayed by passing thunderstorms, netting success was very low.

Discussion

Mist netting

Ten species of bats inhabit New Jersey, and nine occur regularly. In addition to the six species that were captured during this study, the small-footed bat *(M. leibii)*, the silver-haired bat *(Lasionycteris noctivagans)*, and the hoary bat *(L. cinereus)* also occur in the state; the northern yellow bat *(L. intermedius)* is considered “peripheral” (NJDFW 2008). Two of these species were detected at GSNWR during preliminary survey efforts in 2005 and included *M. leibii* and *L. cinereus* (Campbell 2005). *Myotis leibii* is a migratory vespertilionid bat that spends the maternity period mostly in hilly or mountainous terrain (Thompson 2006); one individual was captured at Great Swamp on August 1, 2005. Since little such habitat exists near the Great Swamp and because the capture was a lone adult male, this individual was probably a migrant. *Lasiurus cinereus* may be a temporary summer resident on the refuge, and likely migrates through the area. Echolocation surveys in late June and early August of 2005 indicated the presence of the species (Campbell 2005), and in September 2007 a male was found (dead) roosting in a tree in front of the Somerset County Environmental Education Center (SCEEC), less than 0.8 km from the refuge (Juhasz 2007 pers. comm.). The lack of captures for this species is probably due to its tendency to fly high above the canopy, above the placement of nets. Thus, of the nine species regularly occurring in the state, eight have been detected and six appear to reproduce on or near the refuge (as determined by the capture of juveniles during mist-net surveys). The remaining species (*L. noctivagans*) has been described as having an erratic distribution throughout its range, and its status is listed by the New Jersey Division of Fish and Wildlife as “undetermined”; however, one was found on SCEEC property in September 2008, confirming that they at least migrate through the area (Juhasz 2008 pers. comm.).

High proportions of reproductively active females indicate the presence of maternity colonies, and the capture of reproductive females and juveniles of 6 species at Great Swamp confirms that the area provides suitable maternity habitat for these bats. Although the capture of bats does not reveal whether the area is being used for roosting or foraging, the high proportion of reproductive females of each species suggests that the refuge provides habitat to support both needs, as well as sufficient insect abundance and diversity to support the metabolic demands of mothers and young. At three of the eleven sites sampled during mist-net surveys, all six species were captured (East end - Blue Trail, Confluence, and North Gate); at two of these sites, this occurred in a single night.

For most species, the highest rates of capture occurred within the first hour of netting; the only exception was *L. borealis*, which peaked between 2230 and 2300. Captures for all species decreased toward the end of the netting period (Fig. 6). This pattern indicates that closing the nets at 0200 allowed sufficient time to capture most bats during peak activity. In 2007 additional staffing allowed 2-4 consecutive nights of sampling, frequently at the same site; yet despite an 80% increase in sampling effort in the second year, only 25.5% more bats were caught. Winhold and Kurta (2008) found a significant decline (40%) in the number of bats caught during the second night of sampling, and a similar pattern held at Great Swamp. Mean number of bats captured was 14% lower on the second night and 38% lower on the third; however, the difference was not significant. Capture success may have been increased by more frequently moving net sites in 2007, but year-to-year or nightly variation in bat activity may also have played a role.

Recaptures

Very few bats were recaptured (9/520, or 1.7%); of these, most occurred at the original site of capture. Two bats were recaptured at different sites along the same waterway: one *M. lucifugus* (a post-lactating female) was caught on August 3, 2005 and recaptured 240 m downstream on June 6, 2006 (pregnant); and one *E. fuscus* (a reproductive female) was recaptured two weeks after initial capture, about 810m downstream in an adjoining stream. Thus, all 9 recaptures provide evidence for fidelity to foraging sites within and among years. Gardner et al. (1991) and Kurta and Murray (2002) recaptured banded *M. sodalis* at the same capture site and at the same study area between years, respectively. Many studies have noted the repeated use of foraging and/or roosting areas over successive years, though individuals were not always distinguished (Gardner et al. 1991; Gumbert et al. 2002; Humphrey et al. 1977; Kurta and Murray 2002; Kurta et al. 1993a, 1996, 2002; Murray and Kurta 2004, Sparks et al. 2005, Winhold et al. 2005). Fidelity to a roost area has been suggested for many species of tree-roosting bats in Africa, New Zealand, Australia and North America (Barclay and Kurta 2007).

Myotis sodalis captures

Myotis sodalis was captured at most of the sites where mist-netting was conducted (6 of 7 in 2006 and 10 of 11 in 2007). The site at which *M. sodalis* was not captured (Cement Plant) was the same in both years, although a post-lactating female was caught there in 2008 (Wight 2008 pers. comm.). The wetland adjacent to the Sherwood Lane site drains into Black Brook about 1300 m downstream from the Cement Plant, so it is possible that the Black Brook is used as a travel corridor by Sherwood Lane bats. In one odd example, a juvenile male *M. sodalis* previously captured at the Sherwood Lane site somehow hitched a ride home on the vehicle of a crew member (LSR) whose vehicle was parked at the Cement Plant during surveys there. The juvenile was found two days later on the floor of the crew member's garage, opposite from where the vehicle was parked. Although dead, it showed no signs of injury as would be expected from vehicular impact. The crew member thought that the bat had roosted in the rafters of the garage and succumbed to the summer heat, falling to the garage floor. Though the evidence is weak, there is some chance that the bat, having used Black Brook as a travel corridor, was foraging in the area near the Cement Plant and was gently intercepted by the vehicle during driving or (even more unlikely) chose to temporarily roost on the outside of the vehicle while parked at the Cement Plant. It is more likely that a “gentle interception” would have occurred as the crew member drove to the Cement Plant site, passing less than 800m north of Sherwood Lane along Whitebridge Road; however, if this was the case, the bat would have had several hours during the survey to alight (the crew member returned home another way and did not pass the site again).

Otter Bridge was another site where *M. sodalis* was not captured in either 2006 or 2007 (although this is located within 500m of OU-3, where *M. sodalis* was captured). Maternity roosts were discovered in 2006 and 2007 less than 180m from the Otter Bridge site, even though no *M. sodalis* was captured there. One of the two bats using these roosts utilized 4 trees within 180 m of the site in 2006 and was captured less than 250m downstream; the other bat used 2 trees within 120 m of the site in 2007 and was captured less than 700m upstream. Emergence counts in 2007 documented as many as 72 bats emerging from one of these roosts. Hence, it seems clear that *M. sodalis* was using this portion of the Great Brook as a flight corridor in both years even though no individuals were captured at the Otter Bridge site. This also demonstrates that only a small percentage of bats utilizing the area were captured by mist nets, which is likely to have held true across the study area.

Fewer pregnant and lactating females were captured and thus available for radiotelemetry studies in 2006 compared to 2007. Netting began two and a half weeks earlier in 2007, increasing the opportunity for captures of pregnant and lactating bats in that year; however, it is unlikely that this produced a significant difference in the capture of reproductively active females, since netting in May can frequently be unproductive (Kiser and MacGregor 2005). For example, in 2007 only 3 of 91 captures (3.3%) made prior to 6/15 were reproductively active *M. sodalis*; 10 of the 102 captures between 6/15 and 7/15/2007 (or 9.8%) were reproductively active

M. sodalis (net nights were equal in each period). A more likely explanation for the difference between years is that in 2007 productive sites were known and could be visited early in the season.

The recapture of bat NJDFW 25169 provided an opportunity to view the hair loss that may have resulted from the placement of radiotransmitters. Bats presumably molt in July and August (Barbour and Davis 1969) and depending on when transmitters are placed, bats may retain a bare patch anywhere from a few months to more than a year. Kurta and Murray (2002) recaptured 12 female *M. sodalis* in southern Michigan that had received one or more transmitters in prior years. Examination of the attachment site in these bats revealed most (9 of 12) had normal hair; even those with irregular fur replacement were found to be reproductively active, indicating that transmitter attachment does not prevent successful migration, mating, hibernation, conception or parturition.

The heavily-skewed sex ratio for *M. sodalis* caught at Great Swamp provides clear evidence that at least one maternity colony exists there. Only nine adult males were captured, which is consistent with males summering near the hibernacula or dispersing throughout the range to roost singly or in small numbers (Kurta and Rice 2002, Kurta et al. 2002, Whitaker and Brack 2002). Furthermore, the proportion of *M. sodalis* captured and the proportion of sites at which they were caught indicate that the area provides substantial and important maternity habitat for this endangered species. Many studies do not report the details of their maternity-season mist net surveys, which makes comparisons difficult; however, *M. sodalis* represented 13.7% of captures in KY (although bats were also captured at known hibernacula during fall and spring swarm, Gumbert 2001), 10.3% of captures in MO (Timpone 2004), 2.9% of captures in NY and VT (Kiser et al. 2002) and 0.7% of captures in OH (including some minimal netting effort during fall swarm, Schultes 2002). *Myotis sodalis* constituted 16.3% of captures at GSNWR, where they were the third-most common species. These results suggest that *M. sodalis* may exist at higher densities at GSNWR than in the core of their historic range in MO and KY. In the two studies where *M. sodalis* was more abundant, forests were a dominant feature of the landscape; this suggests that Great Swamp's abundance of unmanaged forests (and/or ample food resources) may explain the species' abundance here. Timpone's (2004) study area was over 75% forested, with most trees being 65-90 years of age, and Gumbert (2001) found that naturally regenerated forest (>70 years of age) was utilized more than would be expected based on availability. In contrast, the studies with fewer *M. sodalis* captures had fragmented landscapes. The Champlain Valley of NY and VT has been described as heavily fragmented and consisting mainly of agricultural, forested, wetland and developed lands (Watrous et al. 2006). Schultes' (2002) study area was similarly patchy, with farmland and small towns embedded within a national forest managed for multiple uses including oil and gas drilling and timber harvesting. Thus it seems quite probable that the large areas of naturally regenerating forest, combined with the abundance of riparian and wetland habitats within GSNWR and its proximity to confirmed hibernacula, provides the species with optimum maternity habitat.

IDENTIFICATION, CHARACTERIZATION AND USE OF ROOST TREES

Results

Twenty-four transmitters were placed on 23 Indiana bats (3 pregnant, 12 lactating, 6 post-lactating and 3 non-reproductive; one bat received two transmitters over the course of 2007 and was pregnant and post-lactating at each respective capture). Bats were tracked to roost trees on 128 of 157 bat days; on the remaining days bats were not located (one bat day is defined as one transmittered bat being located on one day; Table 5). The average weight of bats selected for telemetry was 8.19g (± 0.18, range 7.0-10.5g); radiotransmitters averaged 4.88% body weight. Transmitters remained attached an average of 8 days after placement (range 1-19); this excludes bats that permanently disappeared from the study area while the transmitter remained active. Under ideal conditions, the transmitter was detected at a distance of up to 2.4 km; however, a detection radius of 0.80 – 1.21 km was more common. Transmittered bats were never documented roosting in a man-made structure or with other transmittered bats. Distances traveled between capture sites and the roost tree identified the following day ranged from 97 to 4770 m ($\bar{x} = 1450.7 \pm 324.60$ se).

Seventy-four roost trees were identified (40 in 2006 and 35 in 2007). One roost was used in both years. Seventy-two roost trees were measured; the remaining two were located on private property and the landowner could not be contacted. The two trees on private property accounted for 2 bat days and were removed from any analyses that were associated with roost characteristics.

On 2 occasions (of 35) emergence counts revealed that the wrong tree had been identified during initial telemetry; this was noted and the correct roost tree was measured in further analysis. On 2 additional occasions, vegetation obstructed a clear view of the emergence and the tree could not be unequivocally confirmed; however, telemetry was assumed to have identified the correct roost and that tree was measured during analysis.

Characteristics of roost trees

Species

Eight tree species were utilized as roosts (Table 7). The species most commonly used were red maple *(Acer rubrum)*, shagbark hickory *(Carya ovata)*, American elm *(Ulmus americana)* and pin oak *(Quercus palustris)*, together comprising 75.7% of all roosts. If the number of bat days is used as a measure of importance, these species comprised 80.5% of all roosts. Chi-square analysis using Fisher's exact test revealed no significant difference in the selection of roost species between years ($p = 0.5817$). One living shagbark was used in both years and violated the assumption of independence; however, because this was just one occurrence out of 72 it was assumed that this did not change the test's outcome.

Status (living/dead)

One tree was removed from consideration because its two trunks were of different status and the trunk in which the bat roosted could not be determined. Of the remaining roosts, snags comprised 68.5% (50 of 73), while living trees comprised 17.8% (13 of 73) and declining trees represented 13.7% (10 of 73; Table 7). Only declining or dead *U. americana* , green ash (*Fraxinus pennsylvanica)*, *Q. palustris* and *Q. bicolor* were used as roosts, while most of the *C. ovata* utilized were living trees. Both living and non-living *A. rubrum* and black locust (*Robinia pseudoacacia*) were used as roosts.

Table 7. Species used as roost trees by reproductively active female Indiana bats *(Myotis sodalis)* at Great Swamp NWR, 2006-2007.

Tree species	Common name	Number of roosts	Number of trees live/declining/dead	Number of bat days
Acer rubrum	Red maple	20	3/6/10 [b]	31
Carya ovata	Shagbark hickory	13[a]	7[a]/1/5	22
Ulmus americana	American elm	12	0/0/12	32
Quercus palustris	Pin oak	11	0/0/11	18
Fraxinus pennsylvanica	Green ash	6	0/3/3	12
Robinia pseudoacacia	Black locust	6	2/0/4	7
Quercus bicolor	Swamp white oak	3	0/0/3	3
Quercus rubra	Northern red oak	1	1/0/0	1
Unknown	(Not measured)	2	0/0/2	2
		74	13/10/50	128

[a] One roost was used in both years.

[b] One *A. rubrum* was is not considered because its two trunks were of different status, and it was not known which trunk supported the roost.

Decay stage

The majority of roost trees (83.3%, or 60/72) were either in an early or mid-stage of decay (Table 8). If the number of bat days (126) is used as an indicator, these trees comprised 87.3% of roost trees used. Twenty-six roost trees (36.1%) were decay stage 1; these trees accounted for 34.1% of bat days. The 14 live trees (including 7 *C. ovata*) of this stage accounted for 14.3% of bat days (18/126) while the 12 declining and dead trees accounted for 19.8% of bat days (25/126). Thirty-four trees (47.2%) in decay stage 3 comprised 53.2% of all bat days (67/126).

DBH, Height, Canopy closure, and Bark remaining/exfoliating (Table 9)

Four roosts had multiple trunks at dbh and were measured as separate trees; however, the specific trunk used by the bat could not be confirmed. These multi-trunked trees were excluded from analyses of dbh. Mixed-model ANOVA revealed a significant difference in dbh between years ($p = 0.0034$). The mean dbh in 2006 was 42.1 cm (± 1.87 se; $\alpha = 0.05$; $n = 69$) and in 2007 was 40.5 cm (± 1.87 se; $\alpha = 0.05$; $n = 69$).

Two of the multi-trunked trees had equal trunk heights and were included in analysis of height; two with unequal trunk heights were excluded. Height of roost trees was significantly greater in 2006 (mixed-model ANOVA, $p = 0.0007$; $\alpha = 0.05$; $n = 71$). The mean height in 2006 was 21.2m (± 0.88 se); in 2007 it was 17.7m (± 0.88 se).

Canopy closure at the roost was not different among the cardinal directions ($p = 0.9978$ for 2006; $p = 0.5103$ for 2007) and as such these measurements were averaged. However, canopy cover was statistically different between years (mixed-model ANOVA; $\alpha = 0.05$; $p = 0.0033$; $n = 73$); in 2006 mean closure was 67.3% (± 3.41 se; $\alpha = 0.05$, $n = 73$) and in 2007 it

Table 8. Decay stage of tree roosts used by adult female Indiana bats (*M. sodalis*), 2006-2007.

Number of trees in each decay stage are shown (number of bat days in parentheses.)

			# of	Decay stage				
Tree species	Common name	Status	roosts	1	2	3	4	5
Acer rubrum	Red maple	live	4	4 (5)				
		declining	6	5 (9)		1 (3)		
		dead	10			9 (13)	1 (1)	
Carya ovata	Shagbark hickory	live	7[a]	7 (10)				
		declining	1	1 (3)				
		dead	5	1 (2)	3 (6)	1 (1)		
Ulmus americana	American elm	live	0					
		declining	0					
		dead	12			11 (31)	1 (1)	
Quercus palustris	Pin oak	live	0					
		declining	0					
		dead	11	3 (8)	1 (1)	5 (7)	2 (2)	
Fraxinus pennsylvanica	Green ash	live	0					
		declining	3	1 (2)		2 (2)		
		dead	3			3 (8)		
Robinia pseudoacacia	Black locust	live	2	2 (2)				
		declining	0					
		dead	4		3 (4)	1(1)		
Quercus bicolor	Swamp white oak	live	0					
		declining	0					
		dead	3	1 (1)		1 (1)	1 (1)	
Quercus rubra	Northern red oak	live	1	1 (1)				
		declining	0					
		dead	0					
TOTAL:			72	26 (43)	7 (11)	34 (67)	5 (5)	0

[a] One roost used in both years.

Table 9. Characteristics of roost trees used by adult female Indiana bats *(M. sodalis)*, 2006-2007. Means, p-values (significant = *; non-significant = NS), and standard errors are from ANOVA. Separate means (mm-ANOVA) are presented where a difference existed between years.

Parameter	p-value	2006	2007	Mean
DBH (in cm)	0.0034*	42.1 ± 1.87 (35)	40.5 ± 1.87 (34)	-
Height (in m)	0.0007*	21.1 ± 0.88 (37)	17.6 ± 0.88 (34)	-
Canopy Closure	0.0033*	67.3 ± 3.41 (39)	83.0 ± 3.63 (34)	-
% Bark Remaining	0.5692 NS	69.2 ± 4.14 (39)	72.8 ± 4.31 (34)	70.89 ± 3.59 (73)
% Bark Exfoliating	1.0000 NS	25.6 ± 4.95 (39)	25.5 ± 4.26 (34)	25.90 ± 3.31 (73)

was 83.0% (± 3.63 se; α = 0.05, n = 73). Fifty-six percent of roost trees had greater than 80% canopy closure and 79% had greater than 60% canopy closure (Fig. 7).

There was no significant difference in either the amount of bark remaining or amount of bark exfoliating between 2006 and 2007 (p = 0.5692 and 1.00, respectively; α = 0.05 and n = 72), so results were pooled. The average amount of bark remaining was 70.9% (±3.59se) and the average amount of bark exfoliating was 25.9% (±3.31se, range 0-95). When *C. ovata* was excluded from analysis, mean bark remaining was 64.9% (± 3.97 se) and mean bark exfoliating was 30.3 (± 3.73 se).

Roost type, directional exposure, emergence height

The point of emergence was identified for 26 roost trees (1 in 2006 and 25 in 2007); these points were assumed to represent the location of the roosting bat. Seven roost trees had multiple emergence points and a total of 34 emergence locations were identified. Bark was the predominant roost type (30/34); 3 cavities and one split were also used. Emergence locations showed no strong tendency for directional exposure, though East and South-facing emergence points outnumbered those of other directions (Fig. 8). Mean emergence height was 7.20m (± 0.56 se, range 2.0 – 14.75). Because emergence counts were personnel-limited in 2006, data are pooled and no between-year comparisons were made.

Characteristics of roost tree plots

A total of 3,149 trees ≥10cm dbh were measured from the 72 0.1 ha plots surrounding the roost trees. Plots overlapped on 14 occasions, totaling 4,294.99 m^2 (4 in 2006, 8 in 2007 and 2 between 2006 and 2007), or 5.99% of the total area measured. Trees occurring within these

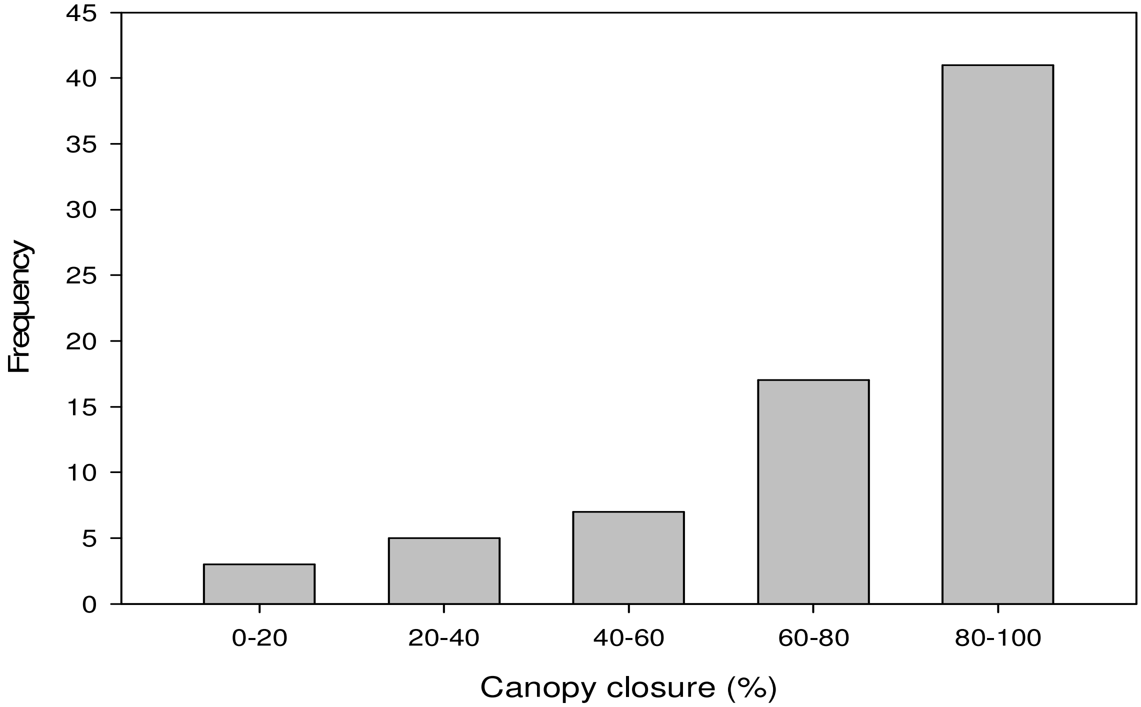

Figure 7. Frequency of roost trees among classes of canopy closure, 2006-2007.

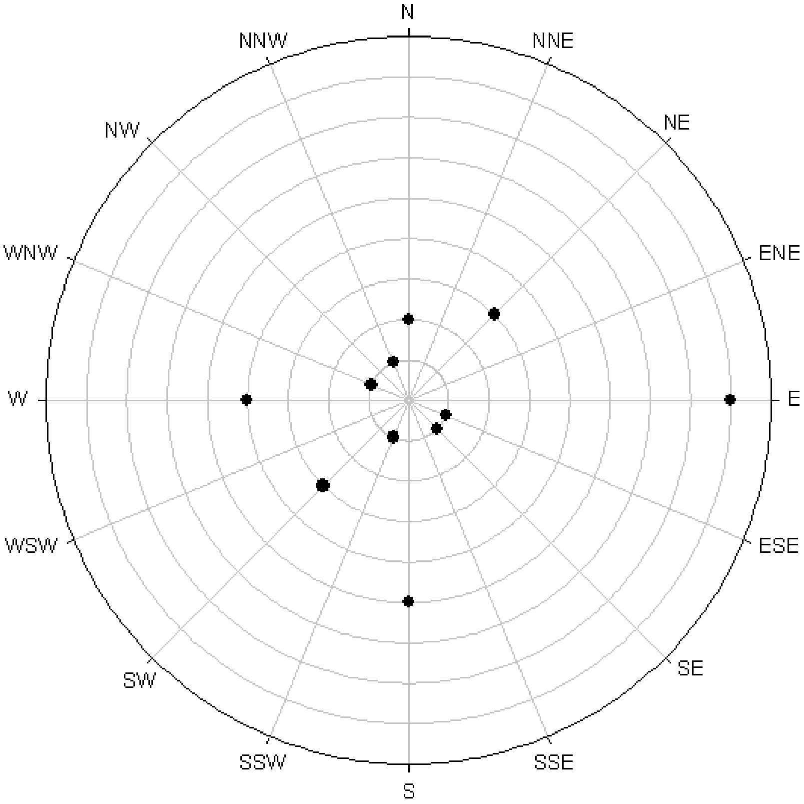

Figure 8. Directional exposure of emergence points identified at Great Swamp NWR, 2006-2007. Number of emergences at each orientation are shown; each concentric circle represents one occurrence. A total of 30 are shown.

overlaps were counted twice in the following analyses. Mean number of trees per plot was 43.7 (± 1.79 se, range 15-96).

Species

Twenty-nine tree species occurred in these plots, the most common of which were *A. rubrum* (43.0%), *F. pennsylvanica*, (12.9%), *Q. palustris* (12.2%), and *U. americana* (5.4%); all other tree species accounted for <5% each. Of these species, three (*A. rubrum, Q. palustris and U. americana*) were commonly used as roosts, as was *C. ovata* (although *C. ovata* accounted for only 2% of the trees measured within plots; Table 10).

DBH

One plot was removed from analysis of dbh since the roost tree was used in both years. The mean dbh of trees within the remaining plots was smaller in 2007 than in 2006 (two-sample t-test, p = 0.0001). In 2006 mean dbh was 25.0 cm (± 0.36 se) and in 2007 it was 23.2 cm (± 0.31 se). Overall, half of all plot trees (1,576/3,149; 50.1%) were less than 20cm dbh and 74.3% (2,341/3,149) were less than 30cm dbh (Fig. 9). Kurta (2005) states, "most trees favored by maternity colonies are greater than 22 cm in diameter"; 56.7% (1,785/3,149) were smaller than this.

Status (living/declining/dead)

One tree was thrown out of this analysis because of a data recording error. Chi-square analysis revealed no difference between years in the status of plot trees (p = 0.4524) and so results were pooled. Of the remaining 3,148 trees, 2452 (77.9%) were living, 241 (7.7%) were declining and 455 (14.5%) were dead. Of the species utilized as roost trees and occurring within the plots, *R. pseudoacacia* had the highest frequency of declining or dead trees (63.8%), followed by *F. pennsylvanica* (37.3%), *U. americana* (28.4%), and *A. rubrum* (19.2%, Table 10).

Table 10. Status of trees sampled within roost tree plots. Count data are shown. Named species were used as roost trees; species not used as roosts are grouped as “Other”.

	Total	Alive	Declining	Dead	% Declining or Dead
A. rubrum	1354	1094	109	151	19.20
F. pennsylvanica	405	254	95	56	37.28
Q. palustris	383	344	9	30	10.18
U. americana	169	121	3	45	28.40
R. pseudoacacia	141	51	6	84	63.83
Q. bicolor	83	75	-	8	9.64
C. ovata	64	61	-	3	4.69
Q. rubra	39	38	-	1	2.56
Other	510	414	19	77	15.10
TOTAL	3148	2452	241	455	

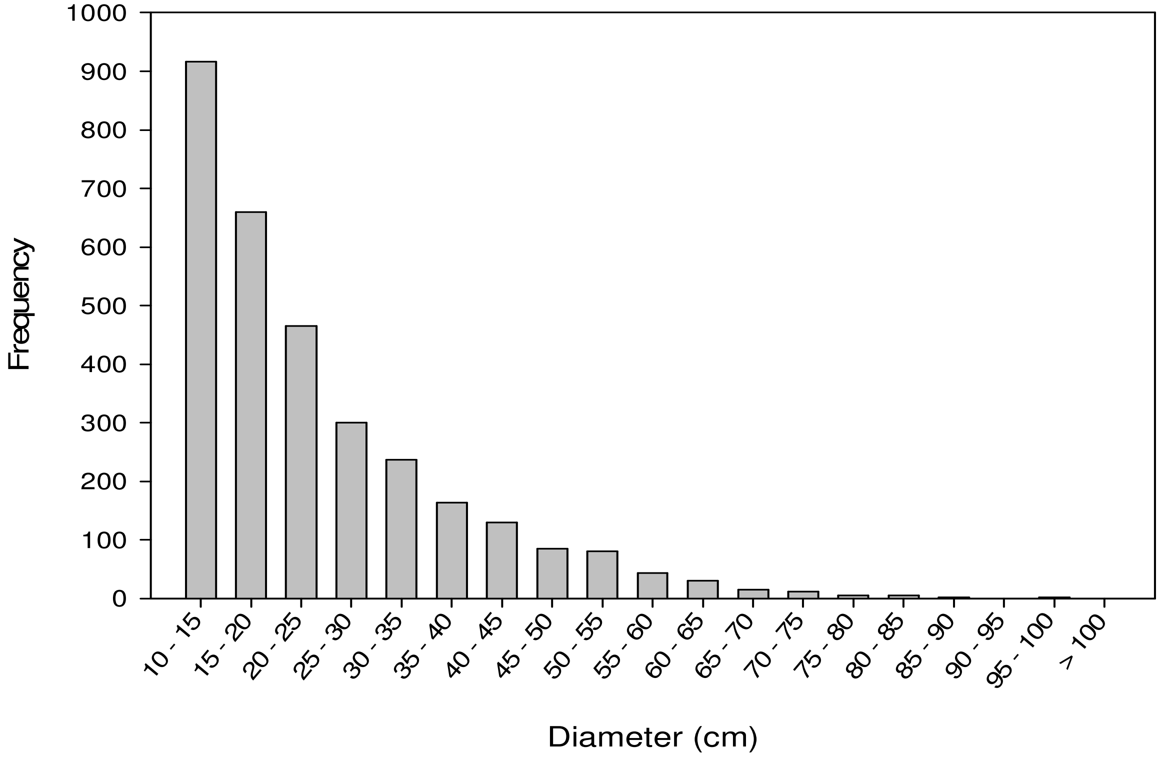

Figure 9. Frequency distribution of the dbh of trees within plots. Column height indicates the total number of individual trees.

Decay stage (1,2,3,4)

Trees that were declining and/or dead do not necessarily have a decay stage. If, for example, the bark was intact on a dead tree, then the minimum decay stage of >0% loose bark would not have applied. Similarly, a given tree could have more than one stage of decay: a tree could have both a broken top and the maximum amount of exfoliating bark. One tree was thrown out of this analysis because of a data recording error; of the 3,148 remaining trees occurring within plots, 669 of them (21.3%) were in some stage of decay (having either loose bark, no bark, a broken top, a decomposing stump or a combination of these factors). A total of 584 (18.5%) had loose bark; 24 (0.8%) had no bark; 290 (9.2%) had a broken top and 32 (1.0%) were considered a decomposing stump.

Amount loose bark

Of the 584 trees that had loose bark (not including 3 *C. ovata*), 341 ranked "low" for *M. sodalis* suitability based on the amount of loose bark (system devised by Gardner et al. 1991); 112 ranked "medium"; and 128 ranked "high" (Table 11). Based on the modified criteria for *C. ovata* suitability, an additional 14, 16 and 28 trees ranked low, medium and high, respectively. Of the species used as roosts, *A. rubrum, C. ovata* and *U. americana* had the greatest number of trees ranked "high" for suitability, followed by *R. pseudoacaia*, *F. pennsylvanica* and *Q. palustris*. *Carya ovata* had by far the greatest percent of trees in this category, distantly followed by *U. americana* and *R. pseudoacacia* (Table 11).

When the number of plot trees was converted to a per-ha density, the most abundant, highly suitable species include *A. rubrum* and *C. ovata*, followed by *U. americana*. These were the three species most commonly used as roosts in this study. Suitable *Q. bicolor* and *Q. rubra*

Table 11. Condition of non-roost trees located within plots. Species used as roost trees are separated out; non-roost species are grouped as "Other". Suitability refers to the ranking system devised by Gardner et al. (1991) and modified here. Percent of trees that fall within each category are shown in parentheses. x = exfoliating bark; c = cavities; s = splits.

Tree species	Suitability low		Suitability medium		Suitability high		No bark	Broken top	Decomposed stump	x	c	s
A. rubrum	130	(9.6)	47	(3.5)	58	(4.3)	3	119	10	235	73	101
F. pennsylvanica	91	(22.5)	37	(9.1)	15	(3.7)	-	60	1	143	20	17
Q. palustris	20	(5.2)	3	(0.8)	3	(0.8)	3	27	2	26	22	16
U. americana	17	(10.1)	4	(2.4)	23	(13.6)	1	15	5	44	13	11
R. pseudoacacia	35	(24.8)	14	(9.9)	19	(13.5)	-	16	2	68	20	25
Q. bicolor	6	(7.2)	1	(1.2)	-	(0.0)	1	6	-	7	1	2
C. ovata[1]	14	(21.9)	16	(25.0)	28	(43.8)	-	2	-	3	1	-
Q. rubra	1	(2.6)	-	(0.0)	-	(0.0)	1	-	-	1	-	-
Other	41	(8.0)	6	(1.2)	10	(2.0)	15	45	12	57	32	46
TOTAL	355		128		156		24	290	32	584	182	218

[1] *C. Ovata* suitability is based on dbh and not percent bark exfoliating.

