BAT SURVEY OF THOUSAND HILLS STATE PARK, KIRKSVILLE MISSOURI, WITH EMPHASIS ON DOCUMENTING THE PRESENCE OF THE NORTHERN MYOTIS (MYOTIS SEPTENTRIONALIS)

By:

Casey L. Zimmerman

An Abstract
of a thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
in the Department of Biology and Agriculture
University of Central Missouri

July, 2015
ABSTRACT

By:

Casey L. Zimmerman

This study was to determine how woodland enhancement techniques impact bats in Thousand Hills State Park, Kirksville, Missouri and document roost tree preferences for the northern myotis (*Myotis septentrionalis*). Bat surveys occurred from May 15 through September 15, 2013, prior to woodland restoration, and again from May 15 through September 15, 2014, 6 months after restoration. Surveys mainly focused on documenting northern myotis and their roosting preferences. Knowing which trees they favor to roost in may help guide the Missouri Department of Natural Resources, Missouri Department of Conservation, and the United States Fish and Wildlife Service with future woodland restoration projects. Bats were identified by mist net capture or call identification using an Anabat detector. After 121 days (605 hours) of mist netting surveys, we captured 7 different species of bats with a total of 303 individual bats. The Anabat detector recorded 9 different bat species and collected 1,093 calls. Northern myotis were tracked to determine roost tree species and location. We tracked 16 different northern myotis (2 males, 15 females) to 7 different species of trees. We documented 19 different roost trees throughout the study site with white oak trees (*Quercus alba*) that

...
had snags or cavities being used the most by northern myotis. We noticed a decline in bats sampled for both mist net and Anabat detector calls collected in 2014 after forest management techniques were used. Species that declined were the big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), silver-haired bat (*Lasionycteris noctivagans*), hoary bat (*Lasiurus cinereus*), Indiana myotis (*Myotis sodalis*), little brown myotis (*Myotis lucifugus*), evening bat (*Nycticeius humeralis*), and the northern myotis (*Myotis septentrionalis*). The one species that did not show any significant difference was the tri-colored bat (*Perimyotis subflavus*), which may be due to its small sample size or because they thrive better in early successional forest growth stages (Loeb and O’Keefe 2006).
BAT SURVEY OF THOUSAND HILLS STATE PARK, KIRKSVILLE MISSOURI, WITH EMPHASIS ON DOCUMENTING THE PRESENCE OF THE NORTHERN MYOTIS (*MYOTIS SEPTENTRIONALIS*)

By:

Casey L. Zimmerman

A Thesis
Presented in partial fulfillment of the requirements for the degree of Master of Science in the Department of Biology and Agriculture University of Central Missouri

July, 2015
BAT SURVEY OF THOUSAND HILLS STATE PARK, KIRKSVILLE MISSOURI, WITH EMPHASIS ON DOCUMENTING THE PRESENCE OF THE NORTHERN MYOTIS (MYOTIS SEPTENTRIONALIS)

By

Casey L. Zimmerman

July, 2015

APPROVED:

Thesis Chair: Dr. Victoria Jackson

Thesis Committee Member: Dr. Stephen Wilson

Thesis Committee Member: Jason Layne

ACCEPTED:

Chair, Department of Biology and Agriculture: Dr. Fanson Kidwaro

UNIVERSITY OF CENTRAL MISSOURI
WARRENSBURG, MISSOURI
ACKNOWLEDGMENTS

I would like to thank all those who helped me achieve this project. To Dr. Victoria Jackson, who is a professor that not only teaches, but can inspire anyone to achieve great things, just as she did for me. To Jason Layne, a biologist who has answers to everything and was willing to go out of his way to help me with this project no matter how busy he was. To Dr. Stephen Wilson, a man who is extremely knowledgeable about biology and willing to assist students in answering biological questions that they may have. To my family for always supporting me in all my ventures. To Caitlin Swadley, a strong willed person who makes things simple and would do things no one could to do to help me fulfill my research when I could not do it alone. To Shelly Colatskie and Tony Elliot for teaching me all that is needed to know on how to successfully capture, handle and properly band bats. To Shauna Marquardt, Chris Crabtree, Ken McCarty, the Department of Natural Resources, Missouri Department of Conservation, and United States Fish and Wildlife thank you for providing me the necessary funds, tools, and equipment that allowed me to do this project and let me experience something that I will truly never forget. Last but not least I would like to thank all bats that volunteered their precious time for allowing me to document necessary things to better my research and answer the question that was asked of me.
INTRODUCTION

Ecology of northern myotis (Myotis septentrionalis) ............................................. 3

Species description of northern myotis ........................................................................ 3

Roosting preference for the northern myotis ................................................................. 6

Foraging preferences for northern myotis ..................................................................... 8

Specific management practices for the northern myotis ................................................. 11

Ecology of bats at Thousand Hills State Park .................................................................. 12

Roosting and foraging preferences for all other bats expected to be found in THSP ........ 12

Impacts of management practices on bats ....................................................................... 17

MATERIALS AND METHODS

Study site ......................................................................................................................... 21

Mist net data .................................................................................................................. 25

Anabat detector ............................................................................................................. 27

Radio-telemetry ............................................................................................................ 28

Roost-tree metrics ....................................................................................................... 28