Table 12. Concentration (number per ha) of tree species providing suitable roost habitat for *M. sodalis* at Great Swamp NWR. Species used as roost trees are separated out; non-roost species are grouped as "Other". Suitability refers to the ranking system devised by Gardner et al. (1991) and modified here.

	Suitability (number/ha)		
	low	medium	high
A. rubrum	18.1	6.5	8.1
F. pennsylvanica	12.6	5.1	2.1
Q. palustris	2.8	0.4	0.4
U. americana	2.4	0.6	3.2
R. pseudoacacia	4.9	1.9	2.6
Q. bicolor	0.8	0.1	0.0
Q. rubra	0.1	0.0	0.0
C. ovata[1]	1.9	2.2	3.9
Other	5.7	0.8	1.4
TOTAL	49.3	17.8	21.7

[1] *C. Ovata* suitability is based on dbh and not percent bark exfoliating.

(two species which did not provide high suitability) occur less frequently on the landscape and their use may be limited by availability (Table 12).

Presence of Exfoliating bark, Splits and Cavities (X, S, C)

Of the 3,149 trees in plots, 613 (19.5%) had either exfoliating bark (according to the definition used in this study), splits or cavities; 584 (18.6%) had exfoliating bark, 218 (6.9%) had splits and 182 (5.8%) had cavities.

Direction/distance from roost

The mean distance of all plot trees from the central roost tree did not differ between years (ANOVA, $p = 0.7286$; one plot was removed from analysis because the roost tree was used in both years) and was 11.8m (±0.07 se). Only 6.7% of trees (210/3149) occurred within 5m of the roost tree; 24.9% (784/3149) of trees were between 5-10m of the roost (Fig. 10). Trees were relatively uniform in distribution around the roost; the percent of trees in each of the 16 directions considered ranged from 5.1 – 7.6%.

Saplings

In 24 of 72 cases (33.3%) no saplings were present along the cardinal transects of the plot; plots with 0-1 saplings accounted for 54.2%; plots with 0-2 accounted for 61.1% and plots with 0-3 accounted for 72.2% of all plots. Of the 48 plots where saplings were present, musclewood (*Carpinus caroliniana*) was most frequently the dominant species (10/48, or 20.8%), followed by *F. pennsylvanica* (5/48 or 10.4%), *A. rubrum*, *F. grandifolia*, sweetgum (*Liquidambar styraciflua*) and *U. americana* (each 4/48 or 8.3%). Mixed-models ANOVA revealed a significant difference between year ($p = 0.0009$); mean number of saplings was 2.0 (± 0.38 se) in 2006 and 3.0 (± 0.38 se) in 2007.

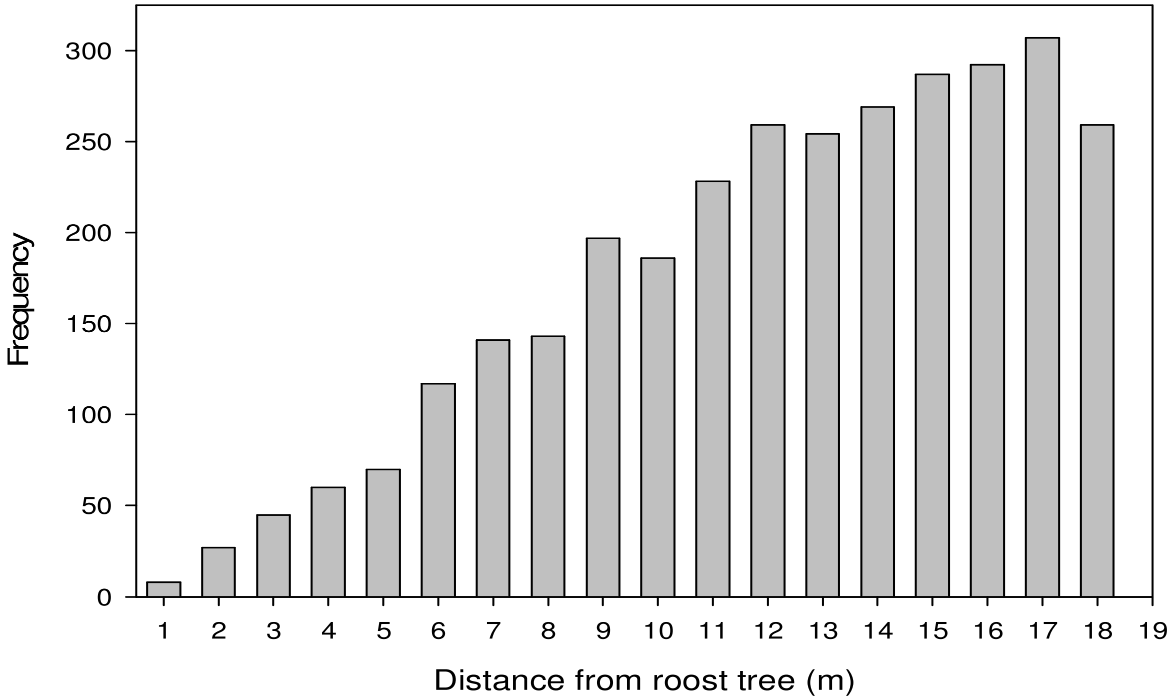

Figure 10. Frequency distribution of distances (in m) from the roost tree to other trees within plots. Column height indicates the total number of individual trees at each distance.

Table 13. Plot characteristics, 2006-2007. Data presented as mean ± se (n). Significant differences are indicated by *. For all comparisons, $\alpha = 0.05$. Results for DBH (plot trees) are from ANOVA; all others are from mm-ANOVA.

Parameter	p-value	2006	2007	Mean
DBH (cm)	0.0001*	25.0 ± 0.36 (1562)	23.2 ± 0.31 (1555)	-
Canopy Closure (plot edge, %)	0.0004*	63.9 ± 3.24 (39)	81.5 ± 3.47 (34)	-
Shrub coverage (%)	0.0004*	16.8 ± 3.01 (156)	29.2 ± 3.21 (136)	-
Saplings	0.0009*	2.0 ± 0.38 (39)	3.0 ± 0.38 (34)	-
Nearest tree:				
Height (m)	0.5512	17.8 ± 1.18 (39)	16.8 ± 1.25 (34)	17.4 ± 0.90 (72)
DBH (cm)	0.5682	24.7 ± 1.88 (39)	25.7 ± 1.93 (34)	25.4 ± 1.73 (72)
Distance from roost (m)	0.0008*	2.3 ± 0.19 (39)	2.9 ± 0.19 (34)	-

Nearest tree, Shrub coverage, and canopy closure

Trees nearest the roost were not found to differ in height or dbh (p=0.5512 and 0.5682, respectively) but did differ in distance from the roost tree (p = 0.0008, mm-ANOVA; Table 13). Mean height was 17.4m (± 0.90 se at $\alpha = 0.05$ and n = 71) and mean dbh was 25.4cm (± 1.73 se at $\alpha = 0.05$ and n = 71); one plot was thrown out of the analysis because the roost was used in both years. Mean distance to the roost was 2.3m (± 0.19 se; $\alpha = 0.05$; n = 73) in 2006 and 2.9 m (± 0.19 se; $\alpha = 0.05$; n = 73) in 2007. Height of the roost and nearest trees were different in 2006 but not in 2007 (p = 0.0466 and 0.5980 respectively; $\alpha = 0.05$). In 2006 roost height averaged 21.3m while the nearest tree averaged 17.3m (± 1.35se; $\alpha = 0.05$; n = 39); in 2007 roost height averaged 17.9m while the nearest tree averaged 17.1m (± 1.13 se; $\alpha = 0.05$; n = 34). DBH of the nearest tree was smaller than that of the roost in both years (2006 $\bar{x}$ = 23.0 ± 2.44 se, p < 0.0001; 2007 $\bar{x}$ = 27.3 ± 2.53 se, p = 0.0003). The location of the nearest tree exhibited no clear pattern: most frequently it was located to the South of the roost tree (11/65 or 16.9%), followed by North (8/65, 12.3%) and West (7/65, or 10.8%).

No significant within-year differences were found in shrub coverage among quadrants (p = 0.4875 for 2006 and 0.4781 for 2007) so results were pooled. There was, however, a significant difference in the amount of shrub cover between years (p = 0.004; $\alpha = 0.05$, n = 292 quadrants). Mean shrub cover in 2006 was 16.8% (± 3.01 se); mean shrub cover in 2007 was 29.2% (± 3.21 se).

No significant within-year differences in canopy closure at the plot edge were found among the four cardinal directions where readings were taken (p = 0.2349 for 2006; p = 0.8576 for 2007) and as such these measurements were averaged. In 2006, average canopy closure was 63.9% (± 3.24 se; $\alpha = 0.05$, n = 73) and in 2007 it was 81.5% (± 3.47 se; $\alpha = 0.05$, n = 73).

These are statistically different (p = 0.0004). There was no difference in canopy closure between the plot edge and the roost tree in either year (2006, p = 0.1975, 2007, p = 0.4873).

Distance to water

No significant difference between years was found and thus the data were pooled. The mean distance to water for roost trees was 88.2m (±18.16 se).

Roost occupancy

A total of 126 emergence counts were performed on 34 trees between June 5, 2006 and August 24, 2007; 121 counts on 31 trees were performed in 2007. Counts ranged from 0 to 252 ($\bar{x}$ 23.4 ± 3.25 se). Twenty counts resulted in zero bats exiting the roost (hereafter referred to as zero-counts); of the 106 non-zero emergence counts, an average of 27.8 bats exited each roost (± 3.71 se).

Multiple emergence counts were performed on 17 trees (Fig. 11), and 11 trees were monitored more than twice. Based on the criteria of use by 30 or more bats on more than one occasion (Callahan 1993), four "primary" roosts were identified during this study (Table 14). Tree W62507BA1 was first identified as a potential primary roost in 2006, when during netting a great number of bats were observed emerging from and returning to the roost. The tree was located less than 45m from each of two nets that captured 18 *M. sodalis* over two consecutive nights; one *M. sodalis* returned to the tree upon release. However, since the tree was not identified via radiotelemetry, it was not officially considered a roost until 2007, when it was identified as a primary tree. There was no significant difference between primary and alternate trees in any of the traits measured (Table 14). However, the number of bats emerging from these

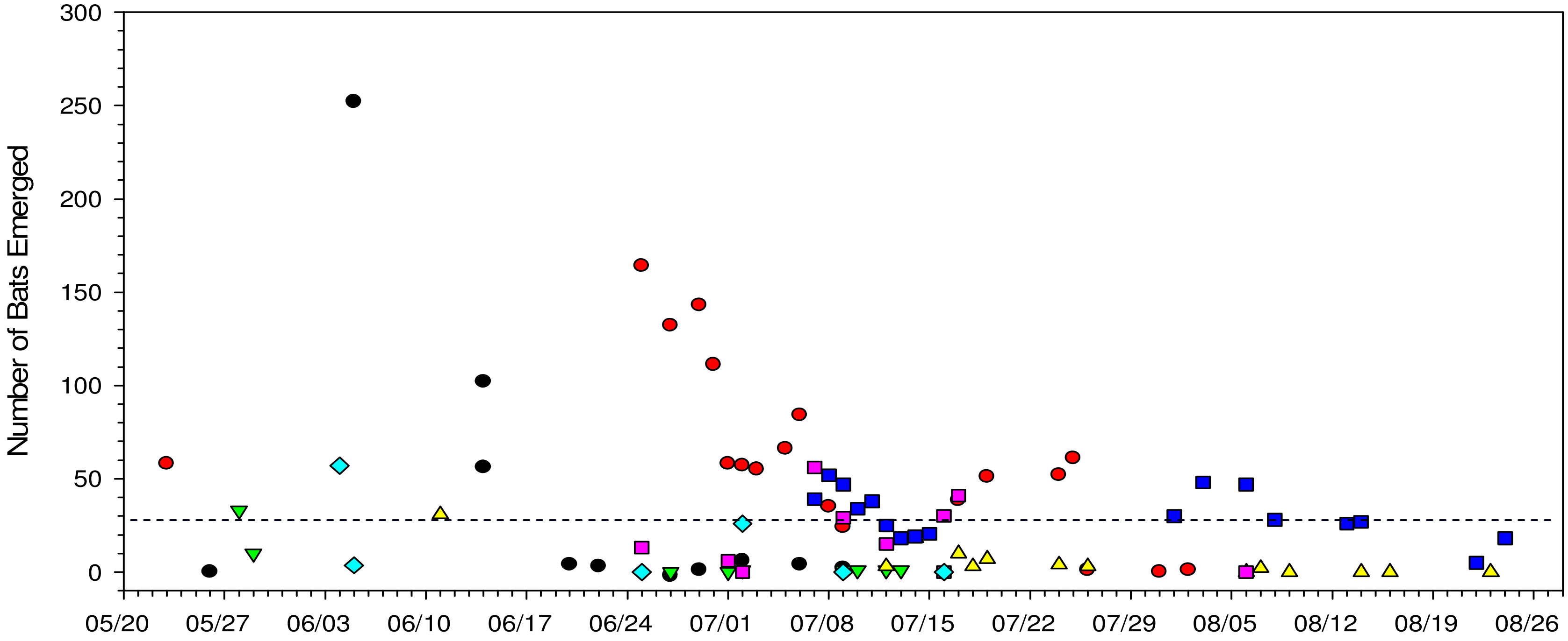

Figure 11. Emergence counts for roost trees observed on multiple occasions at Great Swamp NWR, 2007. Each symbol represents a different roost tree. Roost trees with two or more counts on or above the line were defined as primary roost trees.

Table 14. Characteristics and comparisons of primary and alternate roost trees identified during this study. The four primary roosts are listed individually. Emergence count data shown as mean (n); range below. Primary and alternate data are shown as mean ± se (n); range below.

	Primary roost trees						
Characteristic	M6506MK1	O52307MW1	O7707MW1	W62507BA1	Primary	Alternate	p-value
Species	*Q. palustris*	*Q. palustris*	*U. americana*	*C. ovata*	-	-	
DBH (cm)	68.8	52.9	40.0	57.5	54.8 ± 5.96 (4) 40.0 - 68.8	40.5 ± 1.91 (64) 16.3 - 86.6	0.0721
Height (m)	13.0	13.5	26.0	18.8	17.8 ± 3.02 (4) 13.0 - 26.0	19.6 ± 0.94 (66) 6.5 - 39.5	0.6544
Status	dead	dead	dead	dead	-	-	
Decay stage	4	3	3	2	-	-	
Canopy closure (%)	32.3	98.4	34.9	74.0	59.9 ± 16.00 (4) 32.3 - 98.4	75.4 ± 2.76 (68) 4.9 - 99.2	0.1990
Bark remaining (%)	5	20	70	100	48.8 ± 22.02 (4) 5 - 100	72.2 ± 3.56 (68) 1 - 100	0.1354
Bark exfoliating (%)	5	20	15	2	10.5 ± 4.21 (4) 2 - 20	26.8 ± 3.47 (68) 0 - 95	0.2619
Emergence counts	154.3 (2) 56 - 252	62.7 (19) 0 - 164	30.7 (17) 5 - 52	18.0 (11) 0 - 56	45.3 ± 6.71 (49) 0 - 252.67	9.5 ± 1.93 (77) 0 - 102	<0.0001
Roost type	split	cavity, bark	bark	bark	-	-	-
Roost exposure(s)	W, E	S, E, NNW	E	all sides	-	-	-

trees was different (p = 0.0001); primary trees had a mean of 45.3 bats (± 6.71, $\alpha = 0.05$, n = 49) and alternate trees had a mean of 9.5 bats (± 1.93, $\alpha = 0.05$, n = 77).

Repeated measures analysis revealed that date was the only characteristic to influence emergence count ($p<0.0001$; see discussion page 99). Non-significant characteristics included roost species (p=0.364), dbh (p=0.507), canopy closure (p=0.6603), amount of bark remaining (p=0.1303), amount of bark exfoliating (p=0.7172), and tree height (p=0.9137). Each of these characteristics showed a significant interaction with date. (Date-by-species effect, p = 0.0005; date-by-dbh, p = 0.0029; date-by-canopy closure, p = 0.0005; date-by-bark remaining, p = 0.0012; date-by-bark exfoliating, p = 0.003; date-by-height, p = 0.0029). Date likely drove this significance (Fig. 12-17).

Roost fidelity

Using the method of Kurta et al. (1996, 2002), fidelity estimates for individual bats ranged from 1.0 to 9.0 with a mean of 3.1; 48 roost switches over 111 bat days yielded an overall estimate of 2.3. After modifying this method slightly (adding 1 to the number of observed switches), fidelity estimates ranged from 1.0 to 4.5 ($\bar{x} = 1.8$). Using Britzke et al.'s method (which includes information from Day 1), estimates ranged from 1.0 to 5.0 with a mean of 2.0 (Table 15).

The mean number of trees used by bats was 3.2; there was no difference in the number of trees used by bats of each reproductive status (ANOVA, p = 0.9351). Both the number of roost switches and the number of trees used was positively correlated with the number of days a bat was located (Rho = 0.72, n = 22, p = 0.0002; Rho = 0.78, n = 24, $p < 0.0001$ for number of switches and trees respectively).

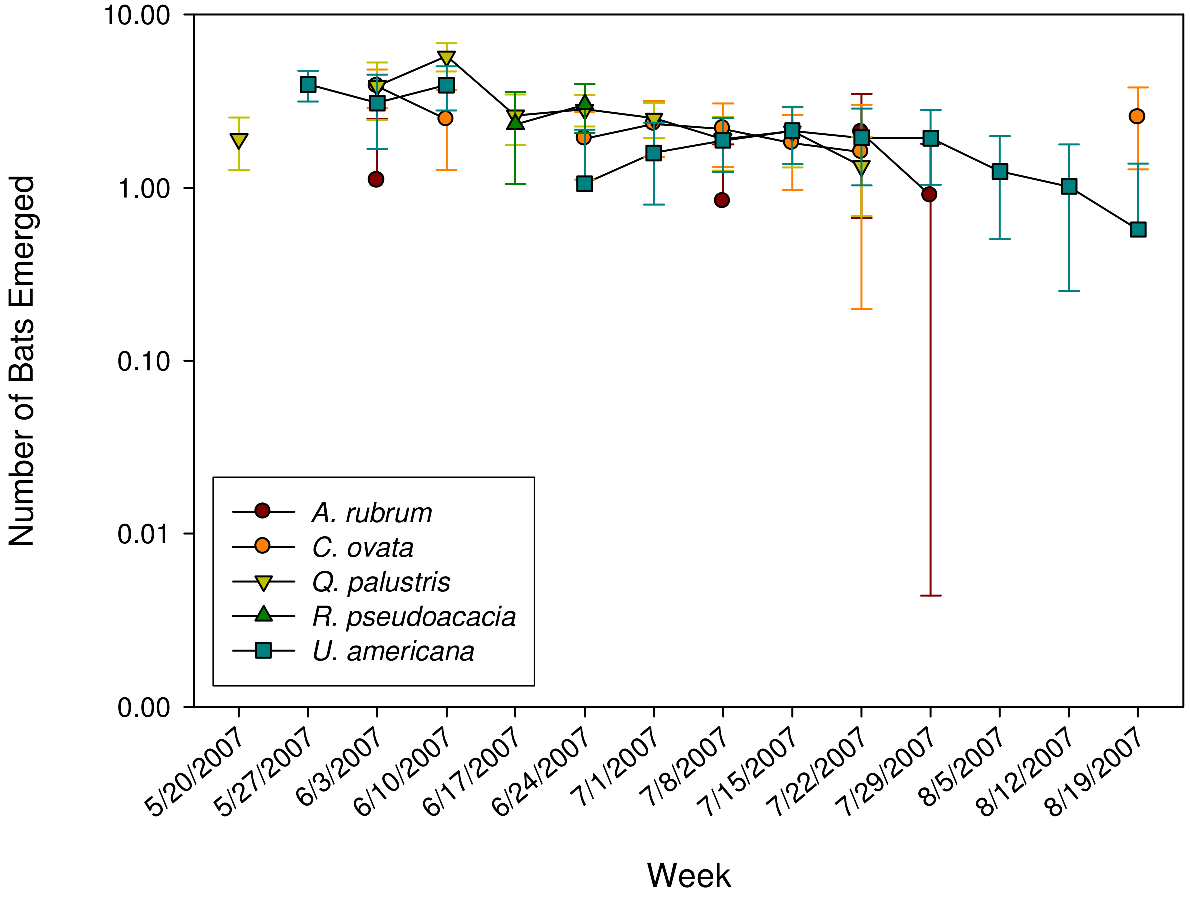

Figure 12. Number of bats emerged from roost trees (mean ± 1 se) by date and species as estimated by repeated measures analysis. Due to the existence of zero-counts, 1 was added to each count before its log-transformation. Missing data are represented by a disconnect in the category's line.

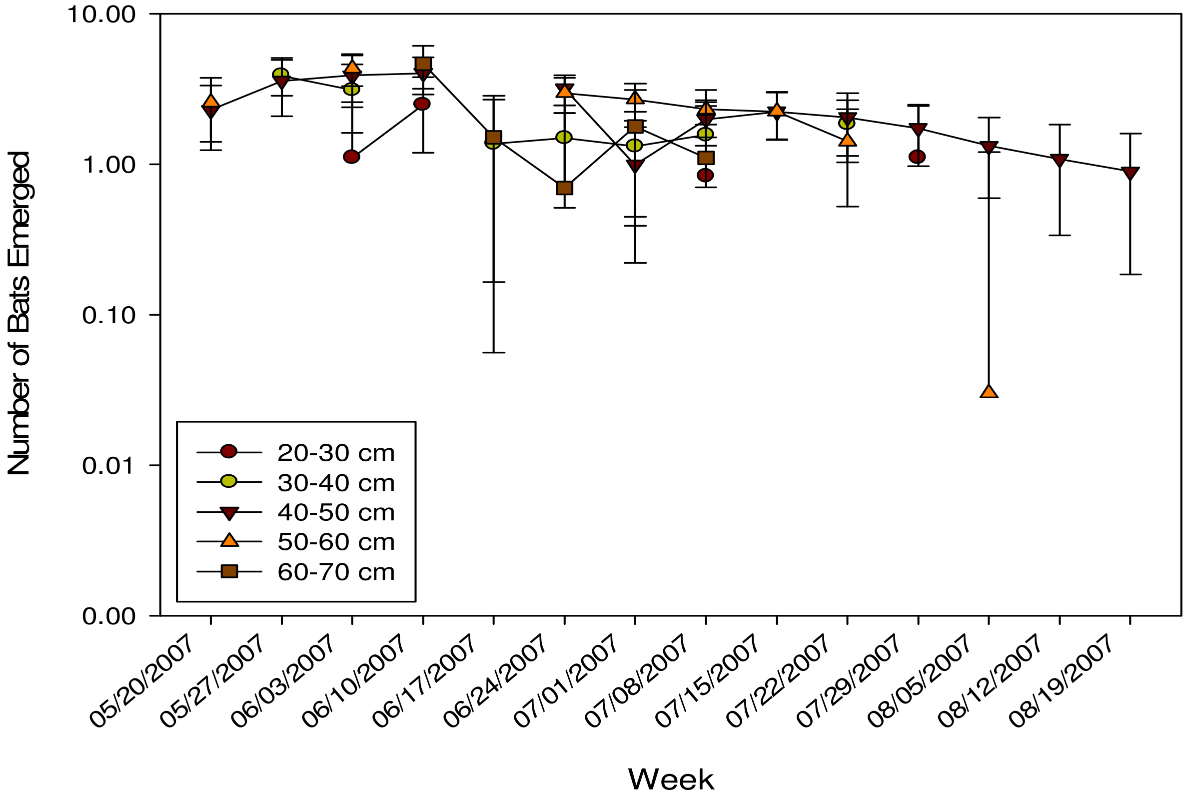

Figure 13. Number of bats emerged from roost trees (mean ± 1 se) by date and dbh as estimated by repeated measures analysis. Due to the existence of zero-counts, 1 was added to each count before its log-transformation. Missing data are represented by a disconnect in the category's line.

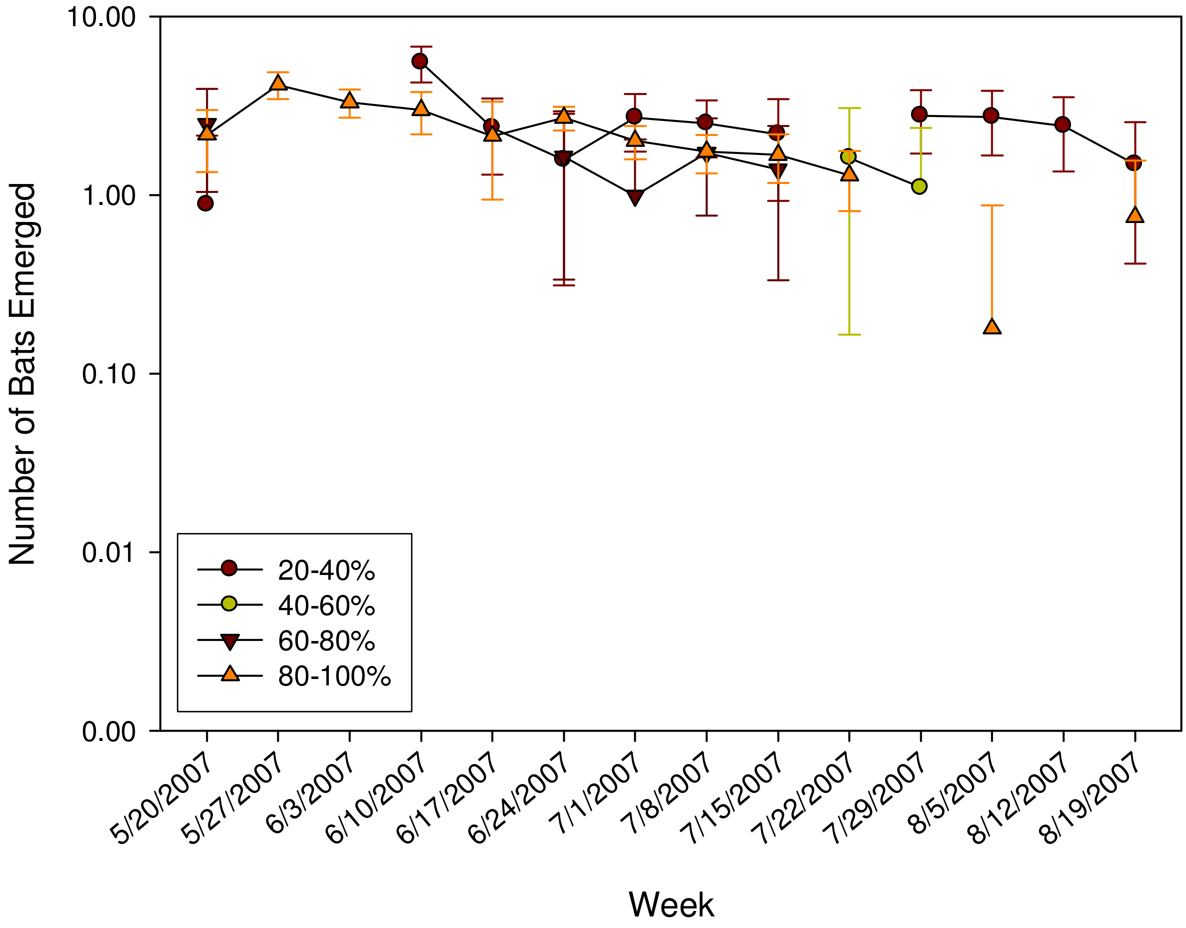

Figure 14. Number of bats emerged from roost trees (mean ± 1 se) by date and canopy closure as estimated by repeated measures analysis. Due to the existence of zero-counts, 1 was added to each count before its log-transformation. Missing data are represented by a disconnect in the category's line.

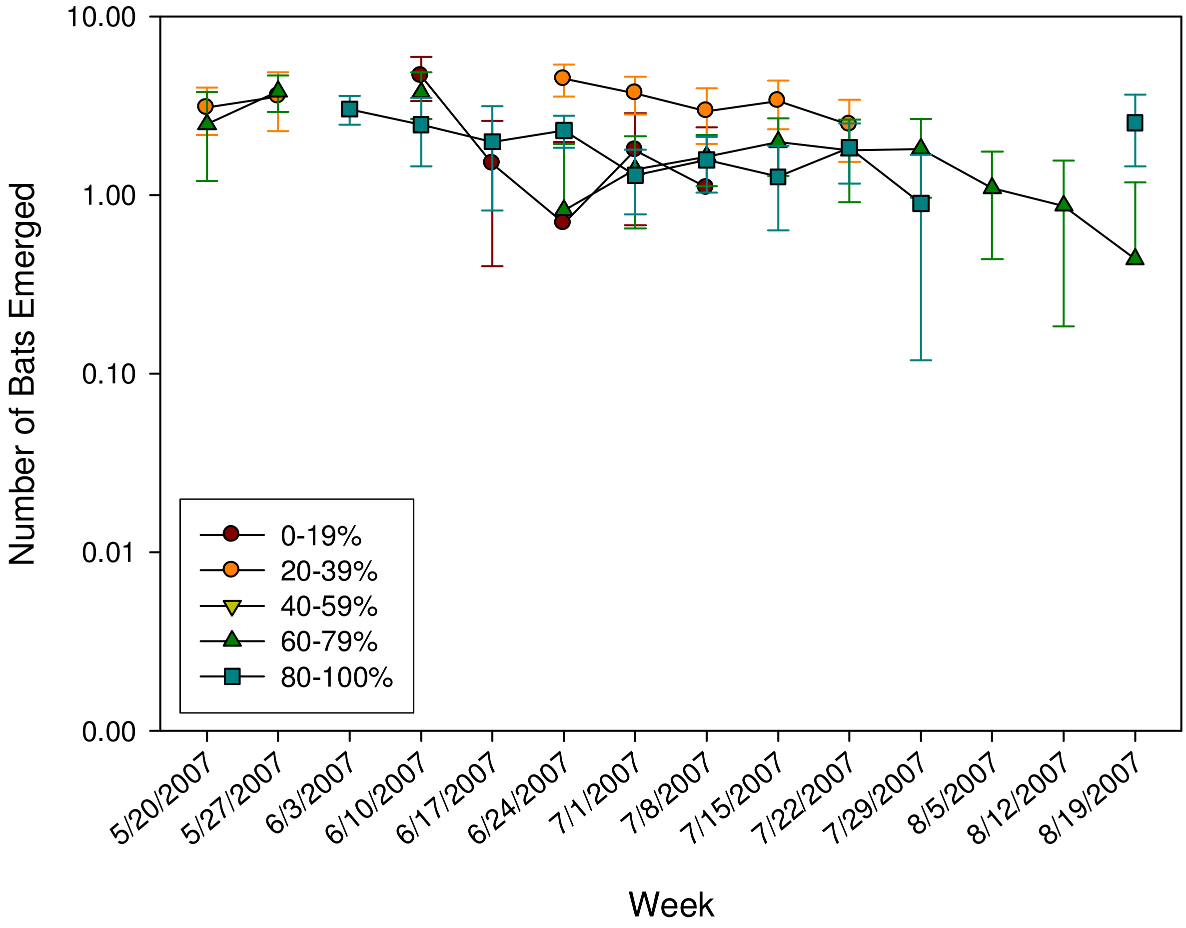

Figure 15. Number of bats emerged from roost trees (mean ± 1 se) by date and amount of bark remaining as estimated by repeated measures analysis. Due to the existence of zero-counts, 1 was added to each count before its log-transformation. Missing data are represented by a disconnect in the category's line.