Statistical analysis ......................................................................................................... 29

RESULTS

Results for 2013 ............................................................................................................. 29

Mist net ......................................................................................................................... 29

Anabat Detector .......................................................................................................... 30

Roost tree metrics ....................................................................................................... 31

Results for 2014: ........................................................................................................... 32

Mist net: ....................................................................................................................... 32

Anabat Detector .......................................................................................................... 33

Roost tree metrics ....................................................................................................... 34

Total data collected from 2013 and 2014 ................................................................... 35

Mist net: ....................................................................................................................... 35

Anabat detector ........................................................................................................... 39
LIST OF FIGURES

Figure 1: The spread of White-nose Syndrome (WNS) from where it originally was found to how far it has spread across the eastern U.S. and Canada as of June 12, 2015 (USFWS 2015). 2

Figure 2: Geographic distribution of northern myotis in North America (USFWS 2014)............. 5

Figure 3: The 4 woodland restoration zones surveyed in Thousand Hills State Park and 1 zone (Control Zone) surveyed in Big Creek Conservation Area during summer months (May-September) 2013 and 2014........................................................................................................... 23

Figure 4: Locations of 22 survey sites where mist net and Anabat data were collected in Thousand Hills State Park. .................................................................................................................................................. 26

Figure 5: Mist net capture totals for 9 bat species collected in Zone 1 in 2013-2014 (May15-September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].................................................................................................................................................. 36

Figure 6: Mist net capture totals for 9 bat species collected in Zone 2 in 2013-2014 (May15-September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].................................................................................................................................................. 36

Figure 7: Mist net capture totals for 9 bat species collected in Zone 3 in 2013-2014 (May15-September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].................................................................................................................................................. 37
Figure 8: Mist net capture totals for 9 bat species collected in Zone 4 in 2013-2014 (May 15 - September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 9: Mist net capture totals for 9 bat species collected in Zone 5 in 2013-2014 (May 15 - September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 10: Total number of individuals collected in between May 15 through September 15, 2013, and 2014 for the 10 Sites in located in Zone 1, 7 Sites in Zone 2, 2 Sites in Zones 3 and 4, and 1 Site in Zone 5.

Figure 11: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May - September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 12: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May - September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 13: Number of total vocal calls recorded for the 9 bat species collected in 2013 - 2014 (May - September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].
Figure 14: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May- September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 15: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May- September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 16: Total number of calls recorded in between May 15 through September 15 2013, and 2014 for the 10 Sites in located in Zone 1, 7 Sites in Zone 2, 2 Sites in Zones 3 and 4, and 1 Site in Zone 5.

Figure 17: Map depicting 19 locations of roosting trees located by radio tracking 16 different bats in 2013-2014.

Figure 18: Mist net capture totals for the 22 sites surveyed in THSP May 15 through September 15 2013 and 2014.
LIST OF TABLES

Table 1 Mist net capture totals for the 6 bat species sampled in the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2013:.......................... 30

Table 2 Total echolocation calls collected from 9 different species with the Anabat detector in the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2013................................................................. 31

Table 3 Metrics collected from 11 different roost trees used by 8 northern myotis females that were tracked by radio telemetry in Thousand Hills State Park between May 15, and September 15, 2013. ........................................................................................................... 32

Table 4: Mist net capture totals for the 7 species sampled within the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2014.................. 33

Table 5 Total echolocation calls collected from 9 different species with the Anabat detector in the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2014................................................................. 34

Table 6: Metrics collected from 8 roost trees used by the 8 northern myotis that were tracked by radio telemetry in Thousand Hills State Park between May 15, and September 15, 2014. ........................................................................................................... 35

Table 7: P-values associated with Sign Tests to determine whether there were significant differences in the 5 different Zones between 2013 and 2014. .................................. 44

Table 8: P-values associated with Sign Tests to determine whether there were significant differences in number of bats captured per species between 2013 and 2014 [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)]. ........................................................................................................... 44

Table 9: P-values associated with Sign Tests to determine whether there were significant differences in number of calls collected per species between 2013 and 2014 [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)]. ........................................................................................................... 46
INTRODUCTION

Over the past two decades, multiple state and federal agencies across the nation have focused significant attention to the management and conservation of forest-dwelling bats in order to restore degraded habitats, minimize disturbances to known hibernacula (a shelter occupied during winter by a dormant animal), and to cure diseases to help restore and promote the populations that are currently under threat (Griggs et al. 2012). This focus is due to their important ecological roles as nocturnal insectivores and as possible indicator species of forest ecosystem health (Fenton 1997). Human disturbance of hibernacula, environmental pollution, and loss of summer habitat have led to population declines (Fenton 1997).

Myotis bat populations are the most widely distributed group of bats in North America, and populations are declining at a rapid rate (Reid 2006). According to USFWS (2014) declines are due to habitat degradation and the spread of White-nose syndrome (WNS; *Pseudogymnoascus destructans*). These two devastating factors have led to a need for increased understanding of roost ecology (winter hibernacula and summer roost trees) to aid in population recovery.