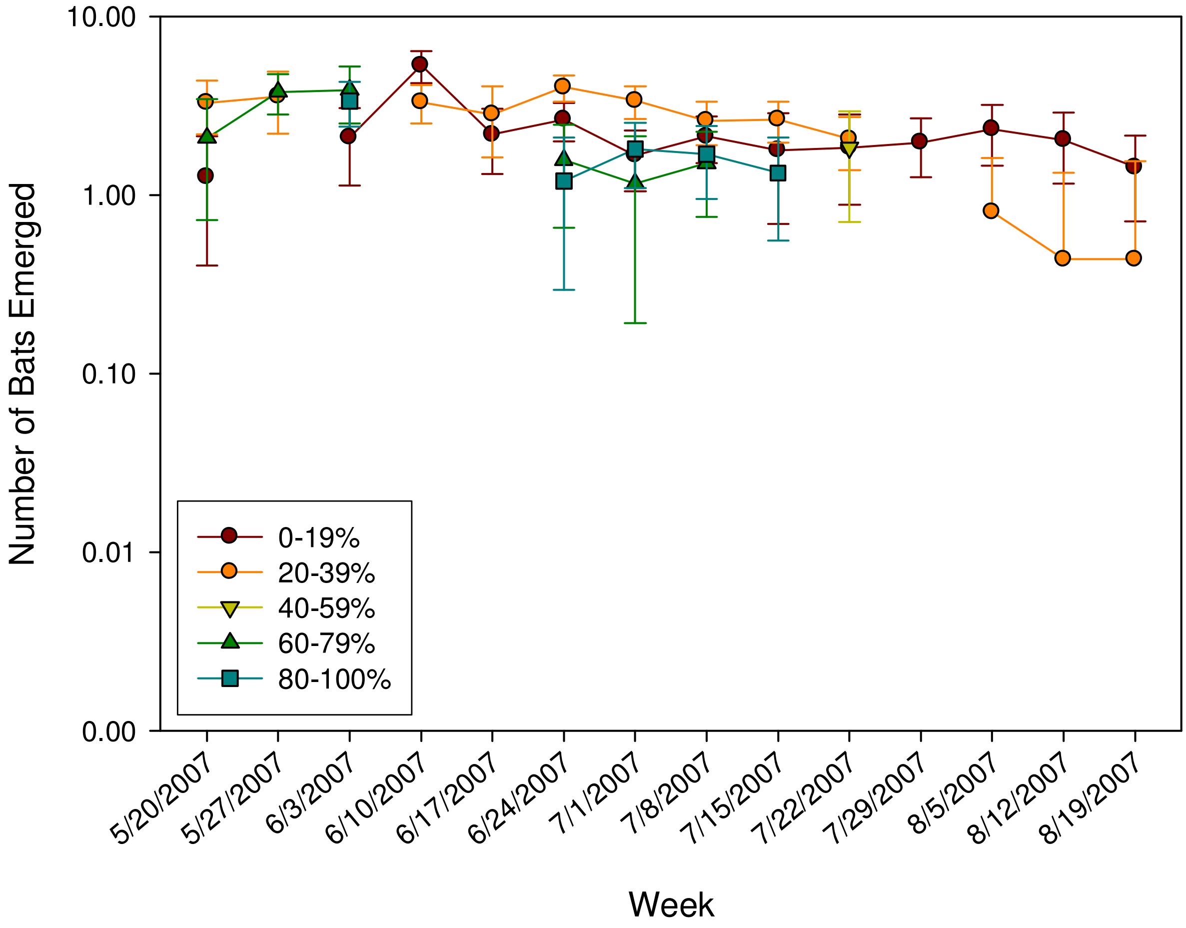

Figure 16. Number of bats emerged from roost trees (mean ± 1 se) by date and amount of exfoliating bark as estimated by repeated measures analysis. Due to the existence of zero-counts, 1 was added to each count before its log-transformation. Missing data are represented by a disconnect in the category's line.

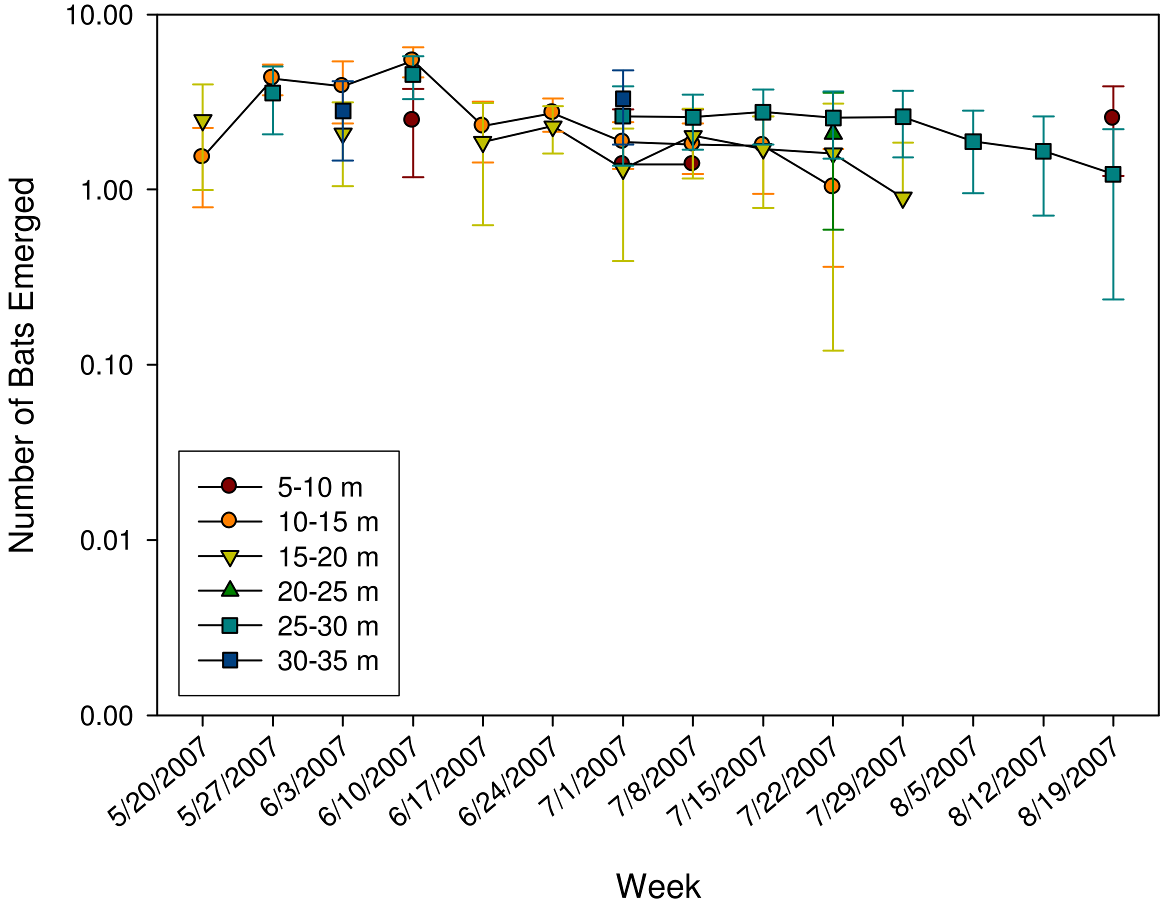

Figure 17. Number of bats emerged from roost trees (mean ± 1 se) by date and roost tree height as estimated by repeated measures analysis. Due to the existence of zero-counts, 1 was added to each count before its log-transformation. Missing data are represented by a disconnect in the category's line.

Table 15. Roost fidelity estimates for female Indiana bats *(M. sodalis)* at Great Swamp NWR, calculated using the methods of Kurta et al. 1996, Britzke et al. 2006, and a method modified from Kurta's in which 1 is added to the denominator. Dashes indicate where insufficient information prevented an estimate.

Bat ID	Frequency	Reproductive status	Kurta	Britzke	Kurta modified
NJDFW 25147	164.306	PL	7.00	5.00	3.50
NJDFW 25158	164.203	L	-	3.00	2.00
NJDFW 25165	164.103	L	1.80	1.43	1.50
NJDFW 25166	164.054	L	1.50	1.00	1.00
NJDFW 25169[a]	164.405	P	1.33	1.25	1.00
NJDFW 25169[a]	164.155	PL	-	-	-
NJDFW 25171	164.255	PL	-	1.00	-
NJDFW 25175	165.021	PL	7.00	2.67	3.50
NJDFW 25176	164.554	NR	1.50	1.20	1.20
NJDFW 25179	164.304	L	1.60	1.29	1.33
NJDFW 25183	165.060	L	1.50	1.40	1.20
NJDFW 25187	164.506	L	3.00	3.00	2.00
NJDFW 25199	164.204	NR	-	1.00	-
NJDFW 25218	165.101	L	8.00	3.00	4.00
NJDFW 25221	165.141	PL	-	-	-
NJDFW 25226	164.430	PL	1.00	1.06	0.94
NJDFW 25231	164.356	P	1.00	1.00	0.67
NJDFW 25233	164.461	P	1.50	1.33	1.00
NJDFW 25235	164.580	L	-	3.00	2.00
NJDFW 25239	164.620	L	-	-	-
NJDFW 25240	164.006	L	4.00	1.67	2.00
NJDFW 25241	164.769	L	1.00	1.00	0.67
NJDFW 25244	164.718	L	9.00	5.00	4.50
NJDFW 25248	165.101	NR	1.00	1.00	0.80
mean			3.1	2.0	1.8
se			0.68	0.28	0.27
n			17	21	19

[a] This bat was fitted with a transmitter on 2 occasions.

Landscape patterns

Distance/direction to previous roosts

Distance to the nearest previous roost (NPR) is a measure of the dispersion of roosts previously used by an individual bat. Mixed-models ANOVA was used to test for differences between years while correcting for individual bat behavior (distances were first log-transformed to normalize the residuals). Mean distance was 571.4m (± 411.91 se) in 2006 and 1205.3m (± 380.06 se) in 2007. These did not differ significantly ($p = 0.28$) and data were pooled. Mean distance to the NPR was thus 891.3m (±299.51 se); there was no difference in the distance moved by bats of different reproductive status (p ranged from 0.1393 to 0.8865, mm-ANOVA).

Mean distance between consecutive roosts is a measure of the successive roost-roost distances moved by an individual bat and may more accurately reflect bat behavior than distance to the NPR. Mixed models ANOVA was used to correct for individual bat behavior (following log transformation), and revealed a 2006 mean of 619.7m (± 408.81 se) and a 2007 mean of 1207.9m (± 414.00 se). These are not significantly different ($p = 0.33$) and data were pooled. Mean distance to consecutive roosts was thus 1003.4m (± 299.98 se). This is very similar to the mean NPR distances, thus it is not surprising that there was no significant difference between the two measures ($p = 0.36$). Furthermore, there was no difference in the distances moved by bats of different reproductive status (p ranged from 0.1560 to 0.7905, mm-ANOVA).

A third measure is distance to the nearest neighboring roost (NN) – this indicates dispersion of suitable roosts on the landscape and may reflect the “choices” available to *M. sodalis,* whereas the other measures reflect an individual bat’s behavior. Mean distance to the nearest roost was 147.5m (± 60.46 se) in 2006 and 438.4m (± 111.81 se) in 2007. These data were log-transformed prior to analysis. Roosts were located significantly farther apart in 2007 as compared to 2006 (ANOVA, p = 0.0003). There was also a significant difference in 2006 between the distance to NN (back-transformed mean = 52.3 m +66.7 se, -44.7 se) and to consecutive roosts (back-transformed mean = 202.9 m +257.2 se, -156.0 se; p = 0.008, Tukey's adjustment). In 2007 there was no difference between the distance to the NN and either consecutive distance or NPR (p = 0.3780, Tukey's adjustment).

Characteristics of random trees

Species

Nine tree species were represented among the 30 random trees, the most common of which were *A. rubrum* (16/30), *Q. palustris* (5/30) and *L. styraciflua*, (3/30). Other species represented among random trees included *C. caroliniana*, *F. pennsylvanica,* tulip poplar *(Liriodendron tulipifera)*, white oak *(Quercus alba)*, blackgum *(Nyssa sylvatica)* and black ash *(Fraxinus nigra)*; each of these occurred once. Chi-square analysis revealed a significant difference in the occurrence of these species as compared to roost trees; *A. rubrum* was used by bats less, and *C. ovata* and *U. americana* were used more than would be expected (p < 0.0001).

Status (living/dead)

Among random trees, snags comprised 6.7% (2/30), while living trees comprised 86.7% (26/30) and declining trees represented 6.7% (2/30). Chi-square analysis revealed a significant difference in the proportion of live, declining and dead trees as compared to roosts (p < 0.0001). Bats used dead trees far more, and living trees far less than would be expected from the random data. Declining trees were also used more than would be expected.

Decay stage

The majority of random trees (93.3%, or 28/30) were in good health with the minimum stage of decay; 6.7% (2/30) were in mid-stage decay. This was significantly different than the proportions in which these classes were represented among roost trees (Chi-square, $p < 0.0001$). Bats used roosts in the earliest stage of decay much less, and trees in mid-stage decay much more than would be expected from the random data.

DBH, Height, Canopy closure, and Bark remaining/exfoliating

Mean dbh among random trees was 21.1cm (± 2.33 se, range 10.2 – 63.6); this was significantly smaller than roost tree dbh in both years (ANOVA $p < 0.0001$).

Mean height among random trees was 15.1 m (± 1.10 se) and was significantly shorter than 2006 but not 2007 roost trees (ANOVA $p = 0.0027$).

Canopy closure at the roost was not different among the cardinal directions ($p = 0.5963$) and as such measurements were pooled. Canopy closure at the random tree averaged 94.1% (± 0.01 se, range 72.7 – 99.2) and was significantly greater than that of 2006 but not 2007 roost trees (ANOVA $p < 0.0001$).

Among all random trees, mean amount of bark remaining was 98.9% (± 0.56 se, range 90-100); this was significantly greater than the amount of bark remaining on roost trees ($p < 0.0001$). (*C. ovata* was excluded from this analysis, although the species was not represented among random trees). Mean amount of bark exfoliating was 0.93% (± 0.51 se, range 0-10); this is significantly less than the amount on roost trees ($p < 0.0001$).

Characteristics of random tree plots

A total of 1,757 trees ≥10 cm dbh were measured from the 30 0.1 ha plots surrounding the random trees. Mean number of trees per plot was 58.6 (± 5.00 se, range 21-115) and was greater than the number of trees within roost plots ($p = 0.0009$).

Species

Twenty-two species occurred in random plots, the most common of which were *A. rubrum* (59.7% or 1,049/1,757), *F. nigra* and *Q. palustris* (each 9.5% or 167/1,757) and *F. pennsylvanica* (6.7% or 118/1,757). All other species accounted for <5% each.

DBH

Mean dbh of trees occurring within the plots was 20.0 cm dbh (± 0.26 se, range 10-110) and was significantly smaller than mean dbh of trees in roost plots in both years (ANOVA $p < 0.0001$). Among all trees, 64.1% (1,127/1,757) were less than 20 cm dbh and 86.8% (1,525/1,757) were less than 30 cm dbh; 70.0% (1,230/1,757) were smaller than 22 cm dbh.

Status (living/dead)

Among all plot trees, 84.6% (1,487/1,757) were living, 6.9% (121/1,757) were declining and 8.5% (149/1,757) were dead. Chi-square analysis revealed a significant difference in the number of trees of each status as compared to roost tree plots ($p < 0.0001$). Snags were more prevalent within roost plots (and live trees less abundant) than would be expected from random plot data; the occurrence of declining trees was about the same.

Decay stage

Among all plot trees, 12.0% (211/1,757) were in some stage of decay: 9.6% (169/1,757) had loose bark (this does not include *C. ovata*); 0.3% (5/1,757) had no bark; 6.3% (110/1,757) had a broken top and 0.9% (15/1,757) were considered a decomposing stump. Due to a lack of independence (each tree could fit more than one of these descriptions), no statistical comparisons to roost plot trees were made.

Amount loose bark

Of the 169 trees that had loose bark and the 13 *C. ovata* that qualified (system devised by Gardner et al. 1991 and revised here), 6.6% (116/1,757) ranked “low” for *M. sodalis* suitability; 1.8% (31/1,757) ranked “medium”; and 1.9% (34/1,757) ranked “high”. Chi-square revealed a significant difference in the number of trees in each category as compared to roost tree plots ($p < 0.0001$); more suitable trees occurred within roost plots than would be expected based on the random data. However, chi-square analysis revealed no difference between random and roost plots in the number of trees of each species (per ha) that qualified as highly suitable ($p = 0.7022$).

Presence of exfoliating bark, splits and cavities

Among all plot trees, 13.7% (241/1,757) had either exfoliating bark, splits or cavities; 9.7% (170/1,757) had exfoliating bark, 4.0% (70/1,757) had splits and 5.5% (97/1,757) had cavities. Due to a lack of independence (each tree could have more than one of these traits), no statistical comparisons to roost plot trees were made.

Direction/distance from roost

The mean distance of all plot trees from the central tree was 11.6 m (± 0.10 se, range 0.43-17.8) and was not different than the same measure in roost tree plots ($p = 0.1570$).

Saplings

In 23.3% of plots (7/30) no saplings were present along the cardinal transects of the plot; plots with 0-1 saplings accounted for 43.3% (13/30); plots with 0-2 accounted for 60% (18/30) and plots with 0-3 accounted for 67.7% (20/30) of plots. Of the 23 plots where saplings were present, *A. rubrum* was most frequently the dominant species (6/23), followed by downy serviceberry *(Amelanchier arborea*, 4/23*)*. The mean number of saplings was 4.5 (± 1.41 se, range 0-40) and was not different than the number within roost tree plots in either year (ANOVA $p = 0.1299$).

Nearest tree, shrub coverage and canopy closure

Mean height of the nearest tree was 16.3 m (± 1.32 se, range 1.92-34.75) and mean dbh was 22.3 cm (± 2.04); neither of these varied from the equivalent measure within roost plots (height $p = 0.4801$; dbh $p = 0.3622$). Mean distance from the central tree was 2.3 m (± 0.24 se, range 0.2-5.0) and did not differ from the equivalent distance in roost tree plots ($p = 0.3172$). Trees nearest the random tree were not found to differ in either height or dbh as compared to the random tree ($p = 0.5035$ and $p = 0.6989$ respectively).

No significant difference in canopy closure at the plot edge was found among the four cardinal directions where readings were taken ($p = 0.5114$) and data was pooled. Mean canopy closure at the plot edge was 88.8% (± 0.03) and was different than that of the roost in 2006 but not 2007 (ANOVA $p < 0.0001$). As was the case within roost plots, there was no difference in canopy closure between the plot edge and the random tree ($p = 0.0651$).

Distance to water

Mean distance to water was 257.2m (± 58.79 se, range 0-1138) and was significantly greater than that for roost trees ($p = 0.0005$).

Discussion

Characteristics of roost trees

Emergence counts in 2007 revealed that 2 of 35 (5.7%) roost trees were incorrectly identified during initial telemetry; this gives some sense of the rate of misidentification that may have occurred in 2006 when limited staffing prevented such verification. However, both cases of misidentification occurred at a distance of < 2m, which instills confidence that the vast majority of 2006 roosts were correctly identified.

Roost trees were generally dead *A. rubrum*, *C. ovata*, *U. americana* or *Q. palustris* in early or mid-stage decay with a mean dbh between 40 and 42 cm, and occurred in areas of high canopy closure (>60%). Mean bark cover and exfoliating bark were 70.9 and 25.9% respectively, and though Gardner et al.'s system (1991) was not used in the field to categorize suitability of roost trees, based on the amount of exfoliating bark they generally achieved "high suitability." Bats nearly always roosted underneath exfoliating bark, and emerged from a mean height of 7.2m. Canopy closure, height and dbh of the roost tree were significantly different between years, but always fell within the range of what has been observed elsewhere (Table 16).

Of the four primary trees identified during this study, 3 occurred on along a habitat edge and received high solar exposure. Roost M6506MK1 was situated along the interface of a marsh/bottomland floodplain habitat; O7707MW1 was located on the edge of a marsh; and W62507BA1 occurred in a narrow strip of trees sandwiched between Great Brook and open fields. Roost O52307MW1 was located approximately 23m into a forest that bordered a residential property (Fig. 18).

Characteristics with significant differences between years

While this is the first study to document a significant difference in canopy cover, height and/or dbh between field seasons, the variability exhibited by this and other studies indicate that the Indiana bat is somewhat flexible in its requirements for these traits on the basis of seasonal changes, habitat differences across its range, or other favorable attributes of the roost. For

Table 16. Roost parameters of adult female and/or juvenile Indiana bats (*M. sodalis*) in various studies (adapted from Kurta 2005 and U.S. Fish and Wildlife Service 2007, and updated by Pruitt 2008 pers. comm.). Data presented as means (n) rounded to the nearest whole number. Values from this study reflect overall means, even though significant differences may have existed between years.

Location/parameter	***Diameter of tree (cm)***	***Height of tree (m)***	***Height of roost (m)***	***Bark remaining (%)***[a]	***Canopy cover (%)***	***Reference***
Illinois	39 (47)	18 (47)	10 (47)	47 (47)	36 (47)	Carter 2003
Illinois	37 (48)					Gardner et al. 1991
Illinois	56 (1)	16 (1)	5 (1)			Kurta et al. 1993b
Indiana	44 (63)	26 (63)	10 (46)		67 (44)	Whitaker et al. 2007
Indiana	62 (17)					Whitaker and Brack 2002
Kentucky (Fort Knox)	38 (12)	17 (13)	10 (10)			Hawkins et al. 2008
Kentucky (Spencer Co.)	52 (24)	16 (24)	7 (12)			Hawkins et al. 2008
Michigan	41 (23)	25 (23)	10 (23)		0-20 (23)[b]	Foster and Kurta 1999; Kurta et al. 1996
Michigan	42 (38)	18 (38)	10 (34)		31 (35)	Kurta et al. 2002
Michigan	34 (14)	20 (14)	10 (14)	50 (14)	58 (14)	Winhold 2007
Missouri	54 (38)			73 (21)	67 (38)	Callahan 1993; Callahan et al. 1997
Missouri	37 (6)	18 (6)				Davidson 2007
New Jersey	**41(68)**	**19 (70)**	**7 (30)**	**71 (72)**	**75 (72)**	**This study**
New York	34 (24)		9 (22)		30 (24)	Mann et al. 2008
New York, Vermont[c]	46 (31)	19 (34)				Britzke 2003
New York, Vermont	48 (50)	21 (50)	7 (18)			K. Watrous, pers. comm. 2008
North Carolina, Tennessee	46 (8)	18 (8)		46 (18)		Britzke et al. 2003
Ohio	38 (2)	21 (1)				Belwood 2002
Pennsylvania	28 (5)	20 (5)	8 (5)	51 (5)		Butchkoski and Hassinger 2002
Vermont	50 (20)			77 (13)	88 (20)	Palm 2003
Average [d]	43 (27)	20 (27)	9 (22)	59 (27)	52 (35)	
Number of studies	21	16	13	7	9	
Number of trees	566	424	287	190	317	

Table 16, continued.

[a] Total bark on tree, not just loose and peeling.
[b] A liberal value of 20% was used when calculating the overall mean.
[c] Trees were located primarily in April and early May; all other studies were mid-May to mid-August.
[d] Calculations of overall average and SE used the unweighted means from the various studies. Weighting each study, based on the number of trees, gave very similar results.

Figure 18. Primary roost trees identified at Great Swamp NWR. Clockwise from top left: M6506MK1, O52307MW1, W62507BA1, O7707MW1.

example, Gumbert (2001) found that Indiana bats selected trees with lower canopy cover in spring as compared to summer and autumn, while Foster and Kurta (1999) found canopy cover to be bi-modal (either 0-20% or 81-100%). Elsewhere, mean reported measures range from < 20% to 88% for canopy closure (Foster and Kurta 1999, Palm 2003); 17.5 to 25.1m for height (Carter and Feldhamer 2005, Kurta et al. 1996); and 26.0 to 63.6 cm for dbh (Butchkoski and Hassinger 2002, Whitaker and Brack 2002). Even though these variables differed significantly by year at Great Swamp, the means for each year fall within the range of reported values (Table 16). As such, the differences could be an arbitrary result of variation in individual bat behavior, or real and caused by a change in the environment (such as weather). The former is likely given the consistency in study sites/colonies at Great Swamp, and because sample size was relatively small in each year (n=10 and n=13 bats); under this explanation, the differences observed may not be biologically significant. The latter explanation is possible for characteristics such as roost height and canopy cover, which are reported as influencing roost thermodynamics and for which changes in bat behavior have been observed with varying weather conditions (Humphrey et al. 1977, Winhold 2007).

The difference in dbh is most likely an arbitrary result of the bats followed each year (in other words, sample variation). This conclusion is supported by the relative similarity of measurements between years (42.1cm ± 1.87 se vs. 40.5cm ± 1.87 se), and by the similarity of results reported in locations where multiple studies have taken place. For example, mean dbh ranged from 40.9 - 42cm in Michigan (Kurta et al. 1996, 2002) and from 47.2-49.9cm in New York/Vermont (Britzke et al. 2006, Palm 2003). These studies, as well as the results from Great Swamp, provide evidence to suggest that a 2 cm difference in mean dbh is likely due to sample variation and is not the result of a change in behavior.

Differences in height and canopy cover are less easily explained. There were no differences at Great Swamp in mean, high or low temperature for the summers of 2006 and 2007 (ANOVA, df =1, p = 0.3607, 0.6659 and 0.3651 respectively) but there was a significant difference in the amount of precipitation between years (p = 0.0031). Mean daily rainfall was 0.36 cm in 2006 and 0.40 cm in 2007. This suggests that bats may have selected shorter trees under higher canopy cover in 2007 to shield them from rainfall. Humphrey et al. (1977) observed *M. sodalis* moving to a living shagbark hickory during periods of cool and wet weather, and showed that the live tree retained heat and perhaps shielded bats from rainwater better than the primary roost, which was a bitternut hickory *(C. cordiformis)* snag. Thus, one might expect the use of living trees to increase with rainfall; however, living trees were used more in 2006 (the drier year, and the year with lower canopy cover), indicating that the difference may have been arbitrary after all.

The timing of data collection varied between years. In 2006 canopy cover information was collected between 9/13 and 9/27, and in 2007 data collection was conducted throughout the summer and was complete by 9/15. Although no noticeable leaf fall had begun by the time 2006 data collection was complete, the between-year difference may be due to the varying timeframes in which information was collected. Alternatively, slight changes in weather may have caused between-year differences in the timing and extent of leaf-out and senescence (Kramer and Kozlowski 1979) or in the roost-selecting behavior of bats. If so, this study is among others that have noted variation in canopy cover. For example, Gardner et al. (1991) found 32 roosts within closed canopies (80-100%) and 12 within intermediate (30-80%), while Foster and Kurta (1999) found canopy cover to be bimodal (13 trees had 0-20% closure while 9 had 81-100%). While a

20% difference in canopy cover between years seems quite drastic, it is impossible to say with any certainty whether the difference is real and, if so, what caused it.

Other than *Q. bicolor*, all tree species utilized as roosts at Great Swamp have been documented in previous studies. While this is the first study to record the use of *Q. bicolor*, ongoing research continues to add to the list of species suitable for roosting by *M. sodalis* and species use probably reflects local availability more than the inherent suitability – although some common species have rarely or never been documented as roosts, indicating that a few species are simply not suitable (Kurta 2005). *Quercus* is the second-most numerous genus utilized as roosts by Indiana bats (after *Carya*; Kurta 2005), suggesting that the genus as a whole decays in a manner consistent with the provision of roosting habitat. The addition of *Q. bicolor* to this list is probably due to its greater abundance at Great Swamp compared to other study sites (although Foster and Kurta 1999 stated that the species partly dominated their study area as well).

Snags were the preferred roost type (50/72, or 69.4%) but they were not preferred for all species. *Carya ovata* roosts were frequently alive and accounted for nearly half (7/13) of the living trees used; both living and dead *A. rubrum* and *R. pseudoacacia* were used; while *U. americana*, *Q. palustris* and *Q. bicolor* were only utilized if dead. This reflects the varying characteristics that these species take on in life and in decay, and indicates that the stage of highest suitability will vary among roost species.

Roosts were most utilized when in either an early or mid-stage of decay; only 6.9% (5 of 72) roosts used in this study exceeded mid-stage decay. This is consistent with the findings of Barclay and Kurta (2007), who compiled numerous studies on tree-roosting bats and found that early-to-mid stages of decay were typically preferred.

Characteristics of roost tree plots

Trees occurring within roost plots were generally living *A. rubrum*, *F. pennsylvanica*, *Q. palustris* or *U. americana* with a mean dbh of 24 cm and no visible signs of decay. About 19% of trees had loose bark, and only 5% of trees earned a "high suitability" ranking (according to the modified system of Gardner et al. 1991). Fewer than 7% of trees had splits or cavities. Several of the plot measures differed between years, including the dbh and amount of loose bark on trees, canopy closure, shrub cover and distance of the nearest tree from the roost. Characteristics of the nearest tree that differed significantly from those of the roost included height and dbh.

Several of these differences are likely the result of sample variation and can be explained in a manner similar to that for roost tree characteristics. The dbh of plot trees differed by less than 2cm and was smaller in 2007, a pattern very similar to that observed for roost trees (although no comparisons could be found among other studies). This may have been the result of increased canopy cover in 2007 that reduced the amount of available sunlight and resulted in smaller trees. The distance between the roost and the nearest tree differed only slightly (although significantly) between years, and is not likely to have had much biological significance in influencing a bat's choice of roost trees (2.3 vs. 2.9m distance). Canopy cover at the plot edge differed between years but was no different than that of the roost tree; as such it may be the result of selection by bats in response to the increased rainfall in 2007, an arbitrary result of sample variation, or due to differences in the periods of data collection for canopy cover.

Shrub cover and number of saplings surrounding Indiana bat roosts is not consistently or well studied and is rarely reported, making comparisons difficult. Schultes (2002) found that shrub cover within 5m of the roost averaged 22.6% (± 9.2 se) in Ohio; and although other studies have recorded similar measures, few report their results. There is not enough information in the literature to suggest that either of these variables influence bat behavior. Furthermore, mean values for shrub cover at Great Swamp (16.8% ± 3.01se and 29.2% ± 3.21se) are similar to and fall largely within 1 se of those reported by Shultes (2002). This suggests that the variation between years is probably due to sample variation.

Several of the characteristics measured as a part of this study speak to the degree of openness around the roost (including canopy cover, number of saplings, shrub cover, mean number of trees per plot and average distance of trees from the roost), a characteristic that is important since roost trees are frequently described as being in the "open." While many have attempted to quantify or measure openness, methods vary tremendously. Some studies rate the amount of solar exposure reaching the roost during the day (Kurta et al. 2002, Timpone 2004, Winhold 2007), while others categorize the canopy (Gumbert 2001) or the canopy position of the roost (Palm 2003, Watrous et al. 2006), note the presence/absence of a canopy gap (Shultes 2002) or rate the roost as being open or interior (Callahan 1993). Other measures of openness deal more with the character of the vegetation surrounding the roost: Winhold (2007) categorized the amount of foliage and twigs (clutter) near the roost exit, and Britzke et al. (2006) categorized the structural complexity around roosts.

In this study, 72% percent of plots had fewer than 3 saplings occurring along the cardinal transects and mean shrub cover (although different between years) ranged from about 17 – 29%. Though clutter was not measured, the bole of most roosts was open and free of surrounding vines or mid-story vegetation (though at least a few roosts were covered with poison ivy vines, *Toxicodendron radicans*, and a few additional roosts were partly surrounded by dense stands of greenbriar, *Smilax rotundifolia* – pers. obs.). These values indicate that the understory and vegetation surrounding roost trees was relatively open, even though the canopy was not necessarily so (mean closure did not vary between the roost and the plot edge, and was 64-69% and 82-83% for 2006-2007, respectively).

Roost occupancy

One flaw inherent in the performance of emergence counts is that it is very difficult to distinguish what species is (or are) using the roost tree. *Myotis sodalis* has been observed roosting with *M. lucifugus* in roost trees and in artificial structures (Butchkoski and Hassinger 2002, Sichmeller et al. 2008), raising obvious problems with the use of emergence counts to estimate *M. sodalis* occupancy. While a few studies have documented *M. sodalis* and *M. septentrionalis* using the same roost trees, the species have not been observed roosting together (Butchkoski and Hassinger 2002, Foster and Kurta 1999, Timpone 2004). *Myotis septentrionalis* appears to have less-specific roosting requirements than its congener and utilizes cavities, living and/or smaller trees, and sites with high canopy cover more often than *M. sodalis* (Carter and Feldhamer 2001, Foster and Kurta 1999). Despite this difficulty, emergence counts provide the only means of distinguishing between primary and alternate roosts.

The occurrence of zero-counts reflects the temporary roost use behavior of female *M. sodalis*, which is known to switch trees every 2-4 days. As such, inclusion of zero-counts in any analysis underestimates the average number of bats using occupied trees. The mean number of bats emerging from occupied roosts was 27.8; however, there was a significant difference between the number of bats exiting from primary and alternate trees (Table 14, although table includes zero-counts). On average, 9.5 bats emerged from alternate roosts, while 45.3 emerged from primary roosts. A histogram similar to that of Kurta et al. 1996 is shown in Fig. 19; unlike their study, most non-zero emergences were of either 2-11 or >42 bats.

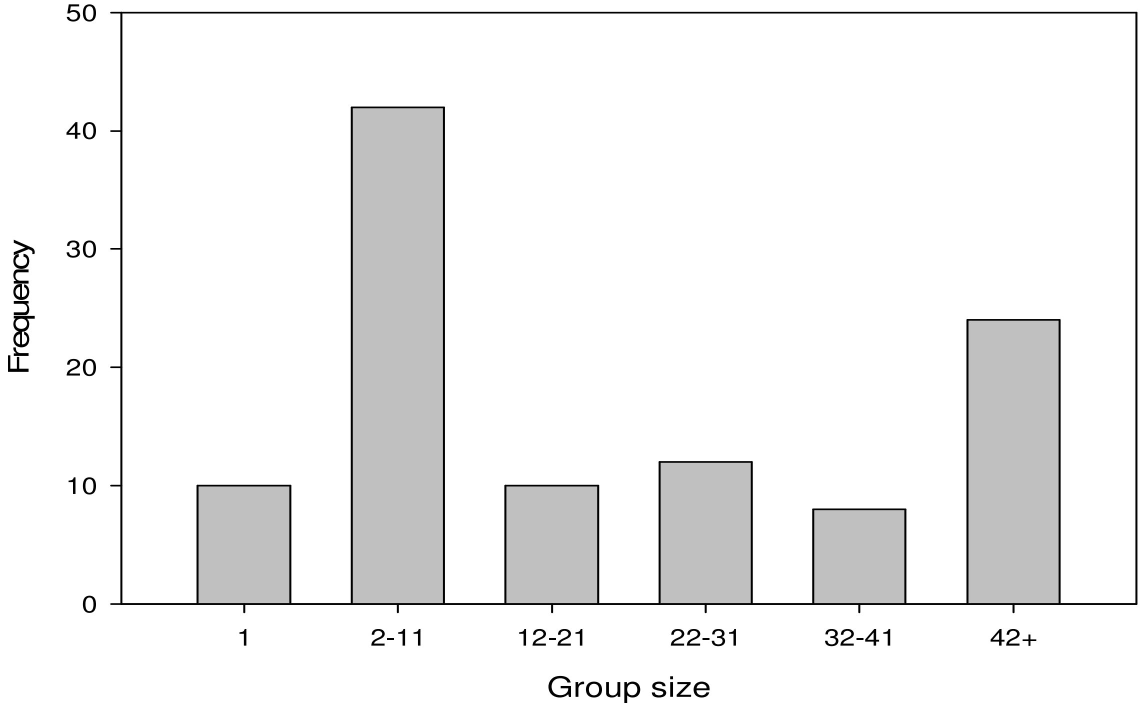

Figure 19. Histogram of non-zero emergence counts, divided in categories used by Kurta et al. 1996.

The peak emergence count of 252 bats observed on June 5, 2006 is the third-largest congregation of Indiana bats yet reported, following counts of 384 (Kiser et al. 2002; now suspected to have been a *M. lucifugus* roost with some *M. sodalis* mixed in, Kiser 2008 pers. comm. and Sichmeller et al. 2008) and 270 (Watrous 2008 pers. comm.); Palm (2003) observed 209 bats emerging from a roost in Vermont. It is difficult to place the number of primary trees identified at Great Swamp in context, since the amount of effort expended for emergence counts varies drastically across studies. A minimum of 0 (Gumbert 2001, Schultes 2002) and a maximum of 7 primary roosts have been identified per colony in prior studies (Watrous 2008 pers. comm.). Regardless of whether the bats at Great Swamp function as one large colony or as 3 separate colonies, the identification of 4 primary roosts seems within the range of what has been identified elsewhere. However, it is interesting to note that primary roost W62507BA1 was the only one to be used for more than 1 bat day; this could be due to the chance behavior of bats that were transmittered, or it could indicate that bats at Great Swamp are less dependent upon primary trees than in other studies, where repeated use of a roost has been documented. Given the high number of roosts identified at Great Swamp and the infrequent re-use of previously identified roosts, this seems likely. Perhaps a saturation of high-quality roosts at Great Swamp causes the colony to be dispersed among more trees, each being used by smaller numbers of bats that switch trees more often than has been observed in other studies.

Associations between emergence counts and roost characteristics are poorly described in the literature; most studies have instead focused on the timing of emergence events and have examined whether emergence is random or clustered (Speakman et al. 1999, Viele et al. 2002). Published papers on roost quality-emergence associations may be rare for several reasons. First, counts are known to fluctuate over time (even at primary roosts) such that that value of any one count, particularly a low count, in predicting roost quality is minimal. Second, conducting a large number of emergence counts on a large number of trees throughout the summer is extremely labor intensive, and few studies are able to gather a substantial data set.

The graphing of each characteristic against emergence was used to examine whether date drove significant by-date interactions (Fig. 12-17). A significant, independent by-date effect should have appeared as distinct and non-overlapping curves and error bars for each category of the characteristic measured through time. Trends should be particularly evident in the first five or six weeks, when thermoregulation by pregnant bats and neonates is most important. This was not shown to be the case for any of the by-date associations, indicating that date was likely the driving factor behind them. However, small sample size early in the summer may have prevented identification of important interactions during this period.

The significance of date in driving emergence counts should be no surprise when the summer phenology of the Indiana bat is considered, especially if thermoregulatory needs are the driving factor behind congregations of females and young (Barclay and Kurta 2007). As females arrive at their summer habitats in late spring, emergence counts should be low; but as poorly thermoregulating late-pregnancy females cluster together for thermal benefits in late May to mid-June, counts should increase. Rising daily temperatures and the improved thermoregulating capacity of developing young would allow bats to congregate in smaller numbers in mid-June, a move that could additionally benefit bats by reducing parasite loads and/or parasite exposure. Counts should rise again as young begin to achieve volancy in early July, and their independence (occurring towards the middle-end of July) should coincide with steadily decreasing counts as colony members depart for hibernacula. This explanation coincides strongly with emergence count data (Fig. 20). The decrease in mid-June (week 6) may be due to females moving older

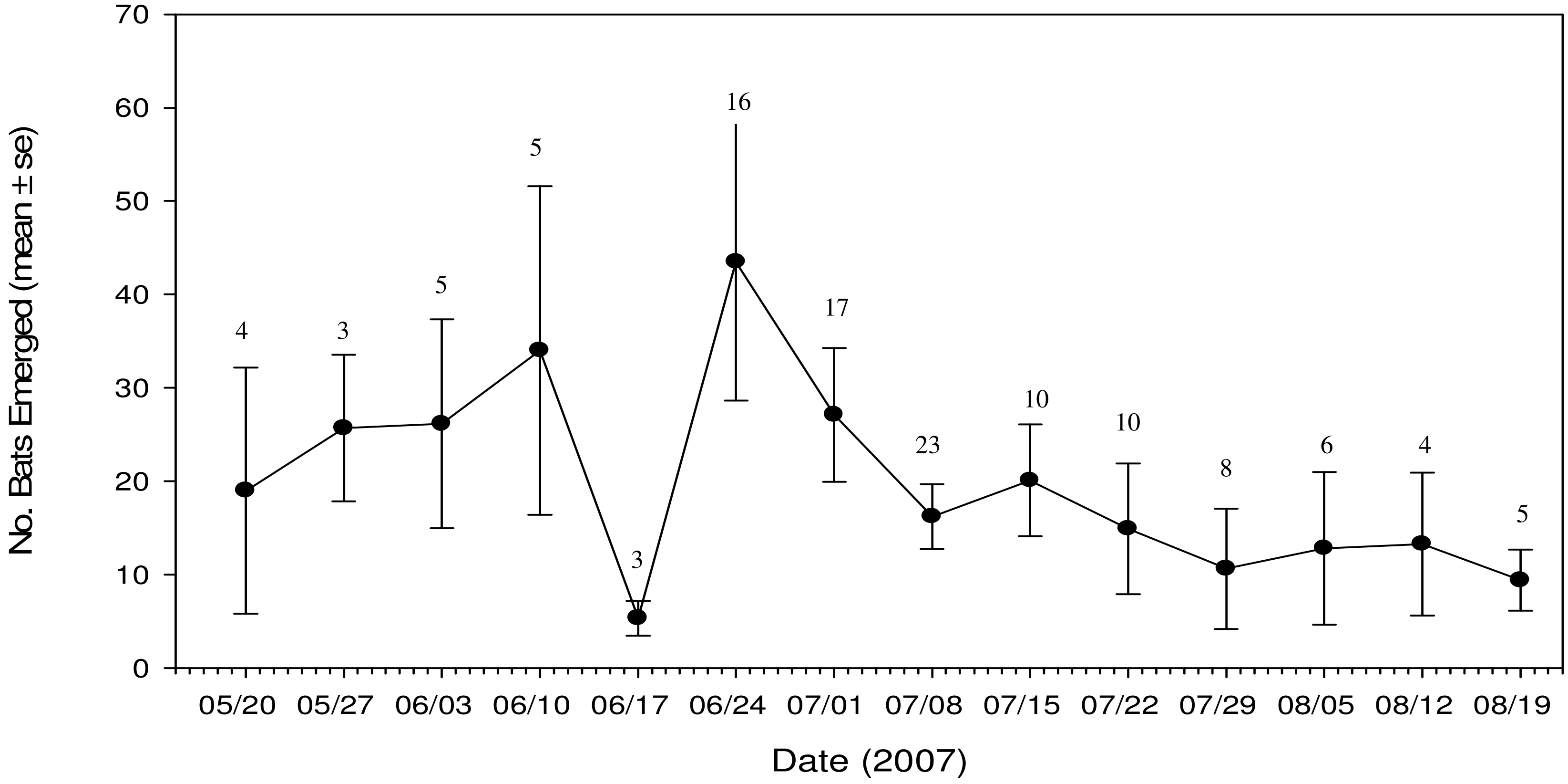

Figure 20. Mean emergence by week for all counts conducted during 2007 at Great Swamp NWR. Number of counts conducted each week are shown.

and better thermoregulating young into smaller congregations, and the magnitude of the decrease observed may be due to a small sample size (n=3 counts). The volancy-induced peak occurs a little earlier than expected (at week 7, or June 24, rather than in early July), but the 2007 capture data reveals that this was indeed the first week that juveniles were captured in surveys (Fig. 21). As expected, counts decrease throughout the rest of the summer as females and independent young move into smaller congregations and depart for the hibernacula. This result suggests that date, as well as peak count, should be considered when making comparisons across studies.

The question tested via the repeated measures analysis (whether emergence counts can serve to indicate significant differences in roost characteristics/quality) is essentially a question of correctly identifying and comparing primary and alternate trees. Until proven otherwise, all trees are relegated to "alternate" status; yet fluctuation in the use of primary trees means they may not always be correctly identified. The repeated measures analysis provides a means for identifying associations between higher emergence counts (assumed to indicate primary roosts) and roost characteristics, though the results are consistent with other studies that have failed to statistically distinguish between primary and alternate roosts. Kurta et al. (2002) found no statistical differences between frequently and infrequently used trees (i.e., primary and alternate) in diameter, height, emergence height, exfoliating bark, canopy cover or amount of sunlight received. Callahan et al. (1997) found that primary trees were more likely to be in open situations rather than in the forest interior, and more likely to be dead; but neither of these characteristics were considered in this analysis. Both studies found that diameter was more variable in alternate trees. The 2007 Draft Recovery Plan (U.S. Fish and Wildlife Service) suggests that an inability to detect statistical differences in primary and alternate roosts may be due to the "scoping" behavior of bats in investigating alternate trees as potential primary roosts

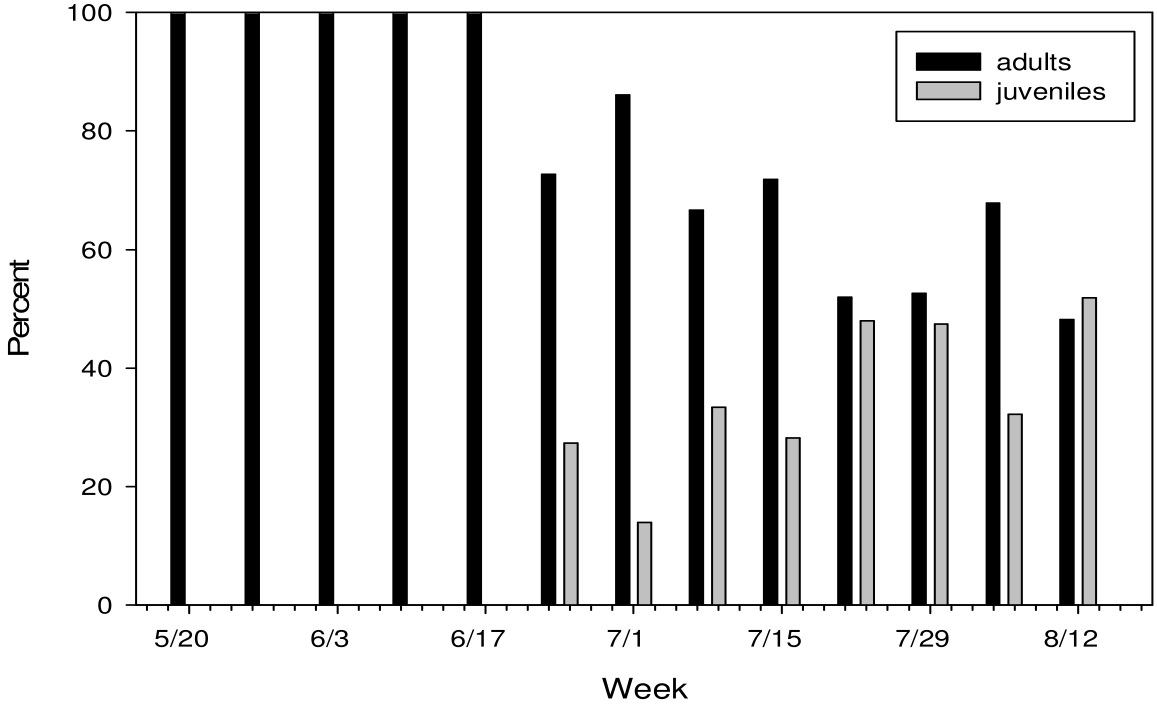

Figure 21. Percent of adults and juveniles captured during each week of mist net surveys at Great Swamp NWR, 2007.

(Barclay and Kurta 2007). The as-yet inability to clearly identify minimum necessary characteristics of primary roosts has prevented studies of roost choice in roost-saturated vs. roost-deprived habitats, though comparisons across studies may yield some indications of this.

Roost fidelity

Various methods exist for estimating roost fidelity (a measure of the number of consecutive days bats spend in a roost). The method of Kurta et al. (1996, 2002, in which the number of bat days is divided by the number of switches) overestimates an individual bat's fidelity, since the number of switches functions as the denominator. In other words, a bat located on 10 days that switched trees once would yield an estimate of 10.0, and no estimate can be calculated for a bat with 0 switches. Thus, an alternative estimate was created by adding 1 to the number of observed switches (i.e., a bat that switched 0 times would have a denominator of 1); this seems to provide more realistic fidelity estimates ranging from 1.0 to 4.5 ($\bar{x} = 1.8$). The method of Britzke et al. (2006), in which the number of consecutive days that a bat spends in each roost is averaged, may be most intuitive in revealing how long (on average) bats stay in each roost before switching. Kurta's method is better suited for providing overall estimates of site fidelity, but without the above modification it may overestimate the true value. Thus, mean fidelity of bats at Great Swamp probably lies between one switch every 1.8 (modified Kurta method) and 2.0 days (Britzke method; Table 15), even though the overall estimate (using the methodology of Kurta et al. 1996) was one switch every 2.3 days.

Measures of roost fidelity were similar to those reported in other studies, though they fell toward the lower end of the spectrum. *Myotis sodalis* switched roosts on average every 2.3 days in Ohio; 2.4 days in Jackson and Washtenaw Counties, Michigan; 2.9 days in Eaton County, Michigan; 2.7 days at Brashears Creek, Kentucky; 3.9 days at Fort Knox, Kentucky; and 5.7 days in North Carolina and Tennessee (Britzke et al. 2003, Hawkins et al. 2008, Schultes 2002, Kurta et al. 1996, 2002). Lewis (1995) examined roost fidelity in 43 species of bats, and found that high roost fidelity was inversely related to roost availability. If this pattern also holds for intra-specific comparisons, then low roost fidelity at Great Swamp may suggest greater availability of roosts here than in other locations where studies have been conducted. This explanation is consistent with other observations made at Great Swamp, including a greater number of trees used per bat and greater distances moved between roosts. On average, each bat used 3.2 trees at Great Swamp; in Michigan, 2 and 2.8 trees per bat were used (Kurta et al. 1996 and 2002). A discussion of the distances moved by bats follows (below).

Landscape patterns

Callahan et al. (1997) defined a colony as a "group of female Indiana bats and their young that used the same set of roost trees." This definition is not useful for characterizing colonies at Great Swamp because only 2 trees were used by more than one bat within the same year (O8906MK1 by 2 bats in 2006, W62507BA1 by 2 bats in 2007). Patterns of movement between capture and roost locations, however, seem to indicate three separate colonies: one along the Passaic River, one at Sherwood Lane and one at OU-3 (Fig. 22-24). Bats captured in each location seemed to have similar home ranges (Appendix A), and never roosted within areas occupied by other colonies. However, the proximity of these clusters makes it difficult to consider them completely separate groups: maximum distance between these areas is approximately 4 km (Fig. 25). Timpone (2004) found no colony interchange among what appeared to be 3 separate colonies in 2001, but found significant overlap in 2002 suggesting one

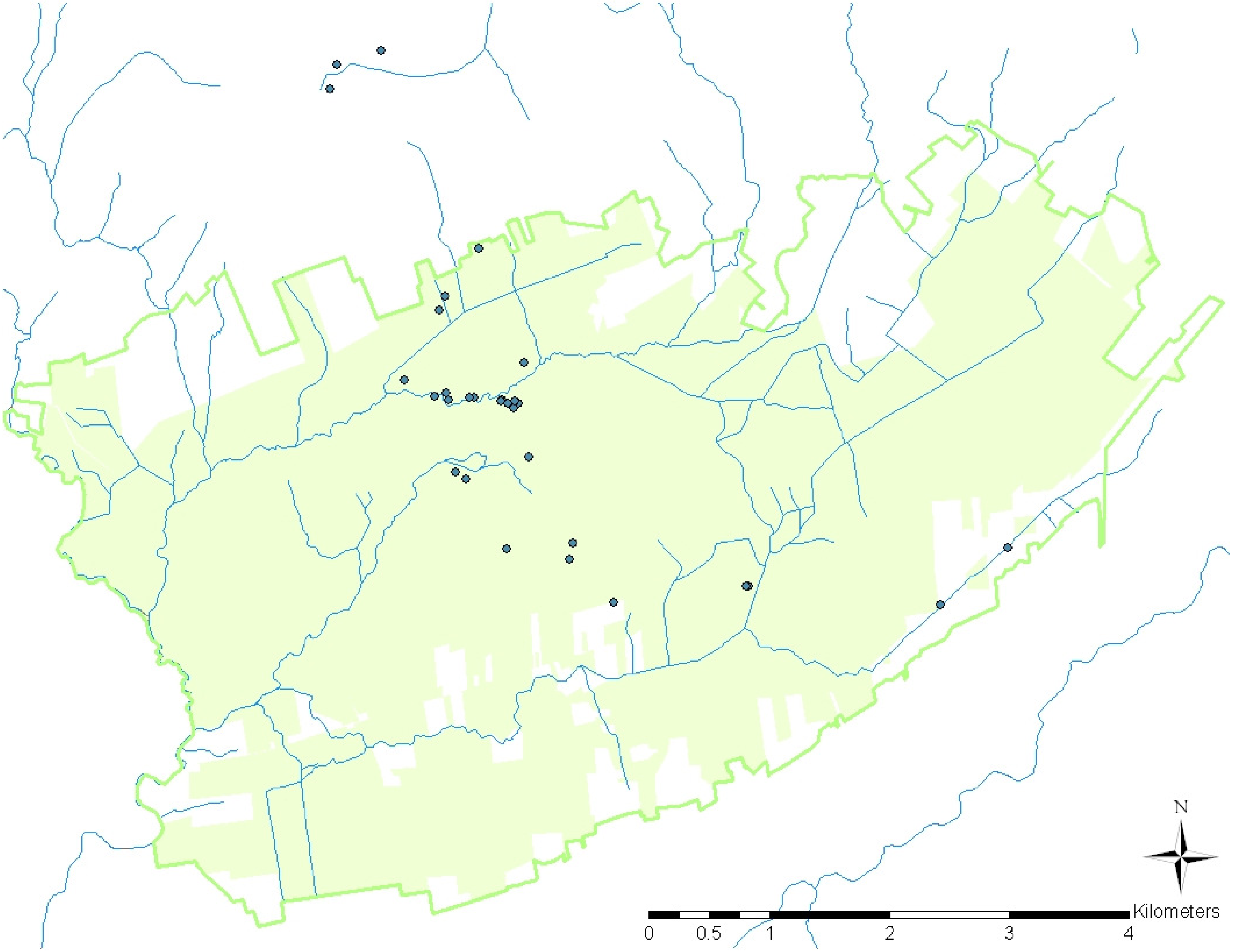

Figure 22. Roosts within the OU-3 colony, 2006-2007. Lands in refuge ownership are shaded.

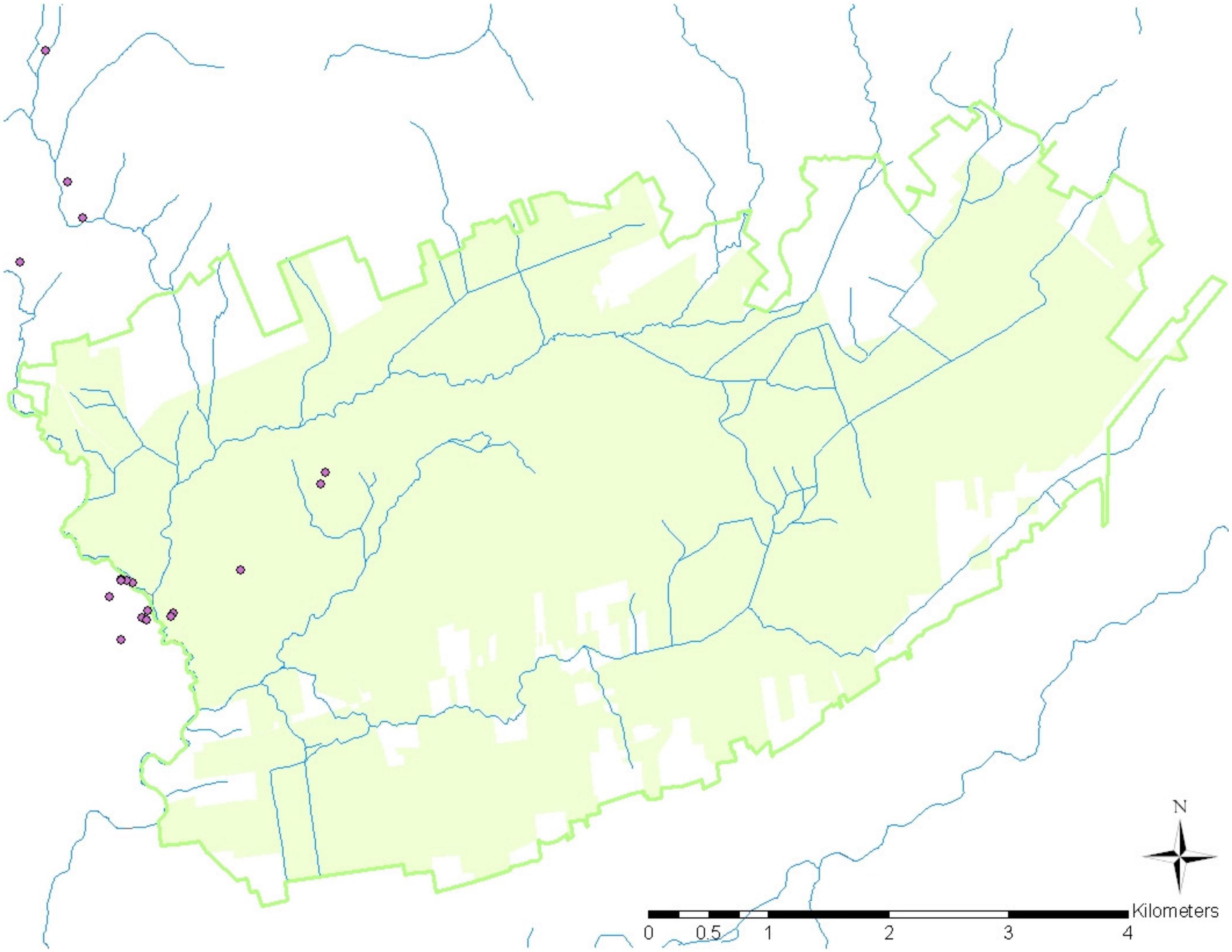

Figure 23. Roosts within the Passaic River colony, 2006-2007. Lands in refuge ownership are shaded.

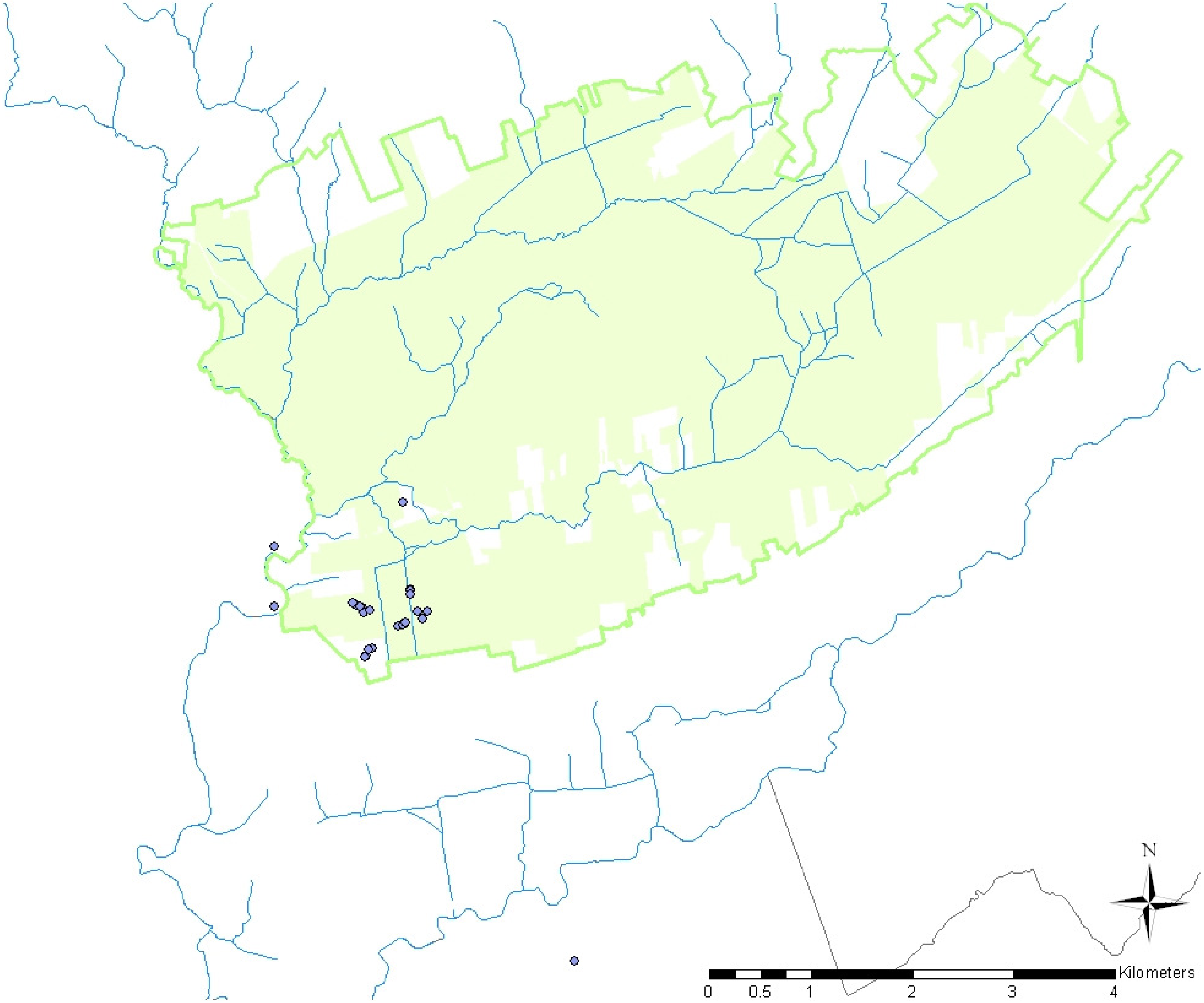

Figure 24. Roosts within the Sherwood Lane Colony, 2006-2007. Lands in refuge ownership are shaded.

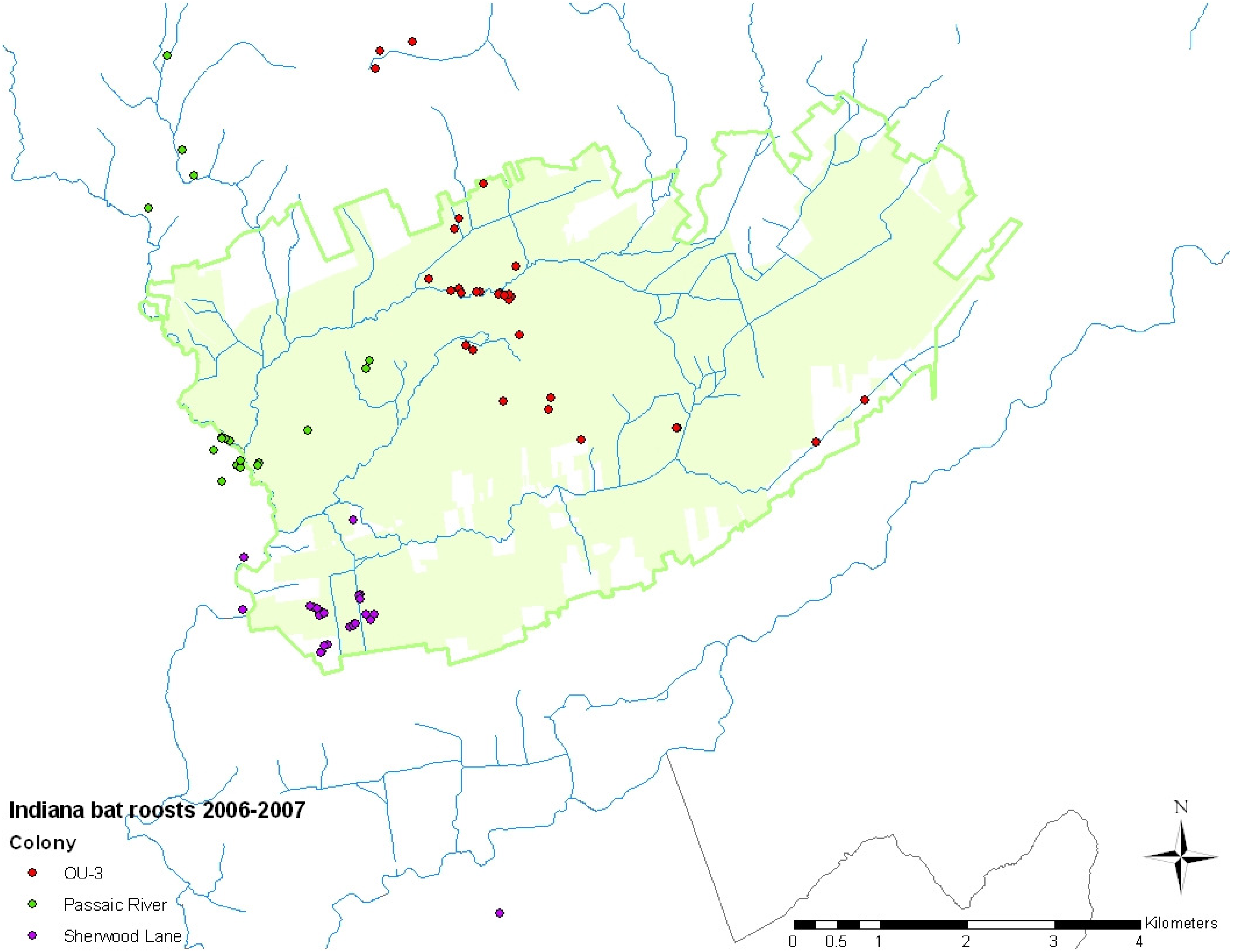

Figure 25. Location of roost trees, 2006-2007. Presumed colonies are indicated. Lands in refuge ownership are shaded.

wide-ranging colony with roost trees separated by as much as 5.1 km. Thus, even though no interactions were observed, it is possible that the 3 colonies located at Great Swamp function as "interacting colonies" or as "subgroups of [the] main colony", as has been described by Kurta et al. (2002). If the roost clusters identified at Great Swamp represent one large colony, then this study represents the greatest number of roosts yet to be identified in a single year (40 and 35 in each year respectively) and the greatest distance between trees so far observed (10.6km in one year).