WNS was first observed near Albany, New York, USA, in February 2006 (USGS 2015). The fungus, *Pseudogymnoascus destructans*, is a psychrophilic (cold loving) fungus that infects the skin of bats and leads to depletion of their fat stores during hibernation (Griggs et al. 2012). WNS has caused dramatic mortality rates (up to 99%) in some winter hibernacula, and has killed 5.5 million bats among 6 cave-roosting species in 26 central and eastern US states and 5 Canadian provinces (Figure 1; USGS 2015). There is no evidence that WNS can be transmitted from bats to humans, although humans may play a role in translocation of the fungus between caves (Griggs et. al. 2012). To limit the spread of this fatal disease, bat biologists have been
primarily focusing on protecting known myotis hibernacula banning access to public caves by gating off entrances to caves to limit human disturbance. This attempt will aid in the protection and hopefully restore and increase threatened bat populations (Clawson 2002). Attempts to protect hibernacula have resulted in population increases for species such as Indiana myotis (Myotis sodalis) and gray myotis (Myotis grisescens; Clawson 2002). The protection of winter hibernacula of myotis is important, but recent research has focused on understanding summer habitat needs (Griggs et. al. 2012). To manage and protect species, it is necessary to have a better understanding of habitat requirements during the summer season because this is where future generations begin.

Figure 1: The spread of White-nose Syndrome (WNS) from where it originally was found to how far it has spread across the eastern U.S. and Canada as of June 12, 2015 (USFWS 2015).
Ecology of northern myotis (*Myotis septentrionalis*)

Species description of northern myotis

This species belongs to the order Chiroptera, suborder Microchiroptera, family Vespertilionidae, subfamily Vesperitilionae, genus *Myotis*, and subgenus *Myotis* (Caceres and Barclay 2000). The average weight of this species ranges from 5 to 8 g, and typically females are larger than males (Caceres and Pybus 1997). Their average body length ranges from 77 to 95 mm, tail length between 35 and 42 mm, forearm length between 34 and 38 mm, and wingspread between 228 and 258 mm (Caceres and Barclay 2000). This species is medium to dark brown on its back, with its ears and wing membranes a dark brown color, and the ventral side pale brown (Nagorsen and Brigham 1993). This species was formerly known as the northern long-eared bat because it could be easily distinguished from other myotis species by its long ears. Its ears extend beyond the nose when they are pressed forward, but will extend less than 5 mm beyond the muzzle (Caceres and Barclay 2000).

Reproduction in the northern myotis

Breeding in Missouri occurs from late July to early October. The majority of male northern myotis testes will not descend until August or September (Amelon and Burhans 2006). Once males are reproductively ready, they begin to migrate to their hibernacula where they will swarm at the entrance and initiate copulation activity with females (Whitaker and Hamilton 1998). Female bats display delayed fertilization and will store sperm throughout the entire winter while hibernating (Racey 1979). As soon as a female northern myotis awakens, fertilization of a single egg will occur, resulting in a single embryo (Cope and Humphrey 1972). Once fertilized,
gestation takes about 60 days for the embryo to fully develop (Kurma 1995). Maternity colonies for northern myotis are generally small, between 30 to 60 individuals (Caceres and Barclay 2000). Birthing likely occurs in late May or early June, but in some cases, birthing has occurred as late as July (Whitaker and Mumford 2009). The majority of births in the colony will occur around the same time and females will give birth to a single pup (Barbour and Davis 1969). Juveniles begin to fly 21 days after birth (Krochmal and Sparks 2007).

**Distribution and abundance of northern myotis**

The geographic distribution (Figure 2) of northern myotis extends across much of the eastern and north central United States and all Canadian provinces west to the southern Yukon Territory and eastern British Columbia (Nagorsen and Brigham 1993). In the United States, they have been found from Maine to eastern Kansas (Whitaker and Hamilton 1998). Three-hundred of the 780 known northern myotis hibernacula occur in Missouri (Shelly Colatskie, pers. comm.). Northern myotis may return to the same hibernaculum year after year, and can occupy a variety of day roosts during warmer seasons (Menzel et al. 2002).
For bat species similar to the northern myotis, such as the Indiana myotis, roosting and foraging behavior determine their preferred habitat. The availability of roost trees could affect the population size and species diversity in an area (Humphrey et al. 1977, Kunz 1982). Many forest dwelling bats, like the northern myotis, require forested areas to live (Sasse and Perkins 1996; Menzel et al. 2002). Greater numbers of maternity colonies have been recorded in old growth forests simply because there are more dying trees and trees that possess snags, which increase the abundance of suitable roost sites (Crampton and Barclay 1998). Roost areas tend to have an open understory which increases solar radiation and aids in the development of pups whereas foraging areas will most likely be in dense vegetation and have greater prey abundance (Jung et al. 2004). When suitable roost and foraging habitats do not occur in close proximity, some species may travel considerable distances (>1000 m) from roost sites to foraging areas.
(Foster and Kurta 1999). In order to understand bat species’ requirements, it is necessary to have information on both foraging and roosting habitat requirements of the species.

**Roosting preference for the northern myotis**

The northern myotis appears to be somewhat opportunistic when selecting roost sites. This species has been documented roosting in many different tree species including black oak (*Quercus velutina*), northern red oak (*Quercus rubra*), white oak (*Quercus alba*), silver maple (*Acer saccharinum*), black locust (*Robinia pseudoacacia*), American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), sourwood (*Oxydendrum arboreum*), shortleaf pine (*Pinus echinata*), shagbark hickory (*Carya ovata*), and cottonwood trees (*Populus deltoids*; Timpone et al. 2010). Researchers suggest that habitat structural complexity or a high volume of roosting resources may be valued higher than the actual tree species (Carter and Feldhamer 2006).