If these groups are instead considered separate colonies, then 10-17 roosts were used by each colony in each year (Table 17) at a maximum distance of 5.2 km. However, it is very likely that many more trees were being used by these colonies than were identified, since no colony could be followed throughout the duration of the maternity season and because so few roosts were re-used. Furthermore, no primary tree was identified at the Sherwood Lane colony during this study (although one such tree was identified in 2008, Wight 2008 pers. comm.).

Bats at Great Swamp appear to be moving greater distances than has been seen in other studies. The average distance moved between consecutive roosts was 1003.4m; among prior studies the greatest distance observed was 686m (Kurta et al. 2002). Furthermore, the authors of that study noted that, "large diameter trees with exfoliating bark were not as concentrated… presumably forcing the bats to travel longer distances to find alternate roosts." This does not appear to be the case at Great Swamp, as evidenced by the infrequency with which known roost trees were revisited by individual or multiple bats. On only 5 occasions did a bat re-visit a roost it had used previously (and 4 of these were by 1 bat that was followed for 19 days); on only 2 occasions was a roost re-used by another bat in the same year; and only one roost was used in both years (although primary roost W62507BA1 may have also fallen into this category, see

Table 17. Characteristics of potential colonies of *M. sodalis* identified at Great Swamp NWR, 2006-2007.

Colony	Number of bats	Number of roosts 2006	Number of roosts 2007	Number of roosts Total	Maximum distance between roosts (km) 2006	Maximum distance between roosts (km) 2007	Maximum distance between roosts (km) Total	Primary roosts 2006	Primary roosts 2007
Passaic River	6	10	8	18	1.0	5.0	5.0	M6506MK1	O52307MW1
Sherwood Lane	7	13[a]	12	25	0.8	5.0	5.0	-	-
OU-3	11	17	15[a]	31[b]	4.5	5.2	6.9	-	O7707MW1 W62507BA1

[a] one tree was used by 2 transmittered bats

[b] one tree was used in both years

results). Furthermore, the mean distance to the nearest roost was much smaller than the distance moved between consecutive roosts; this difference was significant in 2006 (52.3m vs. 202.9m; p = 0.0008). This suggests that suitable roost trees are abundant on the landscape (consistent with observations of low roost fidelity, see roost occupancy discussion) and further raises the question of why bats are moving such distances if other roosts are available nearby. Carter and Feldhamer (2005) suggest bats in their study moved greater distances in order to spread their roost locations throughout what was available to them, to reduce travel time to foraging areas or to reduce potential foraging competition. This is more likely to explain behavior at Great Swamp, since suitable roosts appear to be abundant.

One bat that stands as an example was pregnant when captured at the Sherwood Lane site on 6/7/2007. The following day she roosted 3.8 km south of the capture site and then foraged an additional 3.1 km south, apparently along a golf course. In four of the next five days (one day she was not found), she roosted approximately 7-8km North of the golf course but continued to forage there nightly. This bat weighed 9.5 g upon capture, and traveling this distance to forage each night must have represented a tremendous expenditure of energy. (In several nights of telemetry she made the trip over the course of 30-90 minutes, appearing not to spend much time foraging along the way). Why this bat would have traveled so far to routine foraging grounds, despite the presence of at least one suitable roost of much closer proximity, remains unknown.

Random and selected roost tree/plot comparisons

In many prior studies, the selection of “random” trees for comparisons has been biased. Most frequently, “suitable non-roost trees” are selected based on criteria that make them inherently similar to known roost trees. For example, Kurta et al. (2002) and Schultes (2002) required that random trees be ≥10 cm dbh and have exfoliating bark or cavities in which bats might roost; Timpone (2004) required that they be ≥ 20 cm dbh and have crevices, cavities, or exfoliating bark; and Callahan (1993) required that they be a living *C. ovata* or snag ≥ 25 cm dbh. The justification for such methodology is to enable comparisons between suitable, non-roost trees and known roost trees. However, in doing so the ability to detect selection among trees "available" to bats is severely restricted, since many more trees are available than are typically considered. For example, 4 of 6 primary roosts identified in Callahan's (1993) study were smaller than 25 cm dbh and would not have qualified as "available" under his criteria. Britzke (2003) documented trees as small as 11 cm dbh being used by female *M. sodalis*, though under many of the above criteria this tree would also be excluded. A second problem with this methodology is that there is no way to know whether the "suitable non-roost tree" is being or ever has been used by *M. sodalis*; so comparisons may be artificial. The main problem in the use of such restrictive criteria is that true selection of characteristics by bats may be concealed. For example, Kurta (2005) states that differences between random and roost trees have been found when minimum diameter of available trees is set at 4.5, 10 or 15 cm, but not at 18.5 or 25 cm. Thus, by setting restrictive criteria, characteristics which may be important to bats (such as the presence of exfoliating bark and the size of tree utilized) may become standard among all trees compared and thus selection cannot be detected. This may explain why, for example, the percent bark cover and the amount of exfoliating bark is not a useful predictor of Indiana bat occupancy (Kurta 2005), despite their known importance to bats.

For these reasons, minimal criteria were set in the selection of random trees for this study. Random points were generated in habitats where Indiana bat roosts had been identified (swamp, forest and forest edge habitats) and habitat types in which no use had been documented were excluded (grassland, brush, open water, marsh, developed; Fig. 26). (That random trees were located in areas of suitable habitat is supported by the observation that two 2008 roost trees occurred less than 10 m from random roost R147, Wight 2008 pers. comm.). The nearest tree ≥ 10 cm dbh was selected as the "random" tree; this increased the chances that selection exhibited by bats would be detected. The risk of this methodology is that comparisons will reveal a foregone conclusion: that bats select trees providing suitable roosting habitat. However, it provides the only means of truly comparing available, *random* trees to those selected as roosts.

As expected, a number of random-roost comparisons confirmed already-understood aspects of roost selection by *M. sodalis*: bats selected dead, large-diameter trees in mid-stages of decay more than would be expected. These trees had less bark remaining, and more bark exfoliating, than other trees available to them. However, there is evidence to suggest that bats may also have been selecting roost trees on the basis of certain stand characteristics. For example, within roost plots fewer but larger trees were present; and snags and "suitable" trees (using the system devised by Gardner et al. 1991 and modified here) were more prevalent. The distance to surrounding trees; number of saplings; and mean height, dbh, and distance of the nearest tree appeared to have no effect on selection of roost trees, as no differences were found for these characteristics. Variation makes interpretation difficult for characteristics of the roost tree/plot that differed significantly between years. For example, mean height of the central tree and canopy closure (both at the roost and plot edge) of the random tree differed from 2006 but not 2007 roost trees. Thus, there is not sufficient evidence to suggest that bats selected for these characteristics when choosing roost trees.

Are bats at Great Swamp selecting roosts on the basis of surrounding stand characteristics (i.e., large dbh or high densities of snags/suitable trees), or could it be that these stand

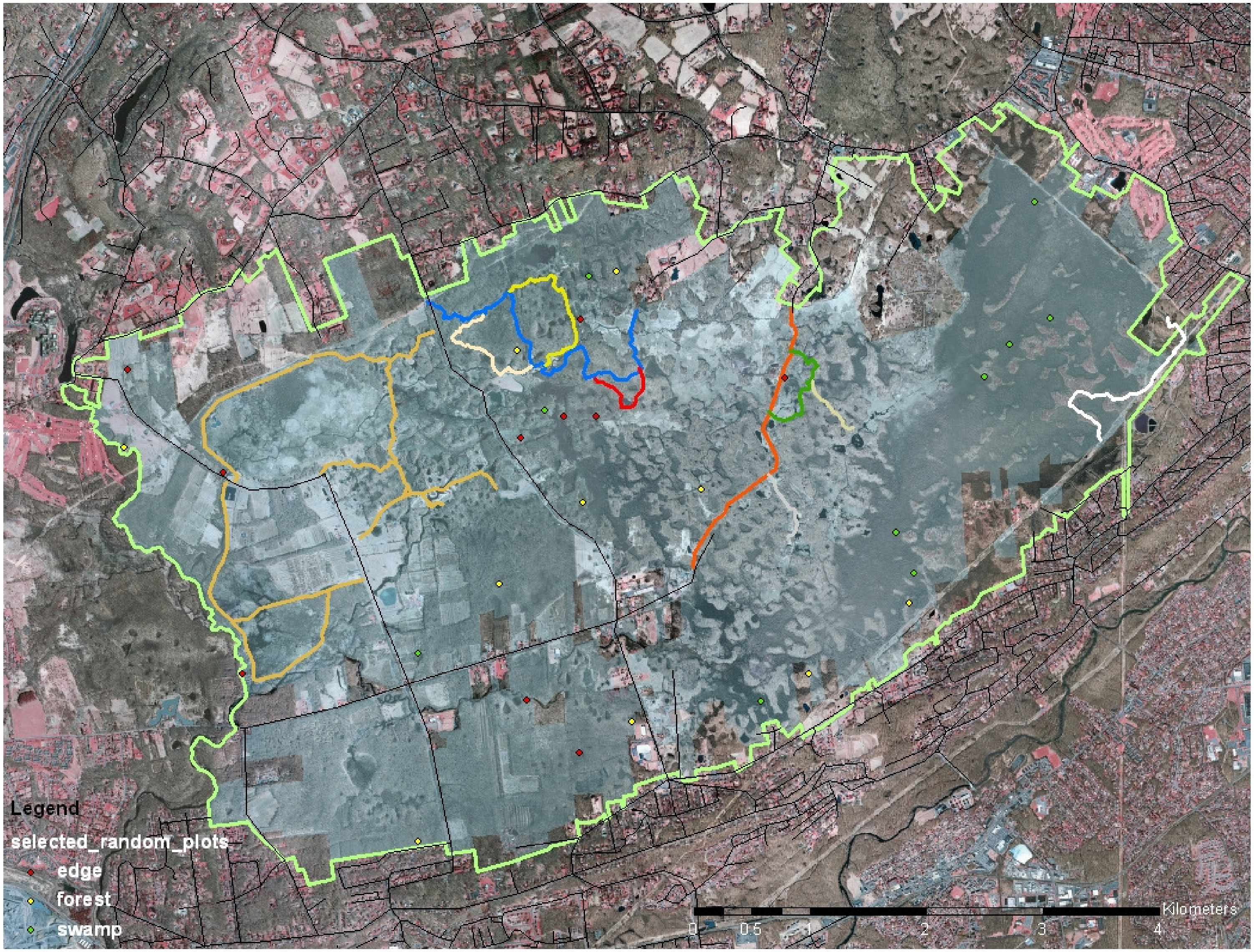

Figure 26. Locations of random trees measured for comparison to roost trees.

characteristics are likely to occur in association with suitable roost trees? This study does not provide sufficient evidence to say. However, the role of forest succession is difficult to ignore – younger stands would have a greater number of smaller trees that are generally in good health (as tended to be the case for random plots). As a forest progresses, competition would result in a natural thinning of the forest leaving fewer trees of larger dbh, and a greater number of dead and dying trees that provide suitable roosting habitat for *M. sodalis* (as was seen in roost plots). It is reasonable to assume that bats may prefer such stands, given the fidelity typically shown to roosting areas and the temporary nature of individual roost trees: mature stands would be more likely to continually provide roosts over the long-term, reducing a bat's need to search for alternate sites/roosts. However, the distances moved by bats in this study (despite the availability of closer, suitable trees) suggests that bats may not be concerned with the proximity of other suitable trees and may focus simply on the characteristics of an individual tree.

Of the species most used as roosts in this study (*A. rubrum, C. ovata, U. americana* and *Q. palustris*), *A. rubrum* was used less than would be expected from the random data; *C. ovata* and *U. americana* were used more than expected; and *Q. palustris* was used roughly in proportion to its availability within roost plots. Significant use of *A. rubrum* in this study thus appears to be a byproduct of its abundance at Great Swamp (the species accounted for 43.0% of trees within roost plots and 59.7% within random plots), while *C. ovata* and *U. americana* were selected for. These species tend to decay in a manner that provides excellent roosting habitat for *M. sodalis*, though in different ways. Gardner et al. (1991) reported that *C. ovata* exhibits a strong tendency to retain bark, which may explain the reuse of shagbark hickory roosts from year to year (observed by Gardner et al. 1991 and in this study). The bark of *U. americana*, however, tends to hang in large, loose sheets that provide excellent roosting habitat for bats but which dislodge easily, especially when rain-soaked or blown by wind (this is very similar to Gardner et al.'s 1991 observations of slippery elm, *U. rubra*). For example, a thunderstorm in early August 2007 appeared to have caused the loss of much of the bark under which bats had previously roosted (*U. americana* roost identified June 11, 2007); by September 2008 approximately 40% more bark had fallen off this tree. Thus, while both species have the capacity to provide excellent habitat, *C. ovata* may represent durable and dependable roosts, while those of *U. americana* appear to be temporary.

Regional comparisons

One of the main goals of this study was to establish characteristics of roost trees used by Indiana bats in the northeast such that comparisons could be made to other portions of the species range. Most studies to examine maternity colonies in summer have been conducted in the Midwest; only Palm (2003) and Watrous et al. (2006) have conducted such work in the Northeast, and both studies were conducted in the Champlain Valley of New York/Vermont. Until this study there was not enough information to meaningfully compare roost characteristics across the species' range, and range-wide habitat preferences were assumed to be similar to those documented in the Midwest. Validating this assumption for the Northeast (or pinpointing its inaccuracies) is critical to managing for this endangered species, especially since the population here has increased 30% since 1960 (Clawson 2002). Documenting what works for the species here may help to manage for recoveries elsewhere in the species' range, and to maintain population increases in the Northeast.

Figures 27-31 show each characteristic as it has been measured across studies, coded by region (information also presented in Table 16). These graphs reveal that regional patterns may

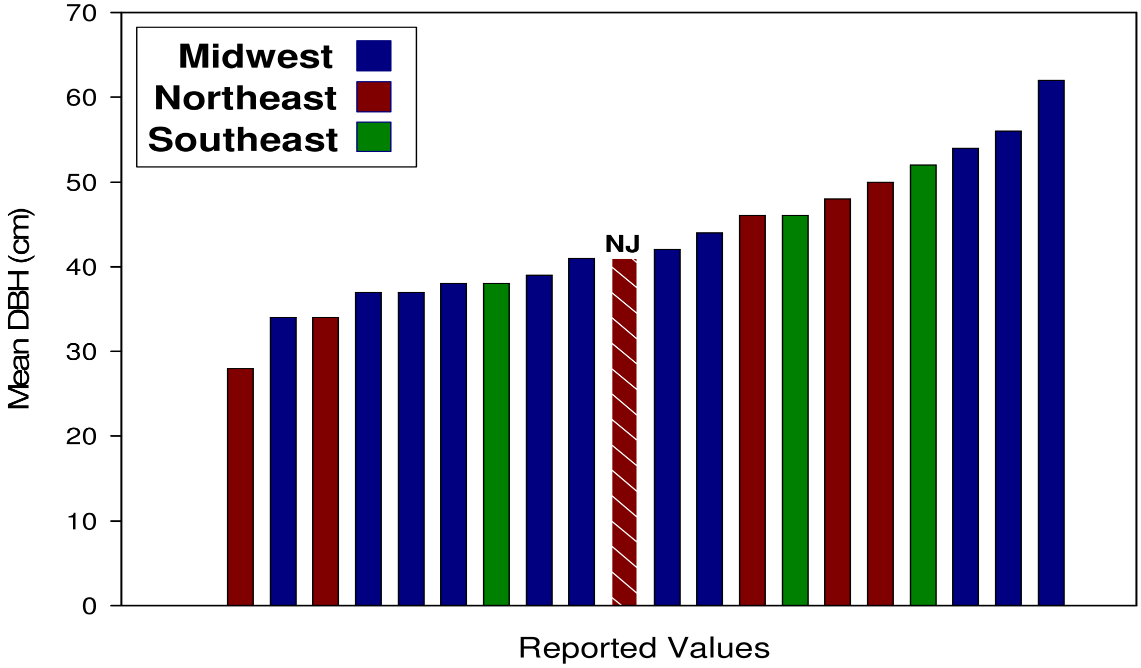

Figure 27. Mean dbh of roosts used by female *M. sodalis* by region, as shown in Table 16. This study's estimate is labeled NJ and appears striped. Each bar represents a different study.

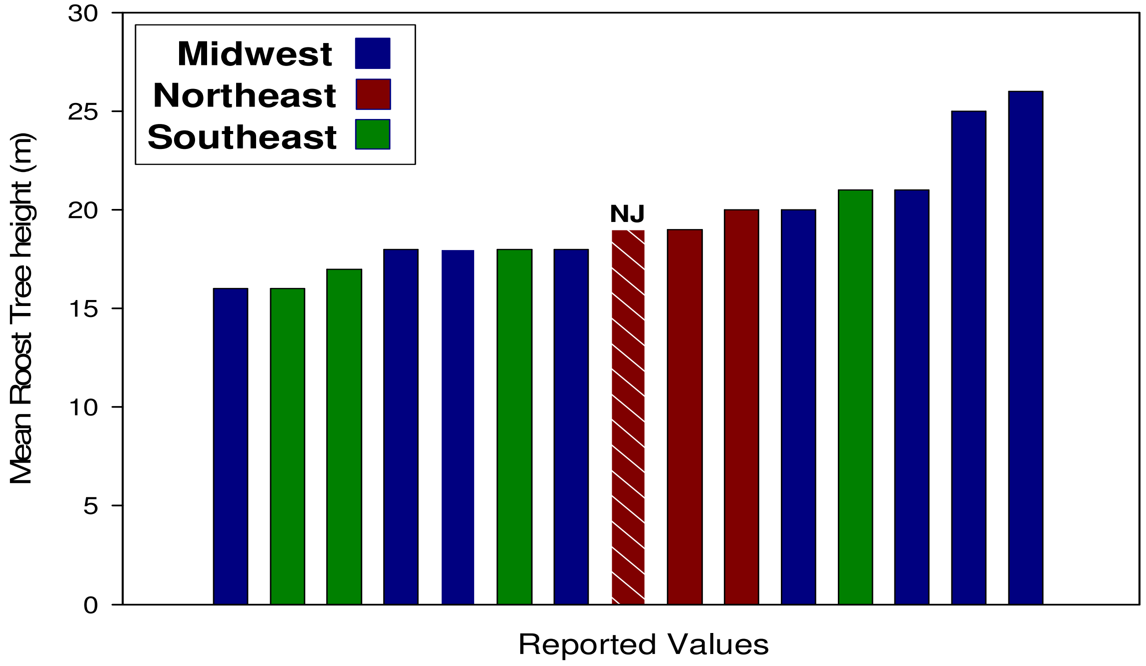

Figure 28. Mean height of roosts used by female *M. sodalis* by region, as shown in Table 16. This study's estimate is labeled NJ and appears striped. Each bar represents a different study.

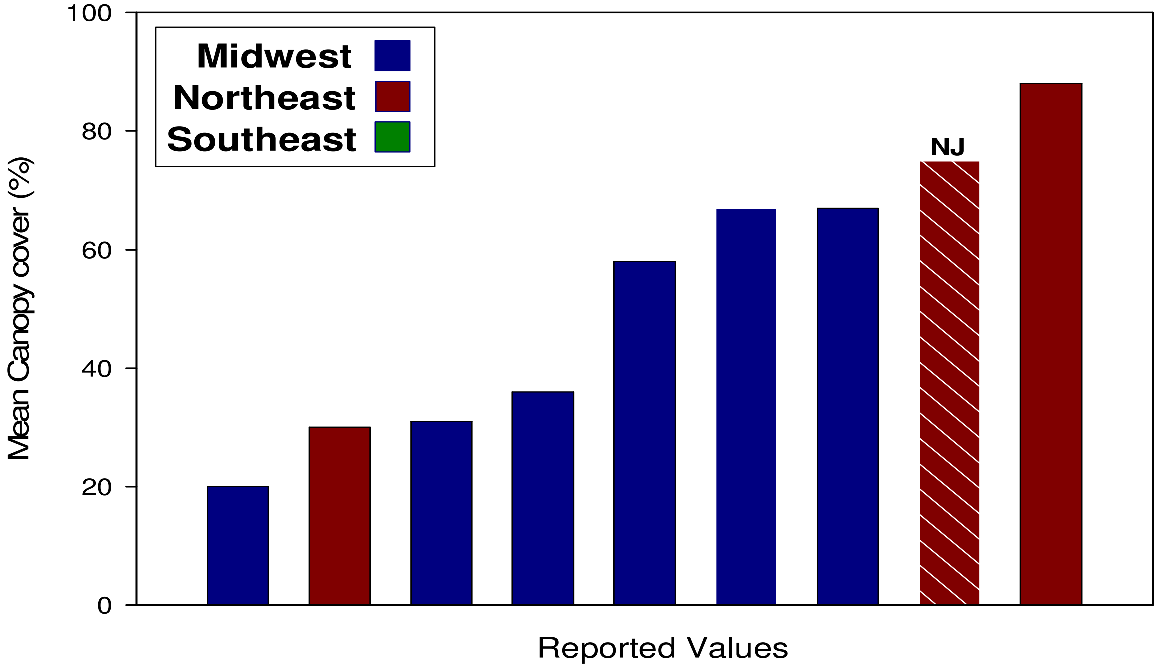

Figure 29. Mean canopy cover at the roost for trees used by female *M. sodalis* by region, as shown in Table 16. This study's estimate is labeled NJ and appears striped. Each bar represents a different study.

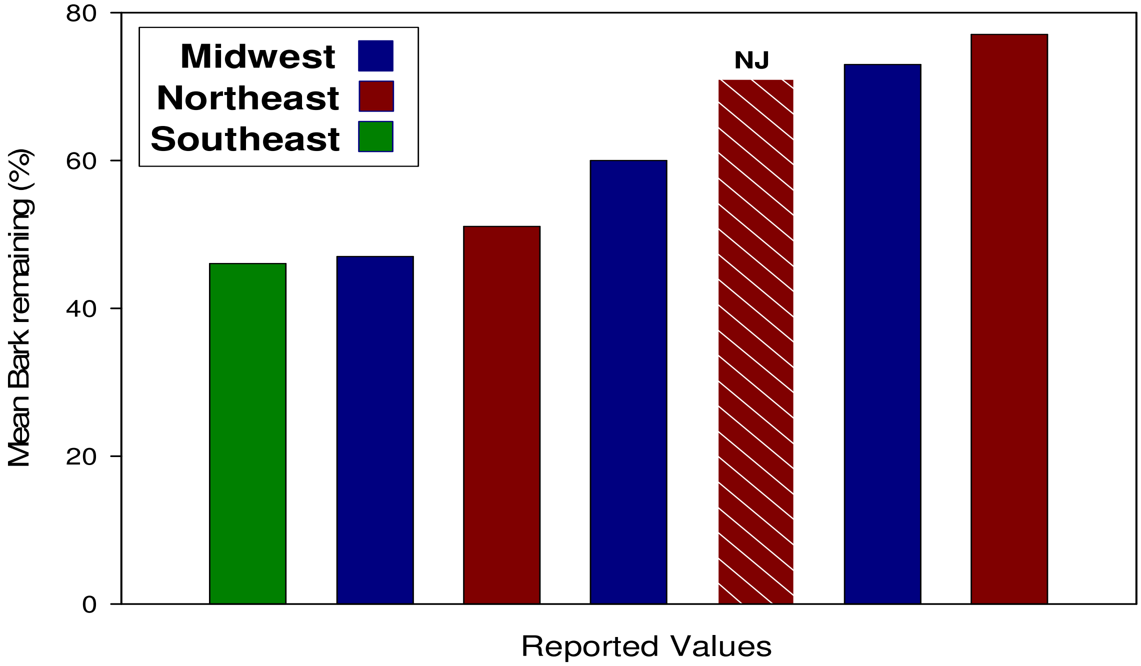

Figure 30. Mean amount of bark remaining for roosts used by female *M. sodalis* by region, as shown in Table 16. This study's estimate is labeled NJ and appears striped. Each bar represents a different study. Butchkoski and Hassinger (2002, 51% above) measured percent of the trunk covered by exfoliating bark.

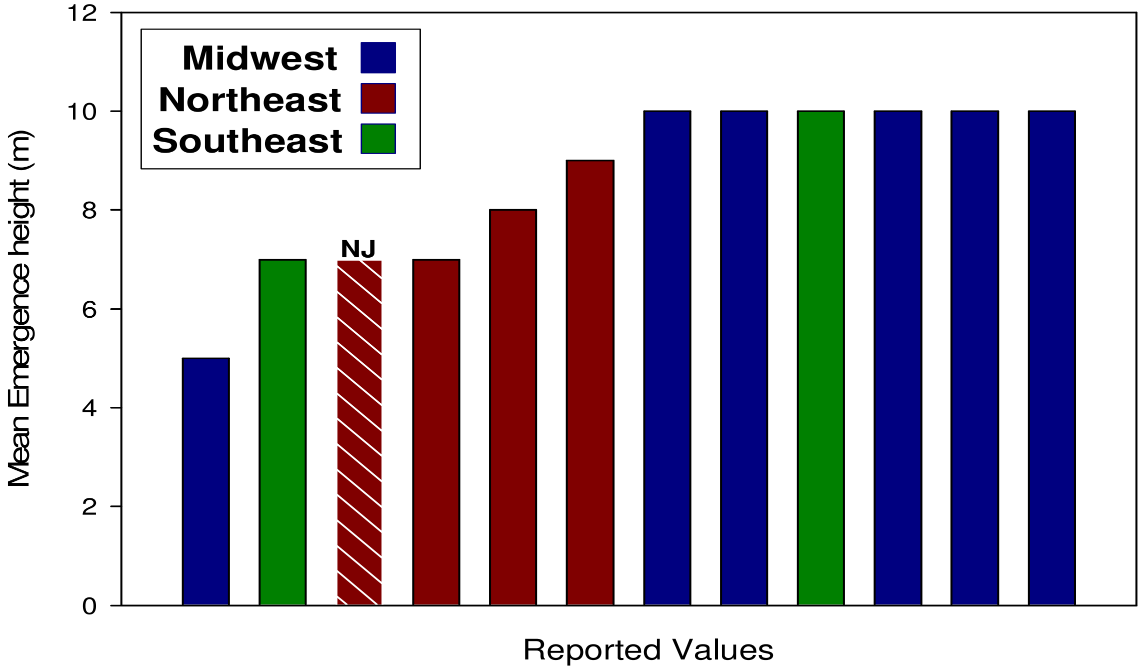

Figure 31. Mean emergence height of female *M. sodalis* by region, as shown in Table 16. This study's estimate is labeled NJ and appears striped. Each bar represents a different study.

exist for height of the roost tree and for canopy cover, but not for dbh or amount of bark remaining. Similarly, canopy cover may be affected by stand-level characteristics, such as patchiness or amount of edge. Diameter at breast height is almost entirely dependent upon the age of the tree and is minimally influenced by stand-level characteristics; this is the most likely explanation for failing to exhibit a regional pattern.

Comparisons of roost tree heights indicate that the northeast falls squarely in the middle range, with midwestern roost trees averaging both taller and shorter than those in the northeast. Height of the roost tree is largely dependent on the cause of tree mortality, and also depends on local soil and rainfall conditions that affect growth rates and patterns (Kramer and Kozlowski 1979). For example, mean height of shagbark hickories at a given age is much greater in the Ohio Valley (where the species grows on the North and East slopes of fertile uplands) than in the Mississippi Valley (where it grows principally in river bottoms; Graney 1990). If this holds true for other species as well, these facts may explain the taller heights of some roost trees observed in the Midwest. However, regional differences in height are probably not the result of bat preferences, since height alone is unlikely to affect the thermal characteristics of the roost – it is more likely that bats would select trees on the basis of their relation to the surrounding canopy.

Emergence height appears to be fairly consistent across studies, generally ranging from 7-10m (Fig. 31). Though emergence points appear to occur at lower heights in the Northeast, this may be in part due to the differences in roost tree height among regions (discussed above).

While canopy cover appears to be higher in the Northeast, it is unclear whether this reflects a difference in stand characteristics or in bat behavior among regions. For example, most studies have occurred in agricultural areas with fragmented forests, where edge habitats or patchiness may result in lower canopy cover (Carter et al. 2002, Gardner and Cook 2002, Gardner et al. 1991, Kurta 2005, Watrous et al. 2006). However, Winhold (2007) suggests that the extreme loyalty exhibited by *M. sodalis* to a home range (as observed by Kurta and Murray 2002) may represent "an attempt…to hold on as the habitat around them disappears," which may suggest that the association with agricultural areas is an artificial result of the prominence of that industry in the Midwest, where most studies have taken place. Palm (2003) found high canopy cover in the Champlain Valley of Vermont, where the dominant matrix communities are large-scale forest communities that have become fragmented into small, discontinuous forest stands since European settlement; this suggests that bats may exhibit a preference for high canopy cover it if is available. High canopy cover at Great Swamp may be due to the availability of larger tracts of forest, the use of living *C. ovata* roosts, or behavioral selection by the bats for this trait.

Though no regional trend was evident for the amount of bark remaining (frequently referred to as bark cover), examination of the literature reveals that a strong pattern does exist which is heavily dependent upon the use of *C. ovata* as roosts. Since living shagbark hickories have 100% bark remaining and dead or dying trees retain their bark well (Gardner et al. 1991), frequent use of the species as a roost tree results in high estimates of mean bark remaining: as use of *C. ovata* declines, so does the mean amount of bark cover (Table 18). (For example, Great Swamp is among the higher observations of bark cover, but this is not surprising given that 13 of 72 roost trees were *C. ovata*). This association was investigated and the variables proved to be significantly correlated ($n = 7$; $Rho = 0.9644$; $p = 0.0004$). This indicates that the frequency of *C. ovata* among roosts drives mean bark cover, and reveals that estimates cannot be compared across studies without acknowledging the use of *C. ovata* as roosts. Removing shagbark hickories from consideration (as was done here and by Palm 2003) may remove a significant amount of the variation observed between studies and could result in more accurate

Table 18. Mean amount of bark remaining and frequency of *C. ovata* as reported in studies of the Indiana bat. Estimates and errors either taken directly from the citation or calculated from data presented therein. Frequency and mean bark remaining were significantly correlated (n = 7; Rho = 0.9644; p = 0.0004).

# roosts	# *C. ovata*	Frequency of *C. ovata*	Mean (± se)	Citation
11	4	0.36	77.3 ± 15.2	Palm 2003
52	18	0.35	78.8 ± 3.15	Callahan 1993
72	**13**	**0.18**	**70.9 ± 3.59**	**This study**
14	2	0.14	55.8 ± 10.1	Schultes 2002
47	1	0.02	47.0 ± 3.9	Carter and Feldhamer 2005
14	0	0.00	49.5 ± 7.8	Winhold 2007
8	0	0.00	46.3 ± 6.05	Britzke et al. 2003

estimates for predicting roost suitability based on the amount of bark cover. This is especially important, since prior observations have suggested that the amount of bark cover is not a useful predictor of Indiana bat occupancy, despite the fact that the vast majority of *M. sodalis* roosts occur beneath exfoliating bark (Britzke et al. 2003, Callahan et al. 1997, Carter 2003, Gumbert 2001, Kurta 2005, Kurta et al. 1996 and 2002, and Palm 2003).