Research has documented the northern myotis occupying live trees over snags, with a range of 10 to 53% selection of live roosts found (Timpone et al. 2010). The availability of snags and other roosting structures in study areas may reflect the use of live trees versus snags (Perry and Thill 2007). Similarities in the characteristics of roost trees used by other forest-dwelling species of bats could result in partial niche overlap (Vonhoff and Barclay 1996, Timpone et al. 2010). Due to this potential overlap, informative speculations of the federally endangered Indiana myotis may occur during field studies on northern myotis. These observations could have potential forest-woodland management implications regarding Indiana myotis (Humphrey 1975, Gardner et al. 1991, Callahan et al. 1997, Kurta and Murray 2002). Vonhoff and Barclay (1996) examined all roosting trees used by Indiana myotis and northern myotis and found differences only in the height of roost trees and canopy cover of the surrounding trees. Indiana myotis
roosted mostly in snags with exfoliating bark and low canopy cover. Northern myotis roosted in
snags with these characteristics, but exhibited less dependence or specificity. Northern myotis
seem to be opportunistic and more adaptive roosters and may roost in the same trees as Indiana
or other bat species (Vonhoff and Barclay 1996).

Canopy coverage for northern myotis bat roosts has varied among different states in the
US and Canada. In Missouri, the average canopy cover for roost trees is 56% (Timpone et al.
2010), while Kentucky’s average canopy cover is greater than 84% (Lacki and Schwierjohann
2001). In Ontario Canada, average canopy cover was 65% (Jung et al 2004). High amounts of
solar radiation aid in pup development which is why females tend to be found in trees with less
canopy cover when compared to males who seem to be more flexible in regard to roost
preference (Perry and Thill 2007). A maternity roost tree with fewer trees surrounding it will
benefit first time flyers because it decreases the chance of juveniles colliding into objects (Perry
and Thill 2007). When it comes to tree selection for northern myotis, studies have found that
there is no consistent theme throughout its geographic distribution when selecting roost trees.
Some research has found that trees in close proximity to the maternity roost tree had smaller
diameter at breast height (DBH) than the actual maternity roost tree (Lacki and Schwierjohannm
2001). Others have found that trees surrounding the maternity roost tree were taller and had
greater DBH (Sasse and Perkins 1996). One characteristic that appears to be apparent throughout
its known distribution is that northern myotis are partial to roosting in higher elevations (Lacki
and Schwierjohann 2001). Research has found that the majority of roost trees are on upper and
middle slopes rather than lower slopes (Lacki and Schwierjohann 2001). Northern myotis will
typically switch roosts quite often, every 2 to 3 days (Sasse and Perkins 1996), due to
temperature, precipitation, predation, parasitism, and ephemeral roost sites (Carter and
Foraging preferences for northern myotis

Like all bats in Missouri, the northern myotis is an insectivorous bat (Lacki et al. 2007). This species is considered a “foraging specialist” preying on coleopteran and lepidopteran species (Jung et al 2004). They can glean insects off vegetation. The various anatomies of each bat species impact differing foraging behaviors of insectivorous bats (Lacki et al. 2007). The size and shape of wings determine flight speed and maneuverability (Norberg 1981). Bats with smaller wings, like tri-colored bats (*Perimyotis subflavus*), are more maneuverable and capable of exploiting foraging space dense with vegetation; whereas larger species like big brown bats (*Eptesicus fuscus*) require more open space (Aldridge 1986). The northern myotis is similar to the tri-colored bat, as it is adapted for feeding in forest canopies but it also feeds near dense vegetation while the tri-colored bat will not (Lacki et al. 2007).

Northern myotis forage under the forest canopy, around water bodies, along paths and roads, or at the forest edge (Fenton 1997). The foraging behavior of this species is unique because they have been observed gleaning prey off substrates (Ratcliffe and Dawson 2003). The northern myotis high frequency echolocation call can range from 40 to 126 kHz which allows them to be successful at gleaning species like moths that are less able to detect high frequency echolocation calls (Faure et al. 1993). Northern myotis will begin to feed at sunset where they will mostly be found above the understory but under the canopy (Nagorsen and Brigham 1993). They forage on forested hillsides and ridges, rather than along riparian areas (Brack and Whitaker 2001) which indicate that mature woodlands are an important foraging habitat (Caceres and Pybus 1997). Foraging activity is at its highest 5 hours after sunset followed by a secondary
peak within 8 hours after sunset (Kunz 1973). Brack and Whitaker (2001) did not find any significant differences in dietary diversity values between age classes or gender.

**Woodland restoration techniques**

There are multiple techniques used by forest managers to re-establish woodlands. Timber harvest techniques include single-tree, group, and clear cuts which will have different effects on individual species of bat. As new tree stands develop, managers may allow succession to proceed uninterrupted or use techniques like prescribed fire and Timber Stand Improvement (TSI; killing undesirable trees and vines) to direct and speed succession toward a targeted stage, whether they want even-aged or uneven-aged timber stands. Woodland restoration will change the dynamics of the plant community that in turn will affect how bats use the area for foraging and roosting (Grindal 1996).

Even-aged timber can be managed by the use of clear or shelter-wood cuts to produce stands of a uniform age. Harvesting timber reduces dense vegetative foraging habitats that would be beneficial for larger bat species, but has the risk of removing roost trees. Bats such as the Indiana myotis and northern myotis are small and maneuverable and tend to forage along edges of clear cuts into forest interiors (Grindal 1996). Larger bats with greater wingspans, such as big brown bats and eastern red bats (*Lasiurus borealis*), utilize open areas such as centers of clear cuts and larger corridors (Hogburg et al. 2002, Putriquin and Barclay 2003, Owen et al. 2003). Even-aged cuts may create roosts for bark/cavity dwelling bats when trees are girdled or damaged but foliage roosting bats such as eastern red and hoary bats (*Lasiurus cinereus*) lose roosts in large clear cuts where all trees are removed (Lacki et al. 2007). Uneven-aged timber management refers to removal of a single-tree or small-group of trees to produce a forest with
trees varying in age and size. The impact of these cuts is difficult to determine because of their small size, thus little evidence to evaluate impact on bats.

Prescribed fire is used to maintain, restore, and assist in the development of natural communities whose derivation and functionality is dependent upon fire as the main or one of the main disturbances and driving forces (Nelson 1985). Prescribed fires improve regeneration of oak (Quercus) and hickory (Carya) species. The size and intensity of the prescribed fires may affect bat species by altering the quantity and quality of roosts, modifying foraging habitat, and changing prey abundance (Carter 1998, Boyles and Aubrey 2005). The intensity of fires may destroy snags while less intense fires may create snags which could affect bats that roost in cavities of trees or under bark (Boyles and Aubrey 2005). In Red River Gorge and Daniel Boone National Forest, Kentucky, Lacki et al. (2009) found that areas subjected to a prescribed burn had more roosts than unburned areas suggesting that prescribed fires benefit bats that roost in snags. Foliage roosting bats, such as eastern red bats that roost in leaf litter during winter, can be negatively affected by prescribed burns either by displacement or mortality from fires (Boyles and Aubrey 2005). These potential issues have prompted recommendations on when to conduct fires, such as burning during warmer days (above 10 degrees Celsius) when bats are not in the leaf litter (Layne 2009). Removal of fire-intolerant, understory trees may produce a less dense foraging habitat benefiting species that cannot forage in dense vegetation.

The woodland restoration practice of TSI involves culling trees to create gaps and openings in the canopy. Openings in the canopy will promote growth in the understory and culling of trees will create less competition with mature trees which promotes the health and functionality of the woodland system. Promoting the health of trees will in turn allow trees to produce more fruit which will attract more wildlife (Moriarty and McComb 1985). Girdling a
tree is another technique used in TSI management which helps create snags (Lewis 1998) for species to roost (Vonhoff and Barclay 1996). Timpone et al. (2010), determined that northern myotis will adapt to managed areas to avoid competition with more specialized species such as the Indiana myotis which is very specific, requiring trees that contain high amounts of solar radiation for roosting.

All woodland restoration projects such as the one occurring at Thousand Hills State Park require roads and trails to be created for vehicle accessibility so that forest managers can enter and exit the forests in a timely and efficient manner. These required elements will benefit forest dwelling bats in various ways. Bats will begin to use the roads and trails as flyways when moving to different foraging areas throughout the night (MacGregor and Kiser 2005). In some cases, forest managers will create woodland ponds which provide bats with access to drinking water and insect prey (Kiser and Elliot 1996). Heavy logging machinery can create deep road ruts in upland areas that can retain rain water another potential water source for bats (Krusac and Mighton 2002). The extreme weight of the machines being used may compact the leaf litter, which may reduce the availability of ground roosts for hibernating bats (Boyles and Aubrey 2005).

Specific management practices for the northern myotis

Northern myotis benefit from the creation of tree hollows and exfoliating bark (Sasse and Perkins 1996, Lacki and Schwierjohann 2001). Woodlands with a dense sub-canopy may provide roosting and foraging habitat infrequently used by other bats. The northern myotis is adapted for dense vegetative stands that provide little usable habitat for woodland species. Single and group tree selection can create a suitable matrix of habitats composed of different tree age classes over
time which will benefit a variety of woodland species.

Ecology of bats at Thousand Hills State Park

Roosting and foraging preferences for all other bats expected to be found in THSP

Since an overall bat assemblage survey was conducted in this study, we expected to document the presence of other forest dwelling bats occupying THSP. These bats include the big brown bat, eastern red bat, hoary bat, silver-haired bat (*Lasionycteris noctivagans*), little brown myotis (*Myotis lucifugus*), Indiana myotis, evening bat (*Nycticeius humeralis*), tri-colored bat, and northern myotis. These species belong to the order Chiroptera, suborder Microchiroptera, family Vespertilionidae, subfamily Vesperitilionae, genus *Myotis*, and subgenus *Myotis* (Caceres and Barclay 2000). All of these bats are insectivorous bats and it is important to know all of these species’ foraging habits as well as roosting habits because they each play a vital role in maintaining a healthy forest ecosystem. Brief descriptions on the roosting and foraging preferences for each species will be discussed in the following paragraphs.