Bark remaining/exfoliating

Exfoliating bark was defined in this study as falling away from the tree and exposing the trunk. This definition was necessary to articulate between the exfoliating bark of dead and dying trees and the naturally exfoliating bark of shagbark hickories, which are prevalent in the study area. This varies from the system used by Gardner et al. (1991), who used the amount of exfoliating bark as a measure of a tree's suitability for *M. sodalis*. In their system, "each roost tree was…ranked according to its potential to provide roost sites beneath its bark. Ranking was based upon a visual assessment of the amount of loose and peeling bark on a tree's trunk and limbs." Their report later states that, "two living *C. ovata* roosts had high bark potential," indicating that their definition includes the naturally peeling bark of this species. Distinguishing this from the exfoliating bark of dead and dying trees is important, both in the methods and interpretation of the data, especially since Gardner et al.'s (1991) system is so highly cited as to have practically become standard procedure. Their system (where shagbarks may be considered to have 100% exfoliating bark) may be appropriate for measuring the suitability of potential roost trees, but it cannot be used to compare the amount of exfoliating bark between trees (as it is frequently used). While most would agree that a large-diameter *C. ovata* provides roosting habitat along its length, the problem arises in lumping estimates of (naturally) peeling bark for this species with estimates of exfoliating bark for all other species, and assuming these are comparable. Abiding by the definition laid out in this study allows for more accurate estimates of the range and mean amount of exfoliating bark for trees utilized by *M. sodalis* at a given study site. Shagbark hickories can then be considered separately, as they are known to provide highly suitable roosting habitat. (Other factors may be similarly influenced by *C. ovata* , as evidenced by the observation of Kurta 2005 that high canopy cover seemed to be correlated with sites where many living shagbarks were used. Further examination of the effects of *C. ovata* on roost characteristics would be worthwhile, but was not conducted here).

A search of the literature reveals that no studies have yet made this categorical distinction between the exfoliating bark of *C. ovata* and other species, though most recognize the difference in character. Most studies use Gardner et al.'s (1991) system as a standard to categorically measure the amount of "loose" (in other words, exfoliating) bark (Gumbert 2001, Kurta et al. 1996, Schultes 2002, Timpone 2004), although specific mention of shagbark hickories and whether or not they were used is rarely made. Thus, studies may not be directly comparable even though a "standard" system was used.

I therefore propose that Gardner et al.'s (1991) system should be used only for the express purpose of ranking suitability, and should not be used to measure the amount of exfoliating bark present on roost trees. Careful attention should be paid to the distinction – suitability for *M. sodalis* is different than the amount of exfoliating bark (using the definition laid out in this study), which is a measure of decay that may *indicate* suitability. Further clarification will be of assistance here, since the bark of *C. ovata* does not provide suitable roosting habitat at all ages or dbh's. Among the literature, the smallest *C. ovata* to be used as a roost was a live tree with a dbh of 12 cm (Callahan 1993); this dbh may therefore be considered the minimum size at which the species becomes suitable for roosting by *M. sodalis*. However, the bark of most *C.*

ovata this size does not peel in sheets large enough to provide roosting habitat for more than a few bats; at Great Swamp peeling is widespread and substantial at about 30 cm dbh (pers. obs.). A review of 7 studies (Callahan 1993; Gardner et al. 1991; Gumbert 2001; Schultes 2002; Watrous 2008 pers. comm.; Whitaker and Brack 2002; and this study) which provided characteristics and emergence counts for *C. ovata* revealed that 6 of 8 primary roosts were over 40 cm dbh, while the minimum dbh of a primary roost (according to Callahan's 1993 definition of use by 30 or more bats on more than one occasion) was 18 cm (Callahan 1993). Therefore, in an attempt to establish suitability criteria for *C. ovata* that is consistent with the widely used system of Gardner et al. (1991), I recommend that *C. ovata* be considered to provide low suitability at dbh's of 12-18 cm; medium suitability at dbh's of 18-30 cm; and high suitability at dbh's over 30 cm. Further investigation of the range of dbh's at which the species is utilized as a roost, and the number of bats emerging from such roosts, may provide additional guidance to revise this criteria.

HOME RANGE ESTIMATION AND FORAGING

Results

Night telemetry in 2006 was limited to occasional post-release monitoring of radiotransmittered bats by a single staff member. In 2007, increased staffing allowed simultaneous monitoring by three or more observers (triangulation). Of the 14 Indiana bats that received radiotransmitters in 2007, evening telemetry was attempted for 11 bats (2 pregnant and 9 lactating) over 24 nights; however, on 2 nights the bats never emerged, resulting in foraging estimates for only 9 individuals. Bats were followed for a mean of 2.9 nights each (± 0.56 se, range 1-5).

Of the 678 scheduled timepoints at which readings were taken, 426 produced successful location estimates within LOAS. Of those, 181 biangulations and 41 triangulations that produced biangulated estimates were discarded. Of the remaining 204 timepoints for which triangulation was possible, 43 estimates produced error ellipses under 2 ha (highly reliable) and 43 produced error ellipses 2-10 ha (reliable). On average, 1.8 highly reliable estimates (± 0.60 se, range 0–6) were produced per animal per night (n=9 bats) for a grand average of 4.8 estimates per bat (± 1.41 se, range 0-12). An average of 1.9 reliable estimates (± 0.81 se, range 0-6) were produced per animal per night for a grand average of 4.8 estimates per bat (± 1.90 se, range 0-16). Combined, a mean of 3.7 estimates per animal per night (± 1.34 se) were produced for a grand average of 9.6 estimates per bat (± 3.07 se, range 0-26). Due to the limited number of highly reliable foraging location estimates that resulted per night per animal, analysis of foraging activity was not conducted. Instead, the resulting locations were used to produce estimates of home ranges utilized by individual bats and colonies.

Home range estimates were produced for 10 bats that had more than 5 known locations each. Sample size was not sufficient to separate bats of different reproductive conditions, and results were pooled. Mean size of the MCP's (used to estimate home range size) was 236.6 ha (±136.45 se, range 16.4 - 1391.9). Mean size of the 50, 90 and 95% KDE's was 325.0 ha (± 33.10 se), 1175.2 ha (± 156.13 se) and 1537.1 ha (± 213.99 se), respectively (Table 19). Size of the home range was not correlated with the number of points for any of the estimation methods (Rho and p = 0.42, 0.23; -0.15, 0.68; 0.11, 0.76; and 0.16, 0.66 for MCP and 50, 90 and 95 KDE's respectively, Pearson correlation).

Mean size of colonies was significantly larger in 2007 for two of the measures (50% KDE, p = 0.0045 and 90% KDE, p = 0.0440; paired two-sample t-test). However, no difference in colony size was detected using the MCP and 95% KDE estimates (p = 0.0956, 0.0579 respectively; paired two-sample t-test). (Maps for each colony are shown in Fig. 32-34). With both years combined, mean size of the MCP's for the 3 colonies identified was 1620.6 ha (± 618.57 se). Mean size of the 50, 90 and 95% KDE's was 499.9 ha (± 56.40 se), 2287.7 (± 476.80 se) and 2992.9 ha (± 601.81 se) respectively (Table 20). Core home ranges (i.e., 50% kernel estimates) of the colonies did not overlap, though there was substantial overlap in the 95% KDE's (Fig. 35). Colonies used the same core areas in both years and showed no obvious shift across the landscape (Fig. 32-34). Home range size was not correlated with the number of points for any measure in either year, or when years were combined (p ranged from 0.4639 to 0.9794).

Discussion

The analysis of foraging data was limited by the infrequency with which timepoints resulted in reliable estimates. Some of this is to be expected given the difficulty of tracking a flying

Table 19. Home range estimates for female Indiana bats (*M. sodalis*) with more than 5 known locations at Great Swamp NWR, as estimated by minimum convex polygons (MCP) and fixed kernel estimates. P = pregnant; L = lactating; PL = post-lactating; NR = non-reproductive.

						# Foraging points of ellipse size		Estimated home range (ha)			
								MCP	Fixed Kernel		
Bat	Year	Repro condition	Total # locations	# capture sites	# roosts	< 2 ha	2-10 ha		50	90	95
164.103	2007	L	33	1	6	10	16	38.4	243.9	820.0	1065.7
164.405/164.155[a]	2007	P/PL	27	2	5	12	8	1391.9	424.6	2104.0	2911.6
164.006	2007	L	17	1	3	3	10	16.4	233.4	776.1	1011.5
164.203	2007	L	14	1	1	6	6	24.7	237.0	808.8	1054.7
164.718	2007	L	13	1	2	7	3	495.6	479.4	1820.0	2383.2
164.43	2006	PL	12	1	11	0	0	20.3	239.5	788.4	1022.0
164.304	2006	L	8	1	7	0	0	46.8	259.4	876.0	1146.6
164.461	2007	P	7	1	3	3	0	180.0	425.6	1499.2	1906.6
165.060	2006	L	6	1	5	0	0	119.5	450.4	1401.1	1758.2
164.554	2006	NR	6	1	5	0	0	32.6	256.7	858.2	1111.0
							MEAN	236.6	325.0	1175.2	1537.1
							N	10	10	10	10
							SE	136.45	33.10	156.13	213.99

[a] This bat received 2 transmitters, one on 6/7/07 and a second on 7/24/07. The second transmitter detached in less than 24 hours and resulted in the identification of 1 roost tree.

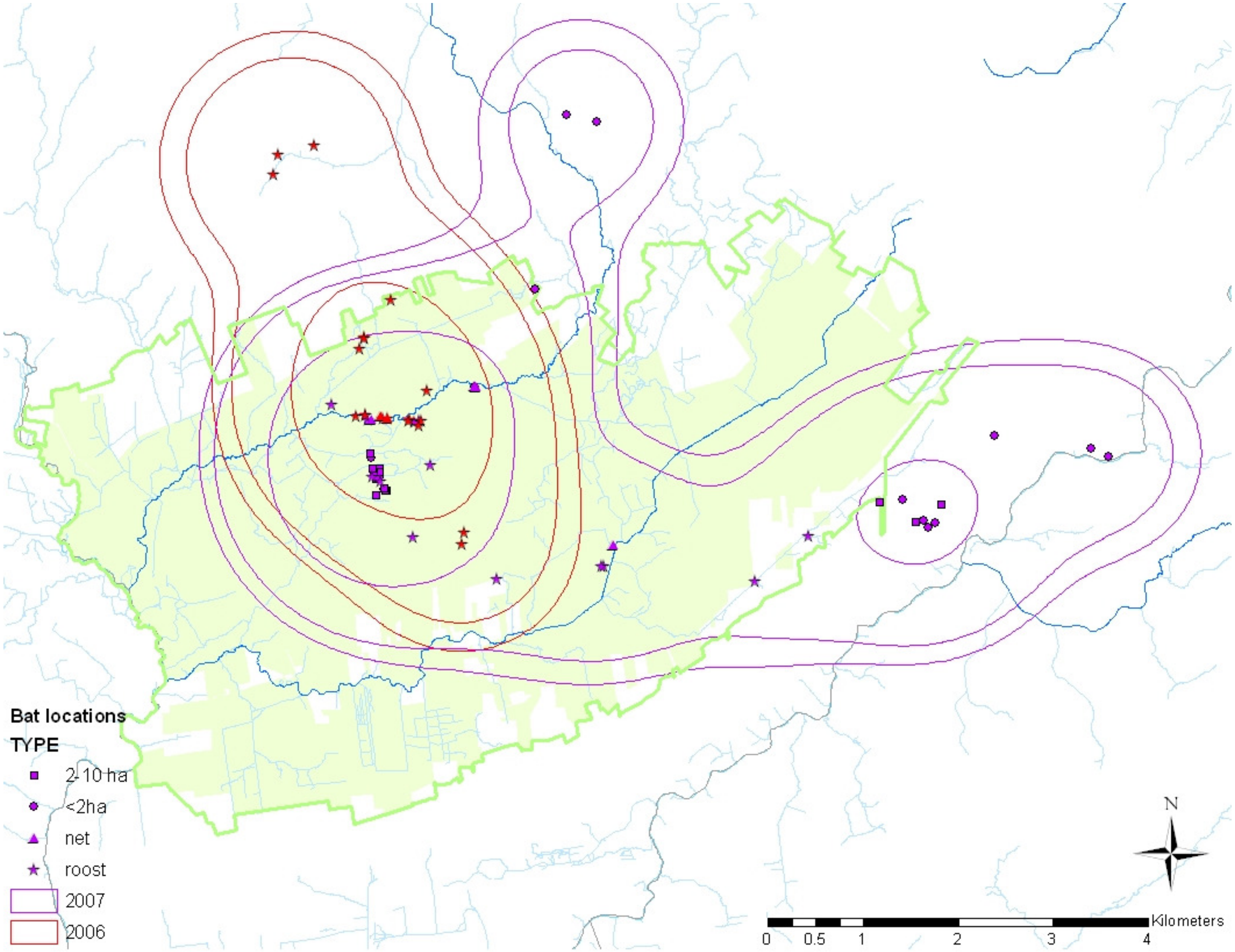

Figure 32. Home range of the OU-3 colony in 2006 (red symbols) and 2007 (purple symbols). The 50, 90 and 95% kernel estimates are shown separately for each year. Lands in refuge ownership are shaded.

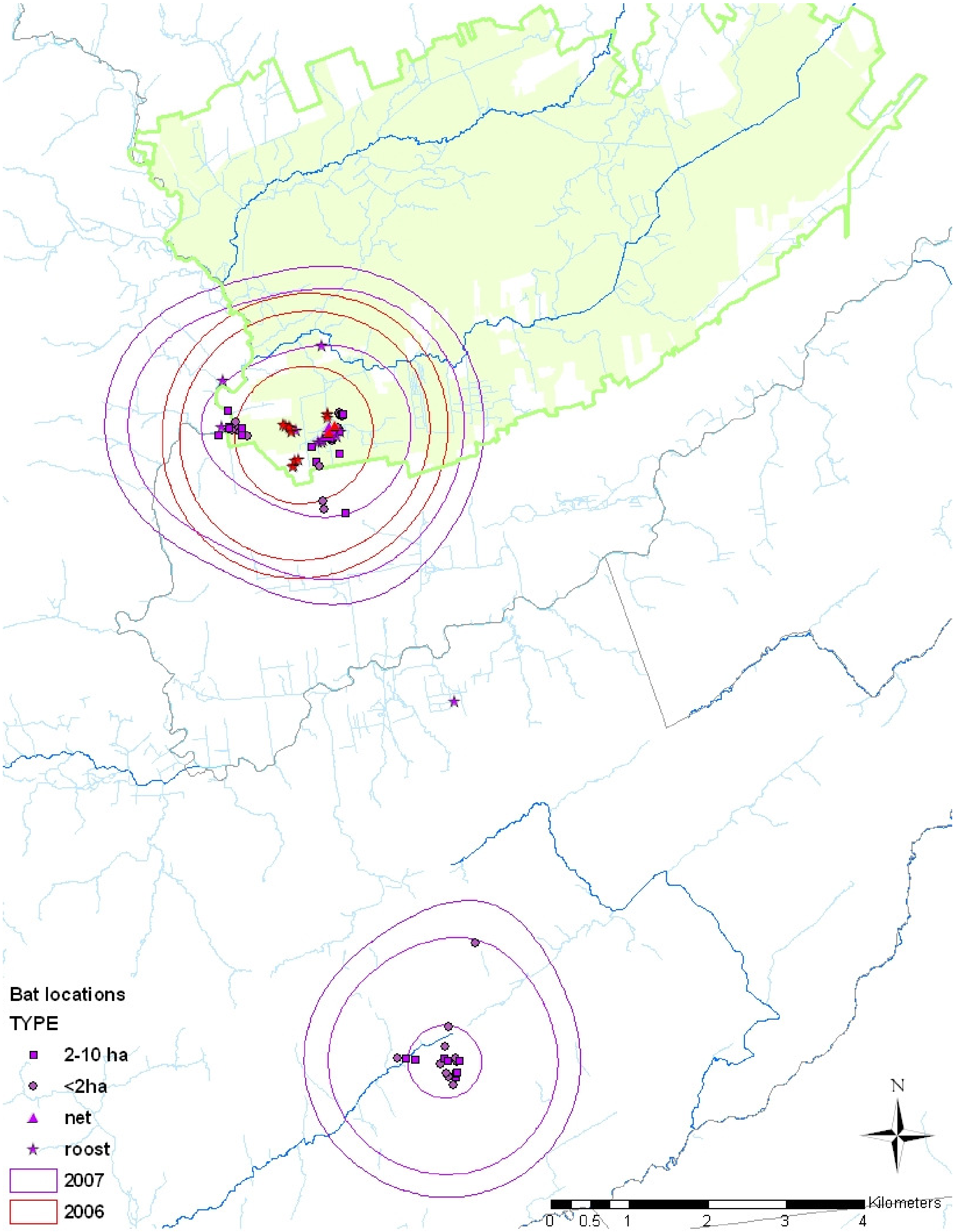

Figure 33. Home range of the Sherwood Lane colony in 2006 (red symbols) and 2007 (purple symbols). The 50, 90 and 95% kernel estimates are shown separately for each year. Lands in refuge ownership are shaded.

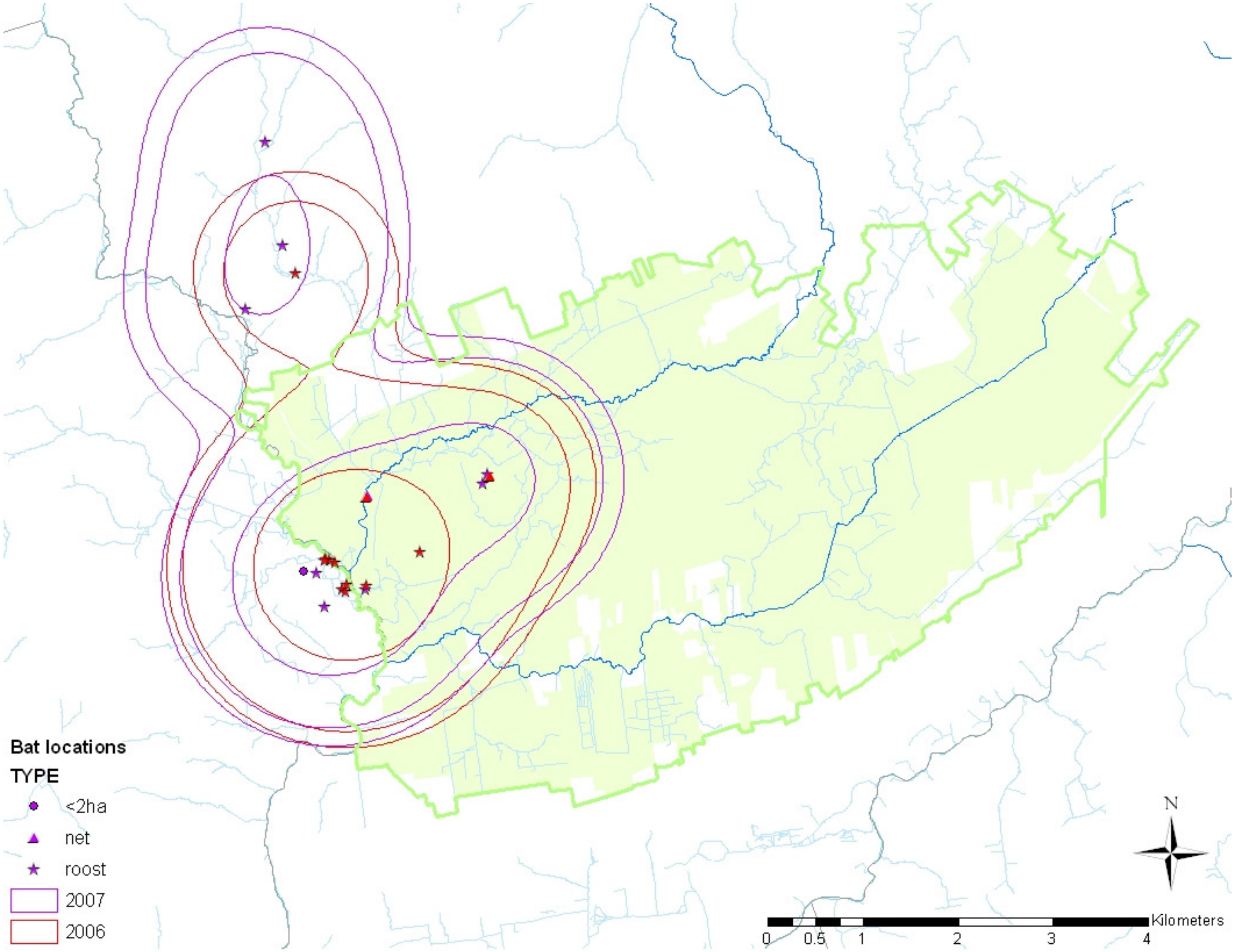

Figure 34. Home range of the Passaic River colony in 2006 (red symbols) and 2007 (purple symbols). The 50, 90 and 95% kernel estimates are shown separately for each year. Lands in refuge ownership are shaded.

Table 20. Home range estimates for colonies of female Indiana bats (*M. sodalis*) at Great Swamp NWR, 2006-2007. Years shown separately and combined, as estimated by minimum convex polygons (MCP) and fixed kernel estimates. Means and errors are shown for the 3 colonies, with years combined.

						# Foraging points of ellipse size:		Estimated home range (ha)			
									Fixed Kernel		
Colony	Year	# bats	Total # locations	# capture sites	# roosts	< 2 ha	2-10 ha	MCP	50	90	95
OU-3	2006	4	19	2	17	0	0	264.11	410.84	1516.49	1940.80
OU-3	2007	7	46	4	15	14	13	2316.04	677.45	3013.69	3824.71
OU-3	2006-2007	11	64	6	31	14	13	2750.27	612.74	3241.27	4192.22
Sherwood Lane	2006	3	15	2	13	0	0	22.86	242.13	794.67	1038.87
Sherwood Lane	2007	3	73	3	12	28	30	1492.41	516.38	1915.32	2631.81
Sherwood Lane	2006-2007	6	88	5	25	28	30	1492.41	443.39	1808.67	2481.42
Passaic River	2006	3	12	2	10	0	0	94.93	327.40	1378.98	1821.68
Passaic River	2007	3	10	1	8	1	0	607.86	656.01	2052.34	2535.42
Passaic River	2006-2007	6	22	3	18	1	0	618.99	443.69	1813.10	2305.09
							MEAN	1620.6	499.9	2287.7	2992.9
							SE	618.58	56.40	476.80	601.81

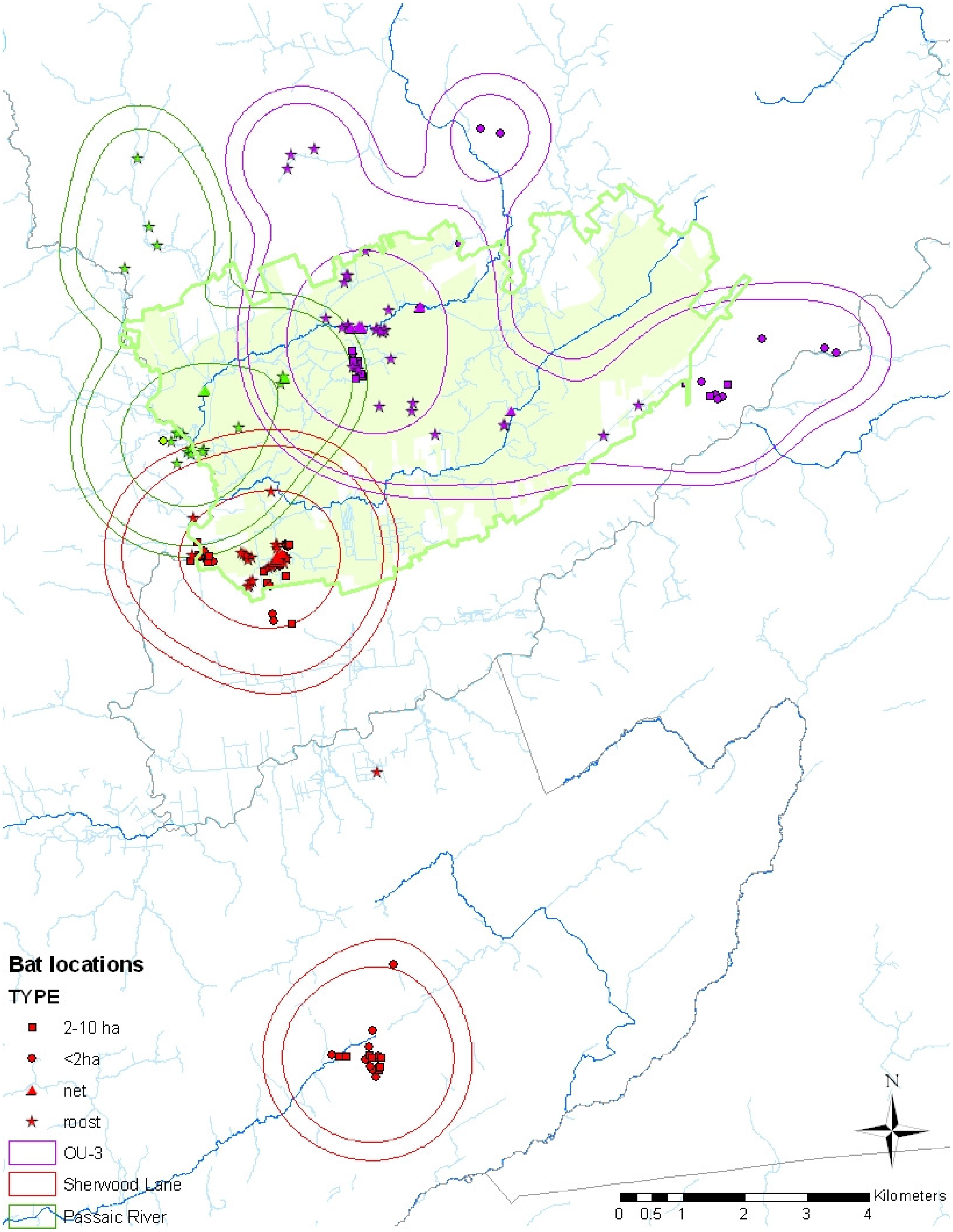

Figure 35. Home ranges of the 3 colonies identified: Passaic River (green symbols), Sherwood Lane (red symbols), and OU-3 (purple symbols); 50, 90 and 95% kernel estimates are shown. Lands in refuge ownership are shaded.

animal across a landscape that has few accessible roads. Inevitably, some or all members of a telemetry team would temporarily lose contact with the transmittered bat, preventing triangulation (as was the case for 309 of 678, or 45.6% of timepoints). While this aspect of telemetry could be improved with the addition of more observers and/or the improved spacing of existing observers, signal bounce, false directions and/or phase cancellation may also prevent successful triangulations (Butchkoski 2004).

Because kernel estimates generate contour lines enclosing a set percent of the locations for each animal (Beyer 2006), 50% KDE's are preferred over 100% MCP estimates (as created in this study) for identifying where animals spent the majority of their time. This is because the KDE method can reveal activity nuclei within a home range, whereas MCP can only produce mononuclear core areas (Kenward 1987, Wauters et al. 2007). Given small sample size, KDE produces larger home range sizes than an equivalent MCP estimate (Wauters et al. 2007); thus, a 95% KDE estimate is more likely to enclose nearly all of a bat's utilized habitats than a 100% MCP. However, because KDE's do not necessarily enclose travel corridors between core areas (see estimate for bat 164.405 in Appendix A), they too can underestimate home range. Both methods are improved when multiple locations per animal are available; for example, Wauters et al. 2007 recommend that a minimum of 40 fixes be used to describe the home range of a small mammal, and Seaman et al. (1999) recommend a minimum of 30, and preferably 50, locations per animal be used to produce kernel estimates. This condition was met for only 1 of 10 animals and 2 of 3 colonies in this study (Tables 19 and 20), and thus the remaining home range estimates should be interpreted with some caution. However, home range estimates were produced for all colonies and all animals with more than 5 known locations in an effort to identify the general areas used by bats at Great Swamp.

Home ranges for individual bats are shown in Appendix A, and are based upon capture site, roost locations, and estimated foraging points with <10 ha error ellipses. (Though estimated foraging points with > 10 ha ellipses were deemed unreliable and were not used in home range analyses, they are displayed as a means of indicating the general locations in which bats foraged). Home range estimates ranged from 1011.5 - 2911.6 ha (95% KDE), with a mean of 1537.1 ha (± 213.99 se). Core home range estimates (50% KDE) ranged from 233.4 – 479.4 ha (± 33.1 se). There was no correlation between home range size and the number of points used to calculate these estimates, indicating that some other factor (such as reproductive status) may be driving the size of the home range used. Although sample size was too small for statistical comparisons, 2 of the 3 bats with the largest home ranges were pregnant (Table 19), and the remaining (lactating) bat's home range estimate was skewed by the one-time use of a roost tree near the capture site, despite having previously exhibited the highest roost fidelity of any transmittered bat (Table 15, see estimate for bat 164.718 in Appendix A). Kurta et al. (2002) suggest that pregnant bats, having just emerged from hibernation, must refamiliarize themselves with the condition of roost trees on the landscape; this may explain why pregnant bats appear to have used larger home ranges in this study.

Mean size of colonies was significantly larger in 2007 using 50% and 90% KDE's, but not for MCP or 95% KDE estimates. Estimates produced by MCP are a direct result of the spatial relationships between known locations, and in that sense they are highly affected by sample variation; 50% KDE estimates are a more reliable way of examining core areas used by bats. Thus, the difference in size of the home ranges between years may be viewed as significant ($p = 0.0045$). Larger home ranges in 2007 may be due to evening telemetry conducted in 2007 which revealed the use of new areas in the Sherwood Lane and OU-3 colonies; and may be an artifact of sample variation among roosts being identified within the Passaic River colony each year. However, roosts were located significantly farther apart in 2007, although there was no difference in distance between trees used by individual bats (see roost tree section: landscape movements); this suggests that the greater home ranges of 2007 may be independent of radiotelemetry's influence.

Many studies fail to estimate home range for individual bats or for colonies, instead citing the maximum distance between roosts/capture sites or the radius/diameter of a circle that would encompass all roosts (Callahan et al. 1997, Carter and Feldhamer 2005, Gardner et al. 1991, Kurta et al. 2002). Among studies that specifically examine home range, most have focused only on the areas utilized during foraging, even though capture and roost locations may have also been known (Butchkoski and Hassinger 2002, Menzel et al. 2005, Rommé et al. 2002, Sparks et al. 2005, Watrous et al. 2006). This likely results in smaller home range estimates than are actually utilized; for example, Rommé et al. 2002 found that the capture sites of some animals tracked in spring and autumn were up to 8.6 km from their estimated home range. Such methodology makes little sense for studies that examine both roosting and foraging ecology during the maternity season, given that the occurrence of roosts on the landscape is of prime importance to the species' reproductive ecology, and because the capture of animals may occur during evening foraging. Thus estimates that ignore capture and roost locations better indicate foraging ranges than home ranges, and should be specified as such (as was done by Sparks et al. 2005). To clarify this distinction, the estimates produced by studies using this methodology will hereafter be referred to as foraging ranges.

Differences in methodology between studies, as well as the difference mentioned above in this study's approach, make comparisons of home range size difficult. However, it appears that female Indiana bats at Great Swamp may have larger home ranges than those in most other studies. Butchkoski and Hassinger (2002) used 50% KDE's and found core foraging areas of 39-112 ha in size; the same approach at Great Swamp identified core home ranges from 233-479 ha in size. Menzel et al. (2005) utilized 95% KDE's, and found that mean foraging range was 161.1 ha; Watrous et al. (2006) also utilized KDE's (although they do not specify the percent used) and found mean foraging range to be 83 ha (0.83 km^2). The results of this study are by comparison almost an order of magnitude greater – the 95% KDE yielded a mean home range of 1537 ha. This may be due to the inclusion of pregnant, far-ranging bats in this analysis (Menzel et al. 2005 did not have bats of this condition), the inclusion of roosts and capture sites in home range estimations, the limited number of points that were used to produce the estimates, or a combination of these factors. Still, that the distances moved by bats at Great Swamp are greater than has been documented elsewhere (see roost trees: landscape patterns discussion) supports the conclusion that these bats are using larger home ranges. Yet these results are not consistent across estimation methods. Sparks et al. (2005) utilized a 95% MCP and found that foraging ranges averaged 335 ha (3.35 km^2); at Great Swamp the 100% MCP method revealed a mean home range size of 236.6 ha. Sparks et al.'s (2005) study was conducted near Indianapolis International Airport, and foraging habitat consisted mostly of agricultural land (51%), open habitats (including pasture, low-density residential and open water, 15.1%) and woodlands (28%); they found that woodlands were significantly preferred over other habitat types, and also documented bats using a riparian corridor to traverse the landscape. Perhaps bats in Indiana were limited in their preferred foraging habitats and required very large areas to meet their needs. As explained above, the susceptibility of MCP estimates to sample variation suggests that 50% KDE estimates are a more reliable way of examining core areas used by bats. The latter method was not employed by Sparks et al. (2005), so it is possible that the larger home ranges used in their study are a result of sample variation and the chance movement of bats they followed during foraging.