Big Brown Bat

The big brown bat is wide-ranging and often encountered by the public. These bats are located in northern Canada, the United States, and south of Mexico (Reid 2006). Big brown bats are colonial and roost in hollow trees, buildings, and other structures (Willis and Brigham 2004). Big brown bats forage in early-successional forests and open habitats and are relatively intolerant of clutter (Loeb and O’Keefe 2006). Specifically, big brown bats also forage in agricultural fields, small uncluttered wood lots, and urban habitats (Duchamp et al. 2004). Their echolocation call can range from 50 kHz to 25 kHz. Big brown bats primarily prey on beetles using their
robust skull and powerful jaws to chew through the beetles’ (Coleoptera) hard, chitinous exoskeleton. These bats also eat other flying insects including moths (Lepidoptera), flies (Diptera), wasps (Hymenoptera), flying ants (Hymenoptera), lacewings (Neuroptera), and dragonflies (Odonata; Crampton and Barclay 1998). One study indicated that juvenile big brown bats ate a greater range of softer food items compared to adults (Willis and Brigham 2004).

Eastern Red Bat

The eastern red bat roosts in foliage, grass or leaf litter, and under shingles in houses (Mager and Nelson 2001) but predominately roosts in larger trees that occur randomly over the landscape (Menzel et al. 2000). The eastern red bat is found in southern Canada, Central America, Chile, and Argentina. They are also known to migrate to warmer regions during the months of winter (Reid 2006). Their echolocation call can range from 38-50 kHz. Red bats forage in wooded areas including woodlots, areas of shrubby and sapling regeneration, over pastures, open water, and parks (Walters et al. 2006). Their long, thin wings suggest adaptation for foraging in relatively open habitats where foraging is more efficient than in a cluttered environment (Elmore et al. 2004). Eastern red bats have been documented foraging over aquatic and terrestrial habitats across the United States. The most common prey items taken by red bats are moths, beetles, mosquitoes, and midges (Diptera; Elmore et al. 2004). Selection of prey depends largely on availability in the foraging habitat with diet varying seasonally by reproductive status of females and from night to night.
**Hoary Bat**

The hoary bat roosts in tree canopies, often in stands of dominant, mature trees (Perry and Thill 2007). They usually roost in the foliage of trees. They prefer dense leaf coverage above and open area below their roosts. They are also partial to trees that border clearings. Hoary bats may forage in open areas, consistent with their size, wing morphology, and echolocation call. These bats have a wide geographic range throughout the United States, central Canada and Mexico (Reid 2006). Their echolocation call can range from 15 to 30 kHz (Barclay et al. 1999).

Hoary bats tend to forage above or in high, open canopies due to their large size. For example, at the Indianapolis Airport, a juvenile hoary bat foraged predominately over open habitats including agricultural areas and old fields (Sparks et al. 2005). Moths make up the majority of their diet. They also feed on mosquitoes, flies, wasps, dragonflies, and beetles, mainly found over meadows and waterways.

**Silver-haired Bat**

Silver-haired bats hibernate in a wide variety of habitats, occasionally including caves (Beer 1956), buildings (Bartsch 1956), and even rock crevices (Barbour and Davis 1969). During summer, this species roosts in tree hollows (Betts1998, Crampton and Barclay 1998) and presumably uses similar roosts during migration, although a much wider diversity of roosts may be used at this time (Barbour and Davis 1969, Kunz 1982, Brack and Carter 1998). Researchers have found silver-haired bats foraging in the interior of clear cuts; however, they also feed extensively on caddisflies (Trichoptera), which live in streams and wetlands (Whitaker et al. 1981). These bats are located throughout Southern Alaska and range from Canada to northeastern Mexico (Reid 2006). Their echolocation call can range from 25 to 40 KHz. They
have a short-range foraging strategy, traveling over woodland ponds and streams. They tend to forage low to the forest ground consuming larvae of different insects (Whitaker et al. 1981).

**Little Brown Myotis**

The little brown myotis often roosts in large colonies in buildings (Whitaker and Hamilton 1998) but in some parts of their range they may roost in the hollows of trees (Crampton and Barclay 1998). These bats are abundant in southern Alaska, Canada, Mexico, and across the United States. They have also been found in Iceland and Kamchatka (Reid 2006). Little brown myotis may be partial to hydric habitats and frequently forage over water (Barclay and Brigham 1991), often feeding on aquatic insects (Brack and Whitaker 2004). Putriquin and Barclay (2003) suggested this species frequently uses edges of clear cuts but Hogburg et al. (2002) encountered it in the center of clear cuts, suggesting they use all of the canopy openings. Wing morphology (Arita and Fenton 1997) and characteristics of echolocation calls (Broders et al. 2004) indicate adaptation to less cluttered environments than the Indiana and northern myotis. Their echolocation call can range from 80–40 kHz. Little brown myotis diet may consist of moths, beetles, mosquitoes and midges, depending on availability (Broders et al. 2004).