SUMMARY

Great Swamp NWR appears to provide an abundance of suitable roosting and foraging habitat for all species of bats, as evidenced by high rates of capture for reproductively active females of six of the nine species occurring within the state of New Jersey. Furthermore, the proportions of *M. sodalis* captured (16.3% of all species), reproductively active females (97.5% of adult females caught after June 15), and sites at which they were caught (91%) indicates that the area provides substantial and important maternity habitat for this endangered species.

Many of the results of this study, as compared to others, suggest that Great Swamp may represent optimal habitat for both foraging and roosting by *M. sodalis.* Menzel et al. (2005) and Murray and Kurta (2004) both found that bats preferentially foraged over forested and riparian habitats when other types were more abundant; these are abundant within the study area. The use of a greater number of trees at Great Swamp and the lower fidelity exhibited to them, combined with the findings of Lewis (1995) that high roost fidelity was inversely related to roost availability, suggests greater availability of roosts here as compared to other study areas. The infrequency with which known roost trees were revisited by individual or multiple bats provides further evidence for a saturation of high-quality roosts, which is consistent with the concentration of 3 maternity colonies within an area < 9 km^2.

Despite high concentrations of quality roosts, *M. sodalis* in this study moved much farther between roosts than has been seen elsewhere. The large home ranges documented here ($\bar{x}$ = 236.6 ha as estimated by MCP and 325.0 ha as estimated by 50% KDE) are consistent with this observation. As evidenced above, this is not due to a shortage of roosts, but may be due instead to an extensive network of forested streams that facilitates movement across the landscape, and foraging grounds that are productive enough to sustain such movements.

Sufficient numbers of studies have been conducted on maternity colonies of *M. sodalis* that it is no longer fair to claim a poor understanding of its roosting ecology. However, there is need for additional studies in the northeast and southeast to improve understanding of the species' needs across its range. Comparisons suggest that overall, *M. sodalis* choose roosts on consistent criteria: here, chosen roosts were dead, large-diameter trees in mid-stages of decay, with less bark remaining and more bark exfoliating than other trees available to bats. These trees were also much closer to water than random trees, and occurred in stands where snags and suitable trees were more prevalent. *Carya ovata* and *U. americana* were preferred as roosts, while *Q. palustris* and *A. rubrum* were used in proportion to and less than their availability, respectively. Bats seem to roost under higher canopy cover in the northeast, though there is insufficient evidence to say whether this is a preference exhibited by bats or a difference in forest structure between study sites.

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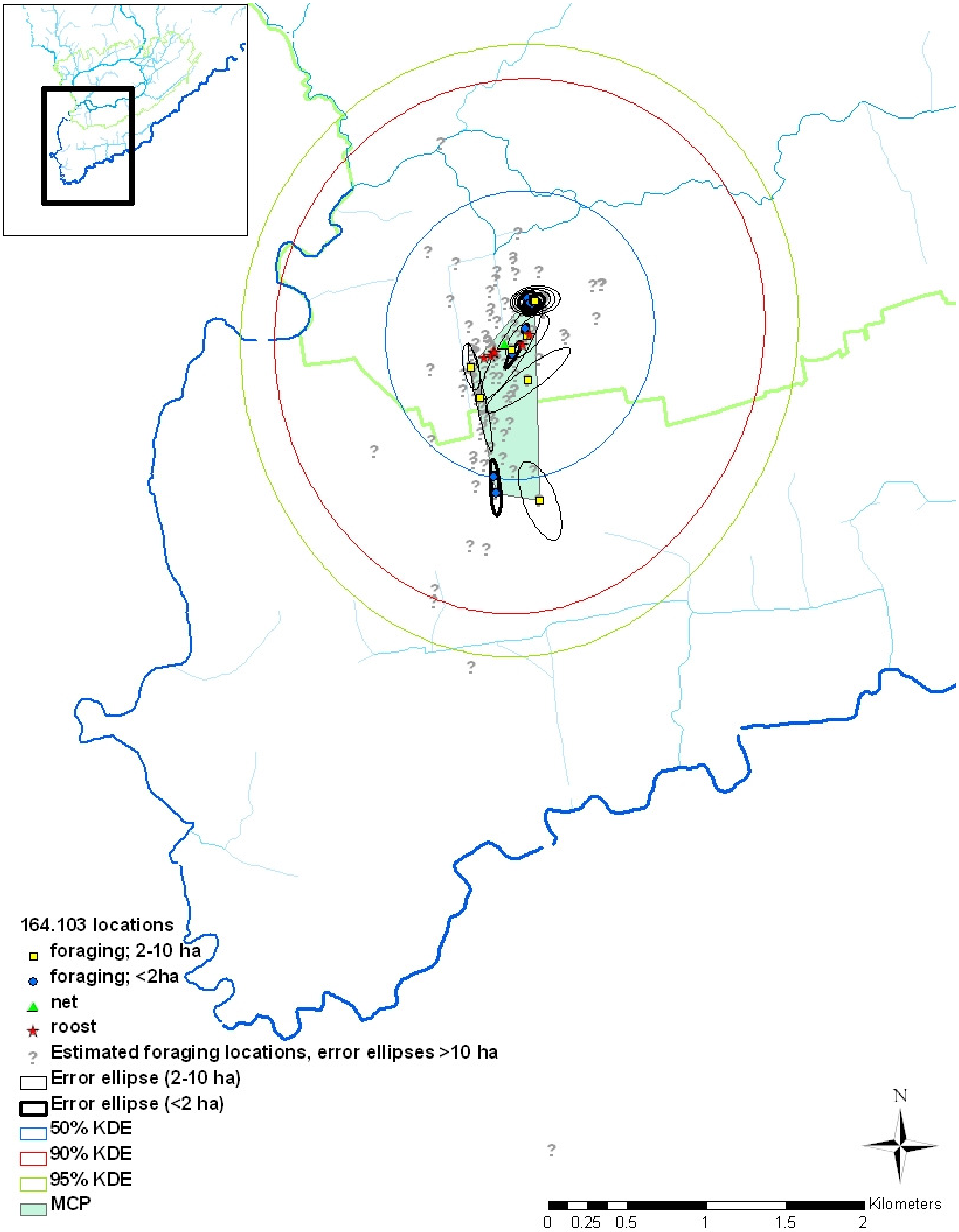
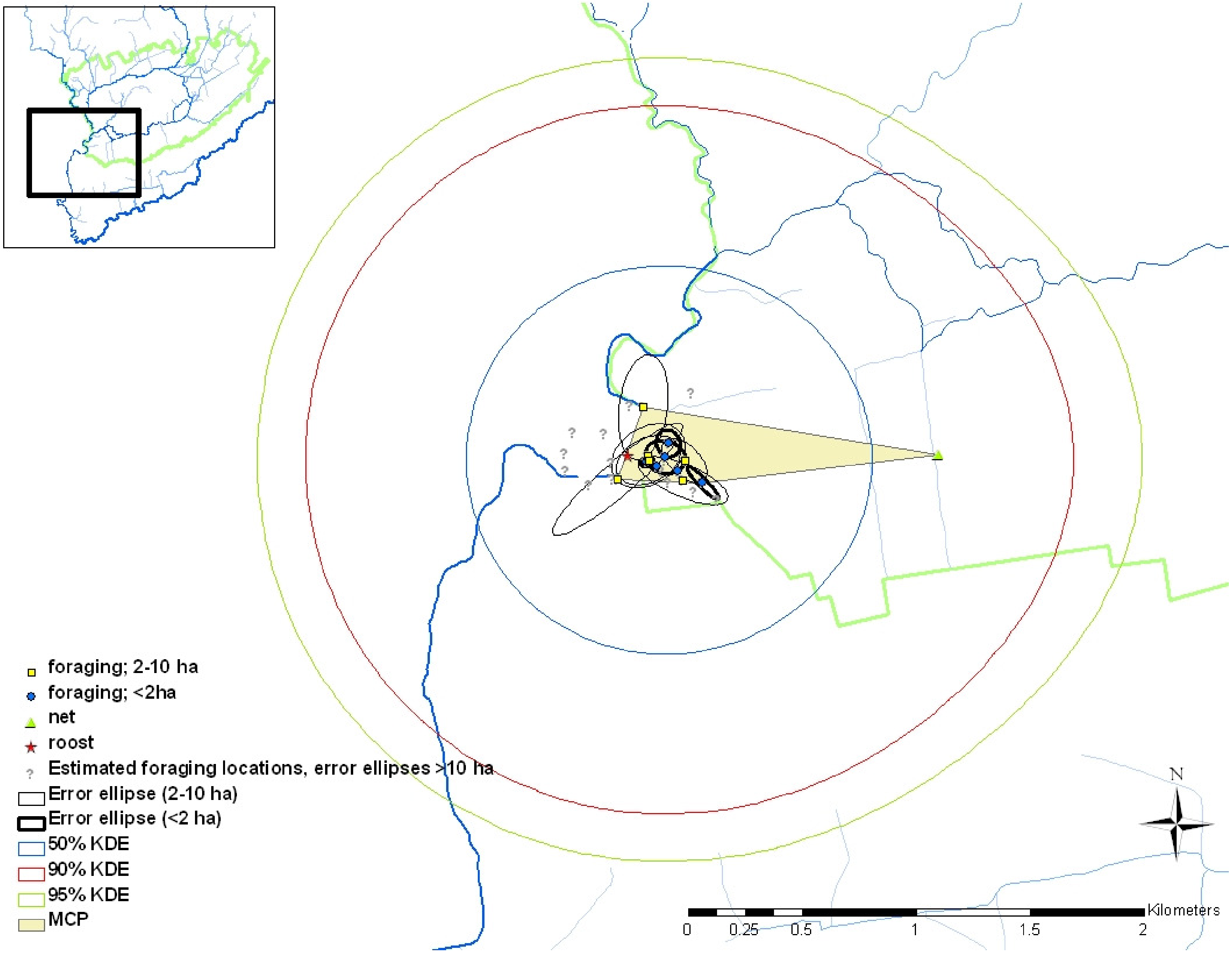
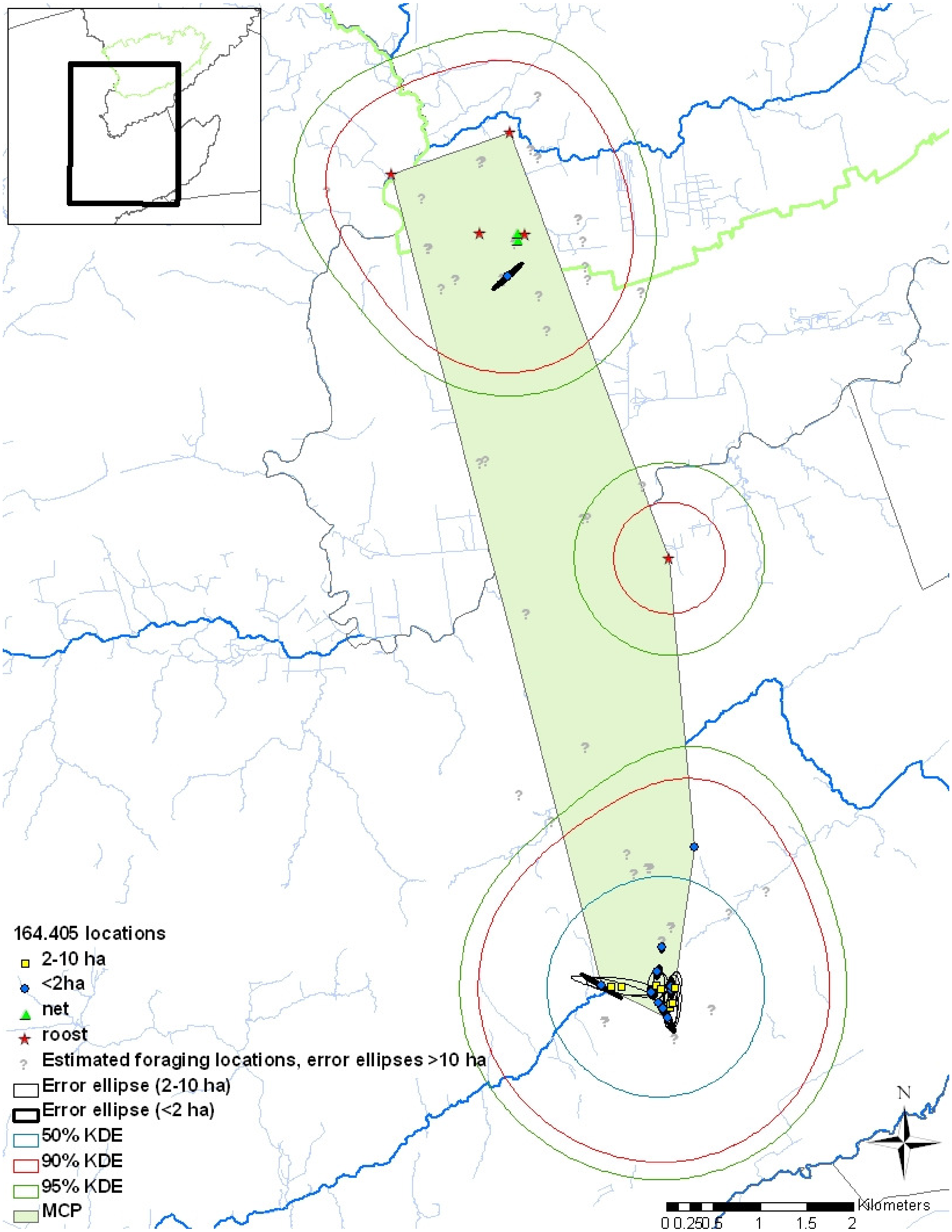
APPENDIX A



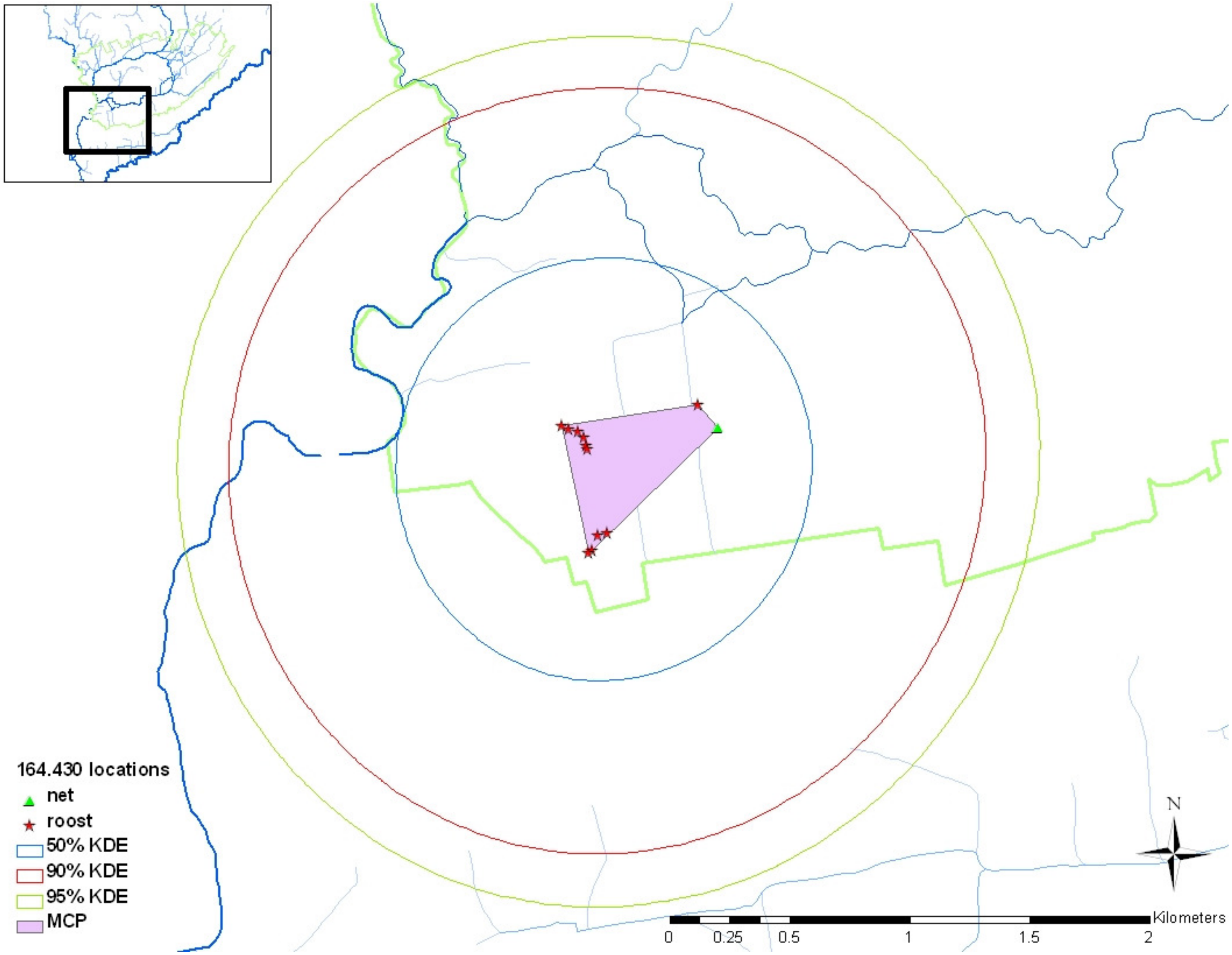
Known locations and home range estimates for bat 164.103 (lactating, captured at Sherwood Lane 7/24/2007).



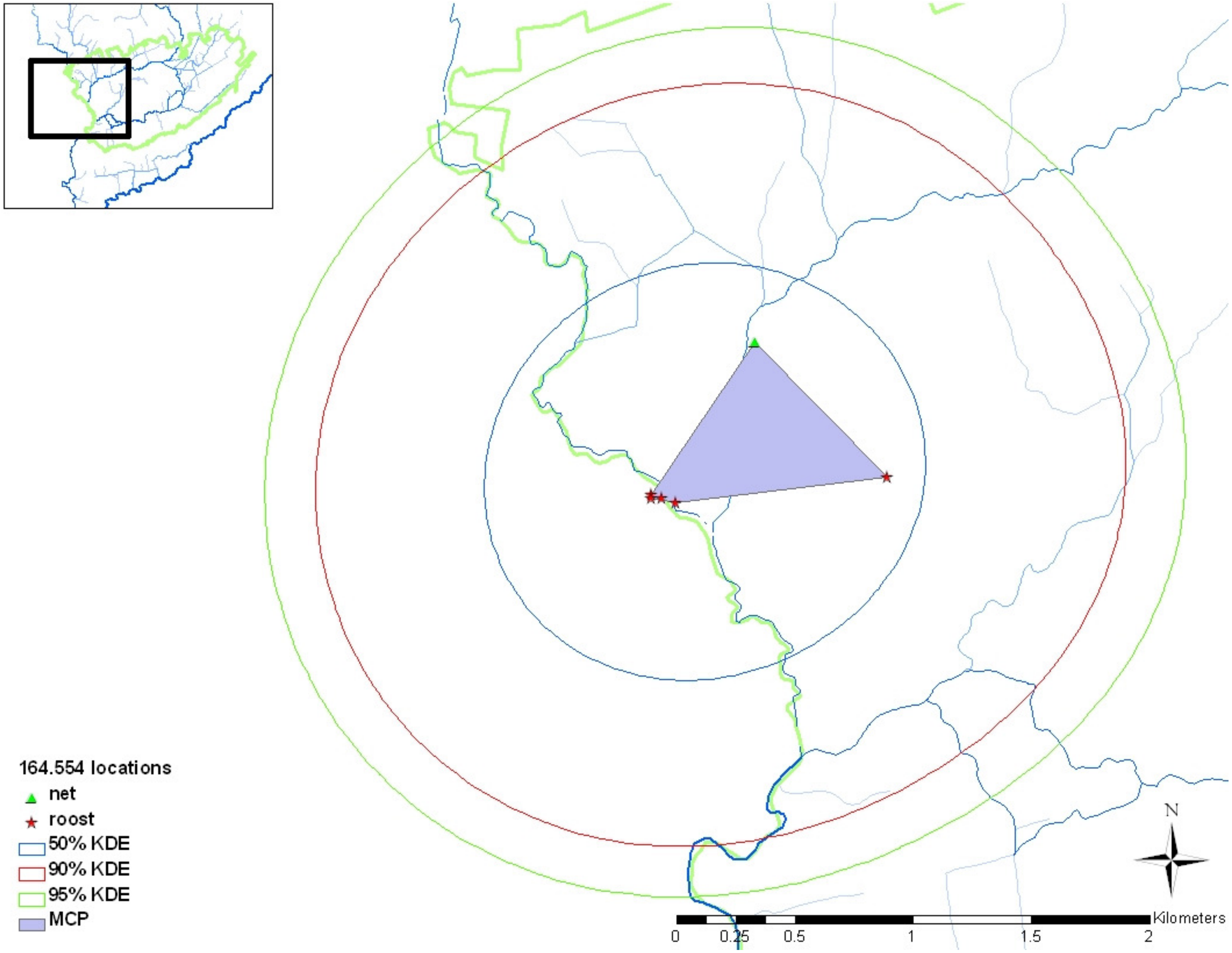
Known locations and home range estimates for bat 164.203 (lactating, captured at Sherwood Lane 7/24/2007).



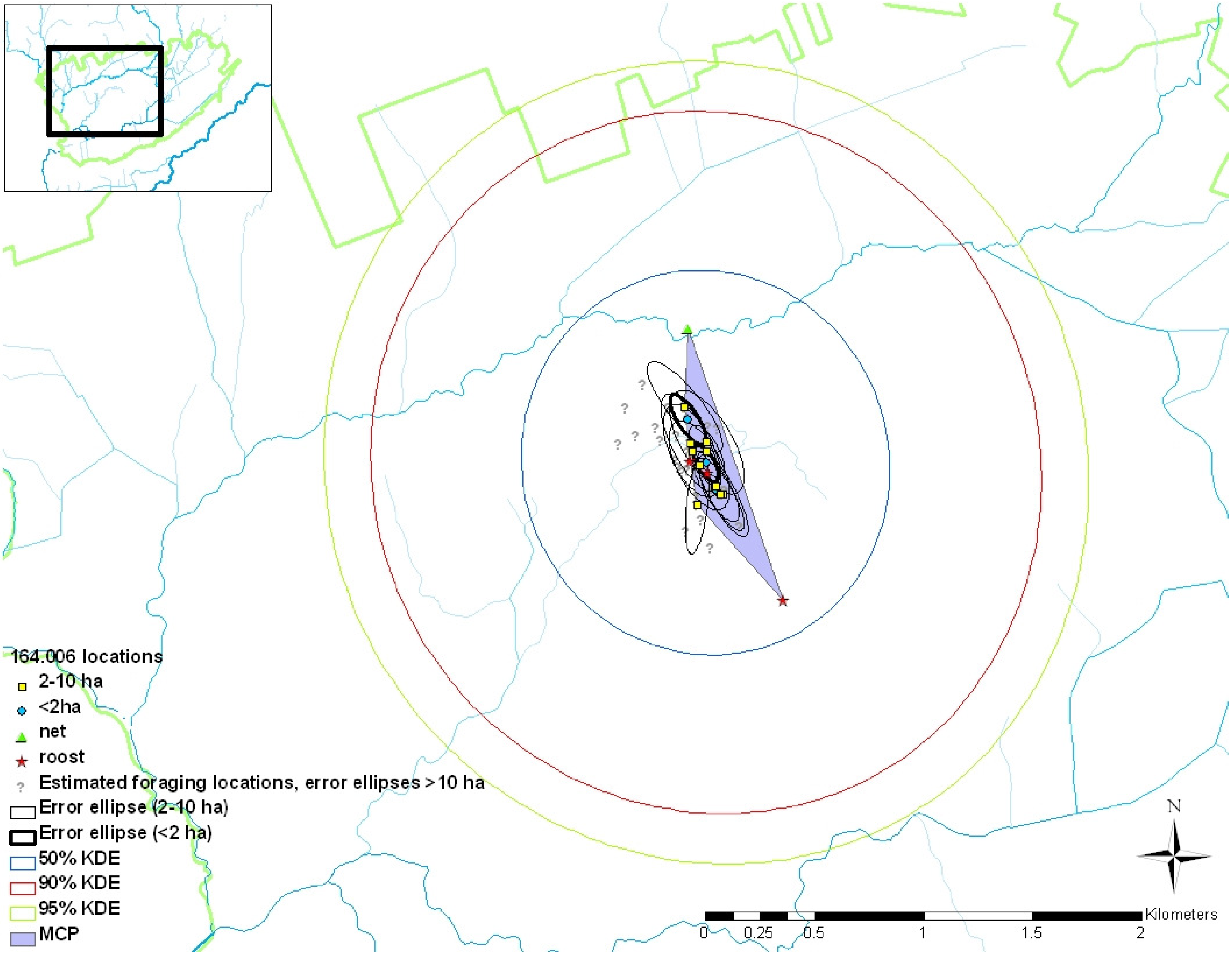
Known locations and home range estimates for bat 164.405/164.155 (Initially captured when pregnant at Sherwood Lane 6/7/2007; later recaptured in same location when post-lactating).



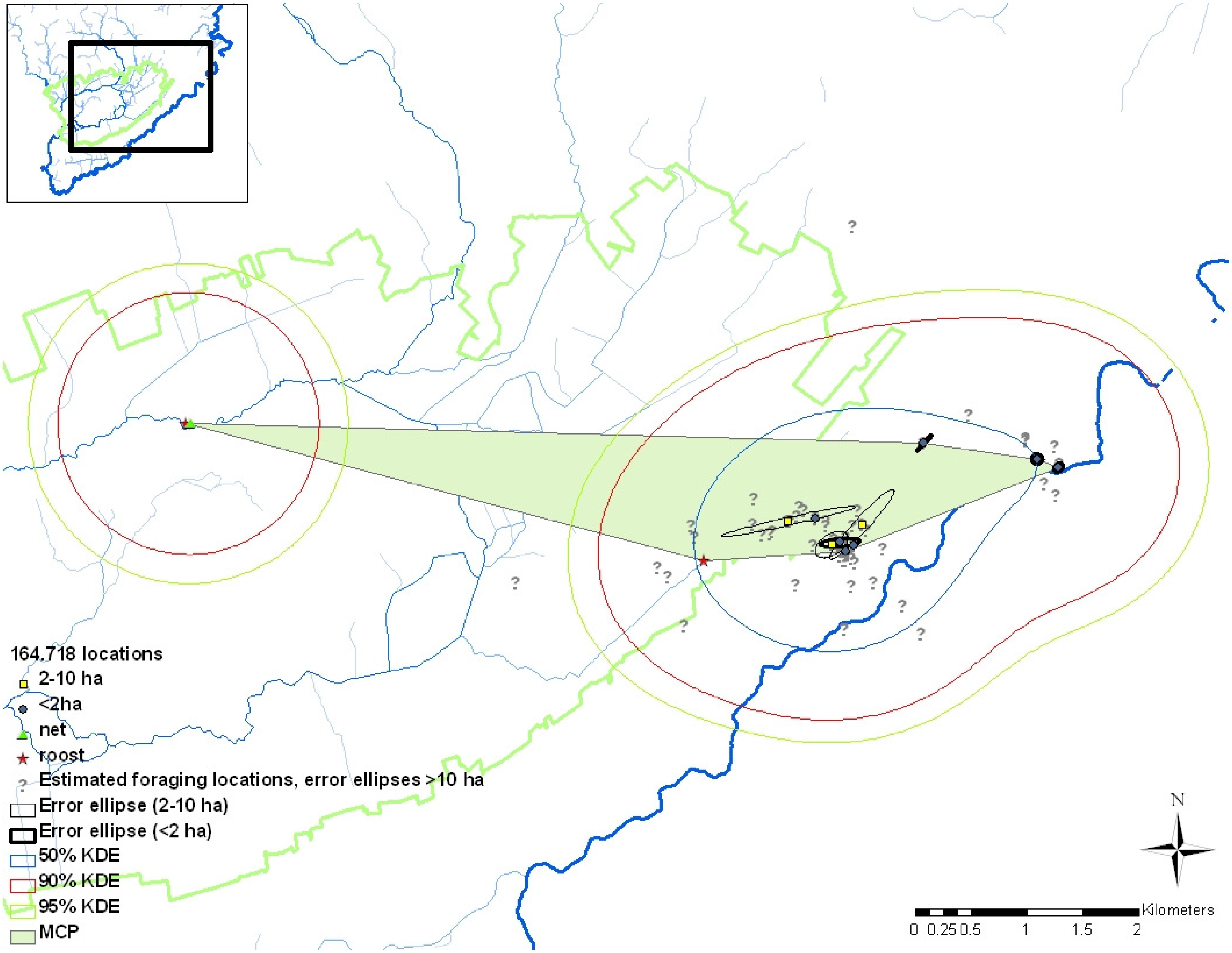
Known locations and home range estimates for bat 164.430 (post-lactating, captured at Sherwood Lane 8/9/2006). No evening telemetry was conducted on this bat.



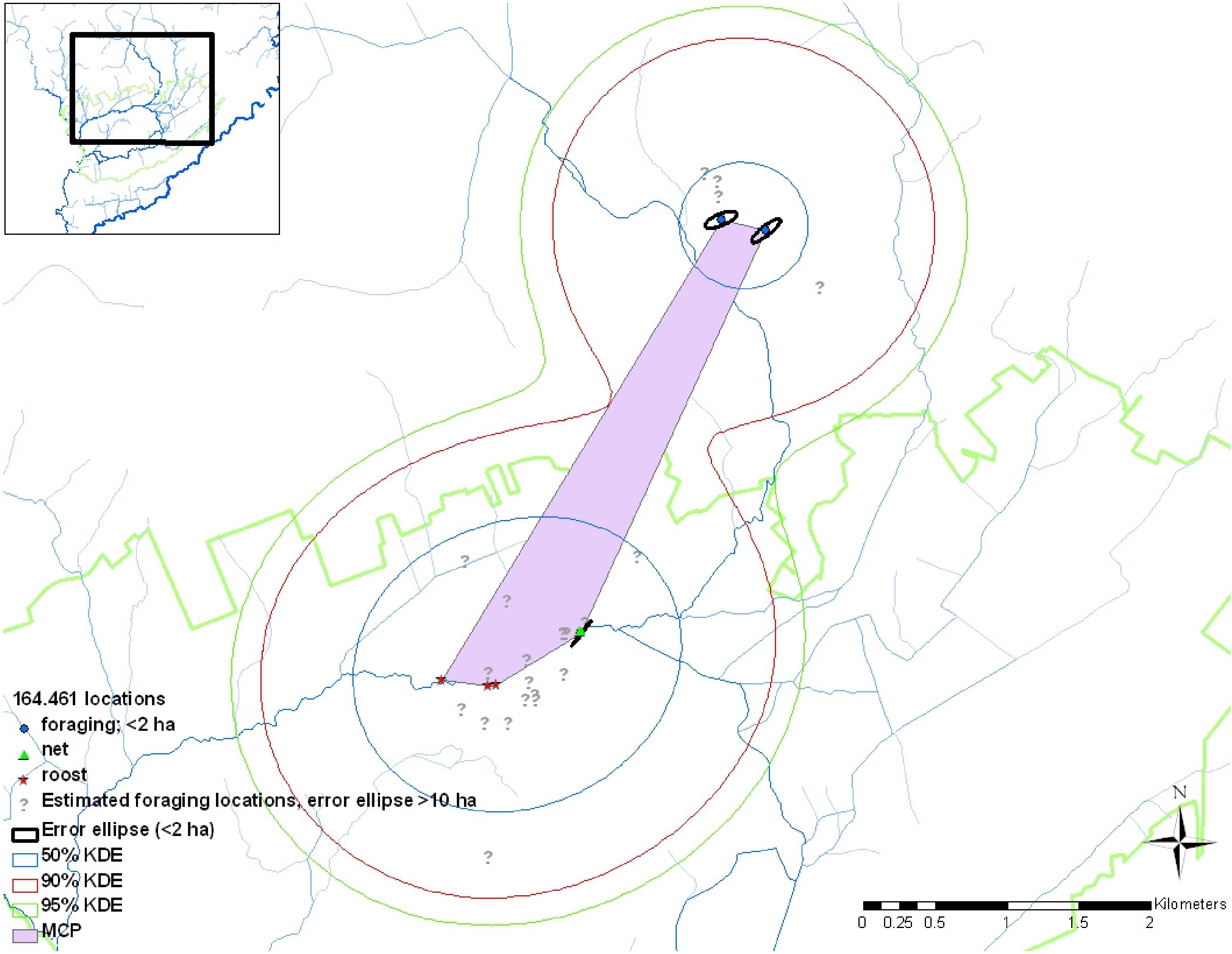
Known locations and home range estimates for bat 164.554 (nonreproductive, captured at North Gate 7/17/2006). No evening telemetry was conducted on this bat.