**Indiana Myotis**

Indiana myotis favor roosting in trees that possess snags and have high amounts of solar exposure to help aid in the production of their pups (Timpone et.al. 2010). This species typically forages along forest edges or hydric habitats such as ponds and streams (Timpone et.al. 2010). The Indiana myotis is located only in North America. They are typically found in Iowa, Missouri, Arkansas, Virginia, North Carolina, New York, Vermont, New Hampshire, and
Massachusetts (Reid 2006). Their echolocation call can range from 80–40 kHz. Indiana myotis diet may consist of moths, beetles, mosquitoes, and midges, depending on availability (Broders et al. 2004).

**Evening Bat**

Evening bats often roost in cavities of trees and bottomland habitats (Timpone et.al. 2010). They have been documented roosting in snags as well as live trees. In some areas where deforestation has occurred, evening bats roosted in old wooden buildings (Timpone et.al. 2010). There may be possible niche overlap with big brown bats that increases competition for roost trees for maternity colonies between the two species (Duchamp et al. 2004). Evening bats may rely on wooded sites more than big brown bats, but also selectively forage in agricultural areas (Duchamp et al 2004). This species is detected 3 times more often above the forest canopy than below (Menzel et al. 2005), making it hard to determine its abundance in forests. Evening bats are found in Nebraska, Missouri, Michigan, Pennsylvania, Florida, Mexico, and along the gulf coast of the United States (Reid 2006). Their echolocation call can range from 25-40 kHz. They feed on mosquitoes, flies, wasps, dragonflies, and beetles (Duchamp et al 2004).

**Tri-colored Bat**

The tri-colored bat is one of the smaller bat species that occurs in Missouri and tends to roost in clusters of dead leaves in the canopy (Veilleux et al. 2003) and in the cavities of trees (Yates and Muzika 2007). These bats are considered a clutter-adapted species (Menzel et al. 2005) and forage in early-successional stands (Loeb and O’Keefe 2006). They hunt at the edges of forests, near streams or over open water. These bats feed on small insects, such as flies, moths,
beetles, leafhoppers (Hemiptera), and other flying insects (Menzel et al. 2005). These bats are located in Canada and the eastern region of the United States (Reid 2006).

**Impacts of management practices on bats**

When focusing on managing a particular area for forest dwelling bats, managers have the daunting task of modifying the environment to satisfy the foraging and roosting needs for bat species (Lacki et al. 2007). A management strategy that benefits all bats will likely require an array of management techniques. A lack of active timber management is one option, but it is itself a type of management that will favor some species over others (Lacki et al. 2007). Using management techniques that increase the number of habitat types and produce a more diverse landscape should yield a greater diversity of bat species. A specific type of management may benefit a species over the short-term but have a negative impact in the long-term. A continuum of habitats, in time and space, is likely to provide the best long-term solution (Lacki et al. 2007). The following sections discuss management techniques for species that occur in Thousand Hills State Park, Kirksville, Missouri.

**Big Brown Bat**

This species often relies heavily on anthropogenic structures for roosts (Cope et al. 1991, Whitaker and Gummer 1992, Whitaker 1997, and Duchamp et al. 2004). Retention of hollow trees will provide natural roosts for this species within forests. Opening the forest canopy in large forest tracts will create foraging habitats. Early successional tree stands resulting from group selection and clear cuts will provide a clutter-free foraging habitat for a few years but over time the above habitats will become too cluttered for foraging.
Eastern Red Bat

Red bats may lose roosting habitat when timber is harvested but in areas dominated by forest the impact may be small. In winter, prescribed fires may kill bats that roost in understory trees or leaf litter (Boyles and Aubrey 2005), unless conducted in fall and spring when temperatures are above freezing. Woodland restoration that incorporates open areas will provide foraging habitat; clear cuts and large group selection cuts create canopy openings. Prescribed burns, herbicide treatment used to treat stumps, and other understory management reduce dense vegetation. Logging corridors provide travel routes.

Hoary Bat

Hoary bats may benefit from management similar to that employed for the eastern red bat, although management should include the retention of tall, live trees for roosts. Clear cuts and open areas should provide foraging habitat, although the species likely often forages high above forested areas. Water sources adjacent to woodlands with an open canopy should benefit hoary bats, because hoary bats can forage several miles from their roosts (Barclay et al. 1999). Managed forests can provide roosting areas that allow the species to forage in open lands within and near the forests.

Silver-haired Bat

Retention of snags or live hollow trees may provide roosting opportunities during migration. However, during migration, this species, and many others, regularly increase the variety of roosts used (Hayward 1970); cracks and crevices in bark may be frequently used (Barclay et al. 1988), and thus trees such as shagbark hickory (Whitaker et al. 2004) may be of
value. Clear cuts, streams, and other forest openings provide foraging habitat

**Little Brown Myotis**

Little brown myotis may respond similarly to the big brown bat to management with artificial roost structures. However, because they also roost in tree cavities (Crampton and Barclay 1998) and under exfoliating bark (Whitaker et al. 2007), they may benefit from management that produces roosts similar to those used by Indiana myotis and northern myotis. Because they routinely forage over water (Barclay and Brigham 1991), they should benefit from strategically located wildlife ponds and access to aquatic habitats like reservoirs, wetlands, and streams. Clear cuts and large group selections will provide foraging habitat for little brown myotis but may benefit the species more if connected by a water body or water corridor.