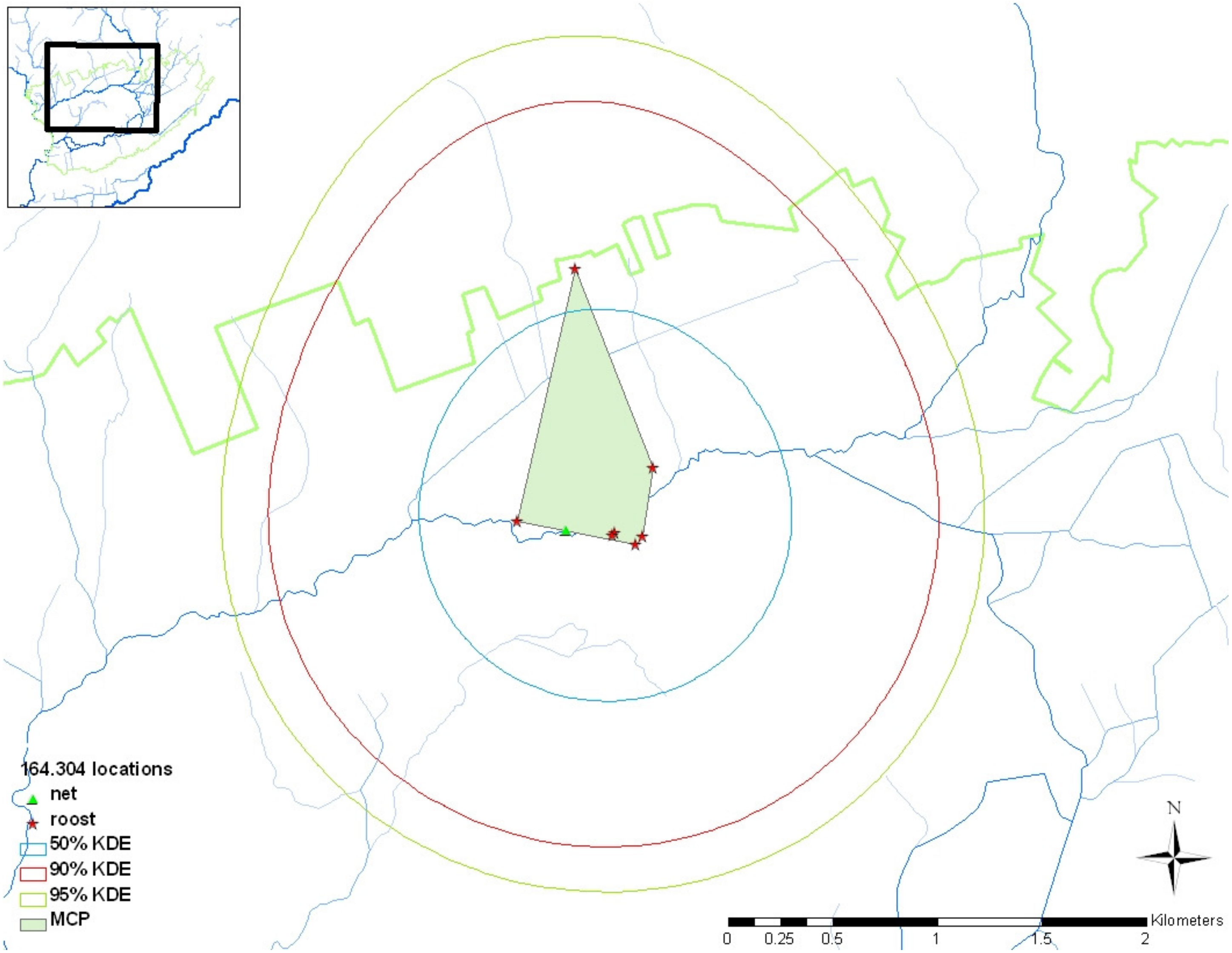
Known locations and home range estimates for bat 164.006 (lactating, captured at OU-3 7/6/2007).



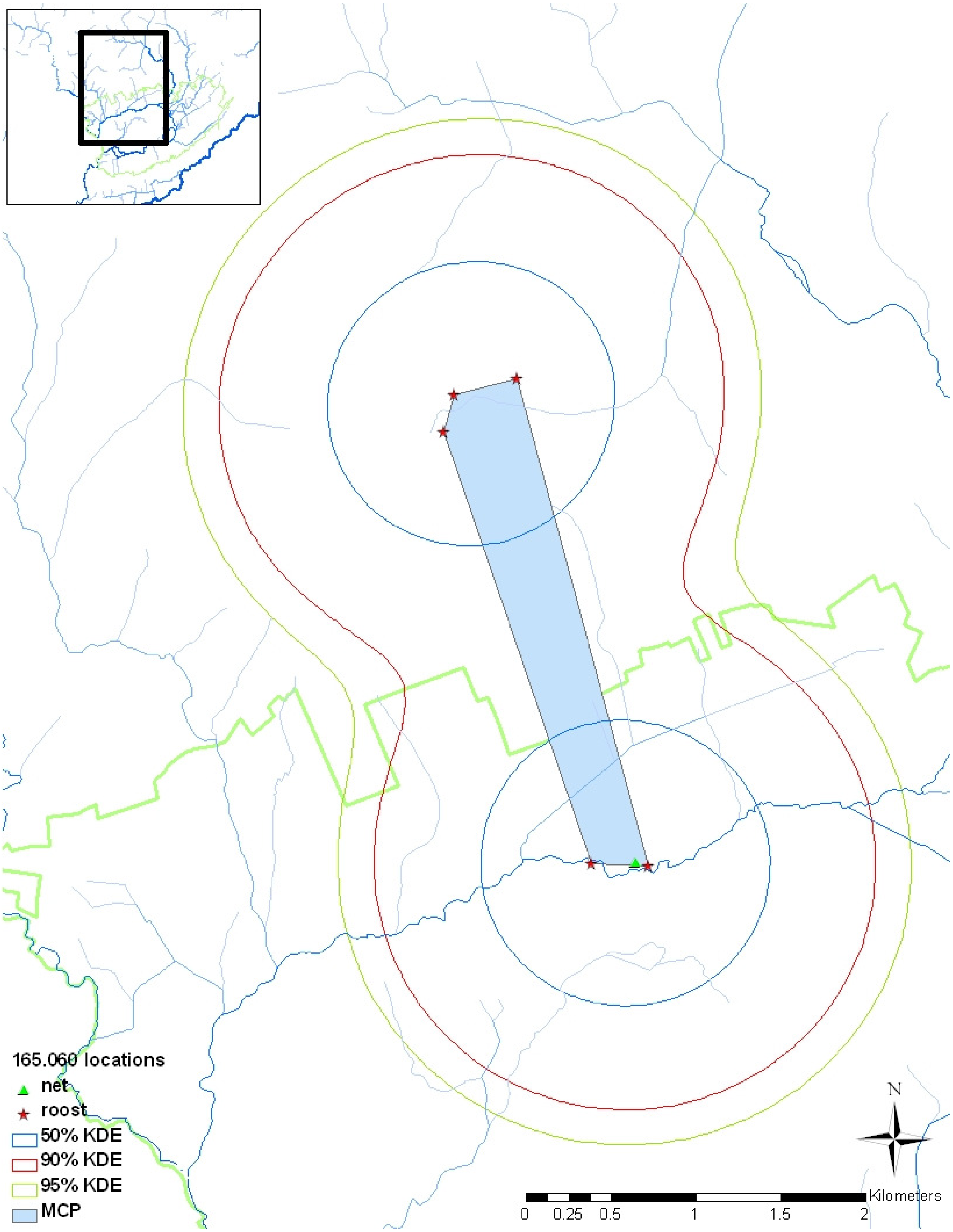
Known locations and home range estimates for bat 164.718 (lactating, captured at OU-3 7/6/2007).



Known locations and home range estimates for bat 164.461 (pregnant, captured at East end Blue Trail 6/22/2007).



Known locations and home range estimates for bat 164.304 (lactating, captured at OU-3 7/6/2006). No evening telemetry was conducted on this bat.



Known locations and home range estimates for bat 165.060 (lactating, captured at OU-3 7/6/2006). No evening telemetry was conducted on this bat.

APPENDIX B

Bat Histories (2006)

Frequency	Date netted	Net of Capture	Location netted	Intern assigned	Reproductive Status	ID	Weight	Forearm length	Transmitter Life^	Bat Days	No. Trees	Switch
164.204	6/3/2006	1B	Passaic River	Marilyn	NR	NJDFW25199	9.30	41.0	2	2	2	1.00

Day 1: Found in tree on private property along Bailey's Mill Rd. Tree never measured. Appears to be elm snag (never confirmed.)
Evening telemetry performed 6/4.
Day 2: Found in M6506MK1, along management road on Pool 3A. Dead pin oak. Emergence count: 252. ~3290m from prior roost (O6406LR1.)
Day 3: Not found?
Day 4: Not found.
Day 5: Not found. Cease searching.
Day 9: Not found.
Day 11: Not found.

Frequency	Date netted	Net of Capture	Location netted	Intern assigned	Reproductive Status	ID	Weight	Forearm length	Transmitter Life^	Bat Days	No. Trees	Switch
165.060	7/6/2006	WG56L06231	OU-3	Marilyn	L	NJDFW25183	7.75	40.0	9	7	5	1.40

Day 1: Found in O7706MK2, behind New Vernon Pres. Church. Live shagbark hickory.
Day 2: Found in W7806MK1, north of OU-3 parking turnaround. Green ash snag. 2703m from prior roost (O7706MK2.)
Day 3: Found in W7906MK1, adjacent to Ivory Trail. Dead shagbark hickory. 332m from prior roost (W7806MK1.)
Day 4: Not found.
Day 5: Found in O71106MK1, in Bayne Park. Dead elm. Distance from prior roost unknown.
Day 6: Found in O71206MK2, on Justine Barth's property. Elm snag. 387m from prior roost (O71106MK1.)
Day 7: Found in O71206MK2. Transmitter dropped?
Day 8: Found in O71206MK2. Emergence count: 0. Transmitter likely dropped.
Day 9: Signal coming stronger from base of O71206MK2. Assume dropped.

Frequency	Date netted	Net of Capture	Location netted	Intern assigned	Reproductive Status	ID	Weight	Forearm length	Transmitter Life^	Bat Days	No. Trees	Switch
164.506	7/6/2006	WG56L06231	OU-3	Marilyn	L	NJDFW25187	7.75	38.3	9	6	2	3.00

Day 1: Not found.
Day 2: Not found.
Day 3: Found in W7906MK3, in swamp along New Vernon Rd. Live shagbark hickory. Distance from prior roost unknown.
Day 4: Found in W71006SK1, very near W7906MK3. Declining red maple. 138m from prior roost (W7906MK3.)
Day 5: Found in W71006SK1. Emergence count: 5, but no information on transmitter emergence.
Day 6: Found in W71006SK1.
Day 7: Found in W71006SK1.
Day 8: Found in W71006SK1.
Day 9: Transmitter recovered from base of W71006SK1.

Frequency	Date netted	Net of Capture	Location netted	Intern assigned	Reproductive Status	ID	Weight	Forearm length	Transmitter Life^	Bat Days	No. Trees	Switch
164.304	7/6/2006	WG56L06632	OU-3	Marilyn	L	NJDFW25179	8.25	39.5	10	9	7	1.29

Day 1: Found in W7706MK1, along Great Brook at OU-3. Live shagbark hickory.
Day 2: Found in W7806MK2, across Otter Bridge. Dead black locust. 456m from prior roost (W7706MK1.)
Day 3: Found in W7906MK2, off Yellow Trail near OU-3. Dead red maple. 376m from prior roost (W7806MK2.)
Day 4: Found in W71006MK1, across Otter Bridge. Dead black locust. 359m from prior roost (W7906MK2.)

Day 5: Found in W71106SK1, across Otter Bridge. Live black locust. 123m from prior roost (W71006MK1.)
Day 6: Found in W71206MK1, across Otter Bridge. Dead black locust. 50m from prior roost (W71106SK1.)
Day 7: Found in W71306MH1, near Wildlife Run. Dead elm. 1330m from prior roost (W71206MK1.)
Day 8: Found in W71306MH1. Chittering heard.
Day 9: Found in W71306MH1. No chittering heard.
Day 10: Found in W71306MH1. No chittering heard; believe transmitter dropped.
Day 11: Found in W71306MH1. No chittering heard.
Day 12: Found in W71306MH1.
Day 13: Found in W71306MH1.
Day 17: Signal coming stronger from base of W71306MH1.

164.554	7/17/2006	MG2122N0623	Passaic River (North Gate)	Marilyn	NR	NJDFW25176	7.00	40.0	8	6	5	1.20

Day 1: Not found.
Day 2: Found in O71906MK1, on SCEEC property by Passaic River. Swamp white oak snag.
Day 3: Found in O72006MK1, on SCEEC property by Passaic River. Dead red maple. 47m from O71906MK1.
Day 4: Found in O72106MK1, on SCEEC property by Passaic River. Dead elm. 16.7m from prior roost (O72006MK1.)
Day 5: Found in M72206MK2, adjacent to Passaic River. Dead pin oak. 105m from prior roost (O72106MK1.)
Day 6: Found in M72306MK1, behind Steve's. Dead red maple. 798m from prior roost (M72206MK2.)
Day 7: Found in M72306MK1. No chittering heard.
Day 8: Found in M72306MK1. No chittering heard. Emergence count: 0. Assume transmitter has dropped.

165.101	7/20/2006	WG56L06231	OU-3	Marilyn	L	NJDFW25218	8.75	38.7	10	9	3	3.33

Day 1: Found in W72106MK2, along gas powerline by OU-3. Dead red maple.
Day 2: Found in W72206MK1, along gas powerline by OU-3. Live shagbark hickory. 129m from prior roost (W72106MK2.)
Day 3: Found in W72306MK2, about 30 ft. from W72106MK2. Dead elm. 121m from prior roost (W72206MK1.)
Day 4: Found in W72306MK2. No chittering heard. Signal bouncing around a lot.
Day 5: Found in W72306MK2. No chittering heard. Signal bouncing around a lot.
Day 6: Found in W72306MK2. No chittering heard.
Day 7: Found in W72306MK2.
Day 8: Found in W72306MK2.
Day 9: Found in W72306MK2.
Day 10: Transmitter recovered from base of W72306MK2.

165.021	7/26/2006	M2526L06634	Management road between Pools 1&2	Marilyn	PL	NJDFW25175	7.75	39.3	9	8	3	2.67

Day 1: Found in M72706MK1, near Passaic River. Dead swamp white oak.
Day 2: Found in M72806MH1, but flushed to nearby trees during search. Dead pin oak. 55.35m from prior roost (M72706MK1.)
Day 3: Found in M72906MK1, but exact tree difficult to pinpoint. Dead pin oak. 85.34m from prior roost (M72806MH1.)
Day 4: Found in M72906MK1. No chittering heard.

Day 5: Found in M72906MK1. No chittering heard.
Day 6: Found in M72906MK1. No chittering heard.
Day 7: Found in M72906MK1.
Day 8: Found in M72906MK1.
Day 9: Transmitter located at back of field across from viewing scopes on Pleasant Plains Road.
Day 10: Tranmistter recovered from back of field across from viewing scopes.

165.141	8/8/2006	M89A06233	Sherwood Ln.	Marilyn	PL	NJDFW25221	7.00	38.7	1	1	1	1.00

Day 1: Found in O8906MK1. Dead elm.
Day 2: Not found.
Day 3: Not found.
Day 4: Not found.
Day 5: Not found; cease searching.

164.255	8/8/2006	M89A06632	Sherwood Ln.	Marilyn	PL	NJDFW25171	7.00	36.0	2	2	2	1.00

Day 1: Found in M8906MK1, in swamp at end of Sherwood Ln. trail. Declining green ash.
Day 2: Found in M81006MK1, 20 feet from M8906MK1. Declining green ash. 10.1m from prior roost (M8906MK1.)
Day 3: Transmitter located on ground about 20 feet from M81006MK1, though not recovered.

164.430	8/9/2006	M89A06233	Sherwood Ln.	Marilyn	PL	NJDFW25226	8.25	37.7	19	16	11	1.07

Day 1: Not found.
Day 2: Not found.
Day 3: Found in M81206MK1, in woods off ditch at Sherwood Ln. Declining red maple.
Day 4: Found in M81306MK1, about 30 yards from M81206MK1. Live shagbark hickory. 76.5m from prior roost (M81206MK1.)
Day 5: Found in M81306MK1.

Day 6: Found in M81506MK1, near previous roosts. Declining/live red maple (2 trunks); odd choice of roost but signal bouncing and difficult to pinpoint. 97m from prior roost (M81306MK1.)
Day 7: Found in O81606MK1, near previous roosts but on private property. Live red maple. 437m from prior roost (M81506MK1.)
Day 8: Found in O81706MK1, 25 feet from O81606MK1. Declining green ash. 8.25m from prior roost (O81606MK1.)
Day 9: Found in O8906MK1, roost previously used by another bat (165.141.) Dead elm. 114m from prior roost (O81706MK1.)
Day 10: Found in M81906MK1, about 8 feet from M81506MK1. Declining red maple. 356m from prior roost (O8906MK1.)
Day 11: Found in M82006MK1, near previous roosts. Live shagbark hickory. 80m from prior roost (M81906MK1.)
Day 12: Found in O82106MK1, about 60 feet from O8906MK1. Dead elm. 437m from prior roost (M82006MK1.)
Day 13: Found in M82206MK1, near roosts previously used by 164.255. Dead green ash. 682m from prior roost (O82106MK1.)
Day 14: Found in O8906MK1, previously used on Day 9. 653m from prior roost (M82206MK1.)
Day 15: Found in M82406MK1, about 60 feet from M81306MK1. Live shagbark hickory. 485m from prior roost (O8906MK1.)
Day 16: Found in O81706MK1, previously used on Day 8. Signal made it very difficult to decide between this tree and O81606MK1. 545m from prior roost (M8246MK1.)
Day 17: Found in M82406MK1, previously used on Day 15. 545m from prior roost (O81706MK1.)
Day 18: Not found.

Day 19: Found in M81506MK1 in heavy rain. Signal very weak. Distance to prior roost unknown.

Day 20: Not found. Transmitter dead?

Day 21: No search conducted.

Day 22: Not found. Assume transmitter has died.

Bat Histories (2007)

<table>
<tr><th>Frequency</th><th>Date netted</th><th>Net of Capture</th><th>Location netted</th><th>Intern assigned</th><th>Reproductive Status</th><th>ID</th><th>Weight</th><th>Forearm length</th><th>Transmitter Life^</th><th>Bat Days</th><th>No. Trees</th><th>Switch</th></tr>
<tr><td>165.101</td><td>5/22/2007</td><td>PR2223M07931</td><td>Passaic River</td><td>Mike</td><td>NR</td><td>NJDFW25248</td><td>7.75</td><td>38.7</td><td>6</td><td>5</td><td>5</td><td>1.00</td></tr>
<tr><td colspan="13">Day 1: Found in O52307MW1 (Cheverly's property.) Dead pin oak. Emergence count: 58
Day 2: Found in M52407MW1, near Passaic River. Dead pin oak. Emergence count: 11. 3219m from prior roost (O52307MW1.)
Day 3: Found in O52507SC1, on SCEEC property. Dead pin oak. Emergence count: 7. 461m from prior roost (M52407MW1.)
Day 4: Not found.
Day 5: Found in O52707MW1, near 287. Dead elm. Emergence count: 34. Distance from prior tree unknown.
Day 6: Found in O52807MW1, at intersection of Young's Rd. and Bailey's Mill Road. Dead elm. Emergence count: 33. 1109m from prior roost (O52707MW1.) Transmitter did not emerge; assume dropped.
No evening telemetry performed.</td></tr>
<tr><td>164.356</td><td>5/30/2007</td><td>WG29M07931</td><td>OU-3</td><td>Mike</td><td>P</td><td>NJDFW25231</td><td>9.50</td><td>40.4</td><td>5</td><td>2</td><td>2</td><td>1.00</td></tr>
<tr><td colspan="13">Day 1: Not found.
Day 2: Not found.
Day 3: Not found.
Day 4: Found in W6307MW1, along Long Hill Rd. Dead elm. Emergence count: 21.
Day 5: Found in W7706MK1, tree from 2006. Living shagbark hickory. Emergence count: 57. 372m from prior roost (W60307MW1.) Transmitter did not emerge; assume dropped.
No evening telemetry performed.</td></tr>
<tr><td>164.405</td><td>6/7/2007</td><td>MS67A07632
(Minimal telemetry night of release, 6/7.)</td><td>Sherwood Ln.</td><td>Steph</td><td>P</td><td>NJDFW25169*</td><td>9.50</td><td>39.7</td><td>6</td><td>5</td><td>4</td><td>1.50</td></tr>
<tr><td colspan="13">Day 1: Found in O6807MW1, off Newark Rd. in Watchung. Dead read maple. Emergence count: 2
Evening telemetry 6/8.
Day 2: Found in M6907SC1, in Sherwood Ln. Dead pin oak. Emergence count: 47. 4008m from prior roost (O6807MW1.)
Evening telemetry 6/9.
Day 3: Not found.
Day 4: Found in O61107AG1, along Lord Stirling Rd. Dead elm. Emergence count: 31. Distance from prior tree unknown.
Evening telemetry 6/11.
Day 5: Found in O61207AG1, behind Raptor Trust. Dead shagbark. Emergence count: 7. 1339m from prior roost (O61107AG1.)
Long night evening telemetry 6/12; finish 0510.
Day 6: Found in O61207AG1. Dead shagbark. Emergence count: 22. Transmitter did not emerge; assume dropped.
Four full nights evening telemetry, including one long night.</td></tr>
<tr><td>164.461</td><td>6/22/2007</td><td>WG19N07932</td><td>East end Blue Trail</td><td>Ben</td><td>P</td><td>NJDFW25233</td><td>10.50</td><td>39.6</td><td>4~</td><td>4</td><td>3</td><td>1.33</td></tr>
<tr><td colspan="13">Day 1: Found in W62307BA1, across Otter Bridge. Dead black locust. Emergence count: 9.
(Minimal telemetry 6/23.) Non-focal bat.
Day 2: Found in W62307BA1. Emergence count: 19.
Evening telemetry 6/24. Focal bat.</td></tr>
</table>

Day 3: Found in W62507BA1, adjacent to Ivory Trail. Dead shagbark hickory. Emergence count: 13. 383m from prior roost (W62307BA1.)
Evening telemetry 6/25. Non-focal bat.
Day 4: Found in W62607SC1, across Otter Bridge. Live black locust. Emergence count: 72. 328m from prior roost (W62507BA1.)
Evening telemetry 6/26.
Day 5: Not found.
Day 6: Not found.
Day 7: Not found.
Day 8: Not found; cease searching.

164.580	6/22/2007	WG19N07631	East end Blue Trail	Amy	L	NJDFW25235	8.00	39.5	3[~]	3	1	3.00

Day 1: Found in W62307AG1, deep in wilderness off of Blue/Red Trail. Declining shagbark hickory. No emergence count performed.
Evening telemetry 6/23. Focal bat.
Day 2: Found in W62307AG1. No emergence count performed.
Evening telemetry 6/24. Non-focal bat.
Day 3: Found in W62307AG1. Emergence count: 22, bat did emerge.
Evening telemetry 6/25. Focal bat.
Day 4: Not found.
Day 5: Not found.
Day 6: Not found.
Day 7: Not found??? See foldout map in Amy's notebook, 6/29. Cease searching?
3 nights evening telemetry; 2 nights focal bat.

164.620	6/26/2007	MG26N07231	Great Brook - North Gate	Steph	L	NJDFW25239	8.00	37.3	1[#]	1	1	1.00

Day 1: Not found.
Day 2: Found in O62807SC1, on SCEEC property. Dead pin oak. Emergence count: 4. Transmitter did not emerge.
Evening telemetry 6/28. Unreliable; transmitter never emerged.
Day 3: Found in O62807SC1. Emergence count: 6. Transmitter did not emerge.
Day 4: Found in O62807SC1. Emergence count: 6. Transmitter did not emerge.
Evening telemetry 6/30. Unreliable; transmitter never emerged.
2 nights evening telemetry, both unreliable.

164.718	7/6/2007	WG6L07934	OU-3	Mike	L	NJDFW25244	8.75	40.4	10	10	2	5.00

Day 1: Found in O7707MW1, on Hoag's property along power line. Dead elm. Emergence count: 39.
Evening telemetry 7/7.
Day 2: Found in O7707MW1. Emergence count: 52.
Day 3: Found in O7707MW1. Emergence count: 47.
Evening telemetry 7/9.
Day 4: Found in O7707MW1. Emergence count: 34.
Day 5: Found in O7707MW1. Emergence count: 25.
Evening telemetry 7/11.

Day 6: Found in O7707MW1. Emergence count: 25.

Long night evening telemetry 7/12; finish 0430.

Day 7: Found in O7707MW1. Emergence count: 24.

Day 8: Found in O7707MW1. Emergence count: 19.

Day 9: Found in O7707MW1. Emergence count: 20.5

Day 10: Found in W71607MW1, OU-3. Live red oak. Emergence count: 0, but transmitter emerged. Oak next to live shagbark, foliage obstructed both views. Probably ID'd wrong tree. 4811m from prior roost (O7707MW1.)

Evening telemetry 7/16.

Day 11: Transmitter found at base of O7707MW1.

5 nights evening telemetry, including 1 long night.

164.769	7/6/2007	WG6L07934	OU-3	Amy	L	NJDFW25241	8.50	38.5	10	2	2	1.00

Difficult bat; went missing for 4 days, no search subsequent 2 days; bat reappeared, then signal seemed dead, then reappeared at last tree where transmitter separated.

Day 1: Not found.

Day 2: Not found.

Day 3: Not found.

Day 4: Not found; cease searching.

Day 5: No search conducted.

Day 6: No search conducted.

Day 7: Found in W71307AG1, behind Great Swamp Greenhouses, during search for another bat. Declining red maple. Emergence count not conducted.

Day 8: Not found, but signal detected at Orange Trailhead, constantly changing strength and pitch. No signal from greenhouses.

Day 9: No search conducted; figure transmitter had died.

Day 10: Found in W62507BA1, roost used previously by another bat; at OU-3. Dead shagbark. Emergence count: 30. Transmitter never emerged.

Evening telemetry 7/16.

One night evening telemetry attempted; bat never emerged.

164.006	7/6/2007	WG6L07934	OU-3	Ben	L	NJDFW25240	8.00	37.5	5˜	5	3	1.67

Day 1: Found in M7707BA1, along Long Hill Rd. Dead pin oak. Emergence count: 3.

Day 2: Found in W7807BA1, across Long Hill Rd. Dead red maple. Emergence count: 0, but transmitter did emerge. Possibly identified wrong tree. 98m from prior roost (M7707BA1.)

Evening telemetry 7/8.

Day 3: Found in W7807BA1; no emergence done.

Day 4: Found in M71007BA1, west of Long Hill Rd. Dead red maple. Emergence count: 3. 681m from prior roost (W7807BA1.)

Evening telemetry 7/10.

Day 5: Found in M71007BA1. Emergence count: 4. Transmitter emergence uncertain due to observer error.

Day 6: Not found.

Day 7: Not found.

Day 8: Not found.

Day 9: Not found, cease searching.

Two nights evening telemetry.

164.054	7/18/2007	WO17L07935	Silver Trail	Steph	L	NJDFW25166	8.50	38.6	4	3	3	1.00

Day 1: Not found.
Day 2: Found in O72007MW1, along powerline behind Chatham Board of Ed. Dead snag; species unidentified. Emergence count: 11.
Day 3: Found in W72107SC1, beyond end of Silver Trail. Live red maple. No emergence count conducted. 1602m from prior roost (O72007MW1.)
Evening telemetry 7/21 unsuccessful; couldn't triangulate.
Day 4: Found in W72207SC1, beyond end of Silver Trail. Living red maple. Emergence count: 7. Transmitter never emerged. 17.38m from prior roost (W72107SC1.)
One night telemetry attempted, but minimally successful.

164.103	7/24/2007	MS24L07631	Sherwood Ln.	Mike	L	NJDFW25165	7.25	36.2	10	10	6	1.43

Day 1: Found in M72507MW1, Sherwood Ln. Dead red maple. Emergence count: 1, but unreliable due to late observer arrival.
Evening telemetry 7/25.
Day 2: Found in M72607MW1, Sherwood Ln. Dead shagbark hickory. Emergence count: 1, but unreliable due to late observer arrival. 85m from prior roost (M72507MW1.)
Day 3: Found in M72607MW1. Emergence count: 4.
Evening telemetry 7/27.
Day 4: Found in M72807AG1, Sherwood Ln. Declining red maple. Emergence count: 0, but unreliable due to late observer arrival. 179m from prior roost (M72607MW1.)
Evening telemetry 7/28.
Day 5: Found in M72907MW1, Sherwood Ln. Declining red maple. Emergence count: 0, but unreliable due to late observer arrival. 76m from prior roost (M72807AG1.)
Evening telemetry 7/29.

Day 6: Found in M73007MW1, Sherwood Ln. Dead red maple. Emergence count: 0, but unreliable due to early bat emergence (before observer arrival.) 45m from prior roost (M72907MW1.)
Day 7: Found in M73107MW2, Sherwood Ln. Dead red maple. Emergence count: 2. 5.36m from prior roost (M73007MW1.)
Day 8: Found in M73107MW2. Emergence count: 2
Day 9: Found in M72907MW1, used Day 5. Emergence count: 1. 66m from prior roost (M73107MW2.)
Day 10: Found in M72907MW1. Emergence count: 1.
Day 11: Transmitter recovered along the path/ditch leading to M72907MW1, about 10 feet off the trail.
4 nights evening telemetry.

164.155	7/24/2007	MS24L07631	Sherwood Ln.	Amy	L	NJDFW25169	8.25	40.2	1	1	1	1.00

Day 1: Found in M72507MW2, Sherwood Ln. Dead swamp white oak. Emergence count: 0, but one bat seen flying around roost tree. Transmitter never emerged (this bat was transmittered earlier in the season and had a large bare patch on its back where transmitter was attached.)
One night evening telemetry attempted 7/25, but bat never emerged.

164.203	7/24/2007	MS24L07233	Sherwood Ln.	Ben	L	NJDFW25158	7.75	39.4	3	3	1	3.00

Day 1: Found in O72507BA1, near Passaic River (Ord's property.) Dead pin oak. Emergence count: 4.
Day 2: Found in O72507BA1. Emergence count: 0, but unreliable due to late observer arrival. Transmitter did emerge.
Day 3: Found in O72507BA1. Emergence count: 3, but transmitter did not emerge. Assume dropped.
One night evening telemetry 7/26.

164.306	8/12/2007	MR12A07236	Mgmt. road between Pools 1 and 2	Amy	PL	NJDFW25147	7.50	39.1	10	8	2	2.67

Day 1: Found in M81307AG1, near management road. Dead green ash. Emergence count: 0, but unreliable due to late observer arrival.
Day 2: Found in M81307AG1. Emergence count not performed.
Day 3: Found in M81307AG1. Emergence count not performed.
Day 4: Found in M81307AG1. Emergence count not performed.
Day 5: Found in M81307AG1. Emergence count not performed.
Day 6: No search conducted.
Day 7: No search conducted.
Day 8: Found in M81307AG1. Bat emerged.
Day 9: Found in M82107CO1, adjacent to management road. Dead shagbark hickory. Emergence count not conducted, but bat emerged. 107m from prior roost (M81307AG1.)
Day 10: Found in M82107CO1.
Day 11: Transmitter recovered in thick brush, not adjacent to either roost tree but in general vicinity.
Minimal telemetry attempted by one team member (no triangulation.)