**Indiana Myotis**

In forested areas, retention of snags with exfoliating bark provides valuable roosts. Indiana myotis benefit from forestry practices that encourage a steady supply of large, dead trees (Carter and Feldhammer 2006). For example, in Indiana, these bats occupied trees that were girdled and left standing as part of TSI (Brack and Whitaker 2006). Because they roost in both shag- and shellbark hickories (*Carya laciniosa*), silvicultural practices that encourage growth and retention (especially after death) of these species are valuable. Oaks in uplands and cottonwoods and ash (*Fraxinus spp.*) in bottomlands are also particularly valuable roost trees (Callahan et al.1997) because the bark often stays attached to these trees for several years after they die. Indiana myotis occasionally use artificial roosts including bat boxes.
**Evening Bat**

Management may be similar to that for the Indiana myotis, both for roosting and foraging, although the evening bat is more likely to roost in buildings. In addition, this species requires foraging areas in close proximity to its roosts (Duchamp et al. 2004). Evening bats may not occupy upland forested areas (Whitaker et al. 2007).

**Tri-colored Bat**

Tri-colored bats benefit from a mosaic of foraging habitats (early-successional stands, mature forest stands, and agricultural land). Management that favors foraging habitat for the northern myotis should also favor tri-colored bats.

**Scientific merit**

This multi-agency (Missouri Department of Natural Resources, DNR; Missouri Department of Conservation, MDC; United States Fish and Wildlife Service, USFWS; and University of Central Missouri, UCM) effort is to better understand the effect that woodland restoration practices have on bats in Thousand Hills State Park (THSP), Kirksville, Missouri. Radio telemetry, as well as mist net and Anabat surveys, were used to assess population demographics and habitat use of bats in Thousand Hills State Park, with an emphasis on northern myotis.

Our research seeks to identify the roosting needs of northern myotis in Missouri, specifically to gain a better understanding of the effects habitat enhancements have on northern myotis, a representative of forest dwelling bats in Missouri. These habitat enhancements include TSI and other woodland restoration practices such as use of herbicides to treat stumps from re-
sprouting. We tested the null hypothesis that woodland restoration techniques would have no impact on the bat community that utilizes THSP for foraging grounds. It is important to know the foraging requirements of different species of bats who are also occupying THSP. Having knowledge of the foraging requirements for the different species of bat could help forest managers create and maintain a healthy forest ecosystem.

MATERIALS AND METHODS

**Study site**

Thousand Hills State Park (THSP), located in Adair County, Missouri, is a 1,301 hectare park established in 1951 and managed by the Missouri Department of Natural Resources (DNR). The main human attraction for this park is Forest Lake which is approximately 284 hectares. The habitat surround the lake is dominated by a mix of savanna, woodland, and forest communities (Appendix I) with numerous areas actively managed in order to re-establish pre-settlement community structure. Management strategies include prescribed fire, which was initiated during the mid-1980s, and tree thinning projects which began in 1993. The park is bordered by Big Creek Conservation Area (BCCA) to the east, which is owned and managed by the Missouri Department of Conservation (MDC) and contains nearly 323 hectares of mixed savanna, woodland, and forest with an additional 101+ hectares of native grasslands, old fields, and food plots. Woodland restoration projects at BCCA began in 2007. The combination of restoration projects at THSP and BCCA created a landscape matrix of forest and woodland communities at different points of restoration. This matrix includes areas of unrestored habitat, of which 81 hectares were restored by focusing thinning of trees located ridgetops that had a basal diameter
of 60 centimeters (cm) in January 2014. This allowed for 5 management zones to be assessed within the study area (Figure 3):

**Zone 1.** Previously untreated habitat that received TSI in January 2014, between our 2013 and 2014 field surveys

**Zone 2.** Areas that received habitat improvement (TSI and burning) in 1993-1995

**Zone 3.** Areas that received habitat improvements (TSI and burning) in 2010-2011

**Zone 4.** Areas that received habitat improvements (TSI and burning) in 2009-2010

**Zone 5.** Old-growth oak stand representing the climax of community and restoration efforts
Figure 3: The 4 woodland restoration zones surveyed in Thousand Hills State Park and 1 zone (Control Zone) surveyed in Big Creek Conservation Area during summer months (May-September) 2013 and 2014.
Field surveys for summer 2013 and 2014:

Field studies were conducted from May 15 – September 15, 2013 and May 15–September 15, 2014, in THSP and a portion of BCCA. This time period was chosen due to the maternity period of northern myotis which ends August 15. I extend the survey an extra month to sample any migratory bats that were passing through. A bat assemblage survey was conducted and netting sites were focused in areas thought to be most effective for catching high numbers of bats within the different management zones.

Northern myotis forage in bottomlands, riparian zones, and wetlands (Carter 2006). Areas that contained any of these habitat types and had potential flight corridors where bats would be funneled were chosen for mist netting sites. Following the methodology of Robbins et al. (2008), 2-6 black polyester mist nets with 50-dernier/2-ply nylon with 38 mm. mesh size (Avinet Inc. Dryden, New York) ranging from 6- 18 meters in length were set up for a minimum of 5 hours along with an Anabat detector pointed away from the nets within an open area in the understory (minimum distance of vegetation away from the microphone was 3 meters) within 10-15 m of the mist nets to record bat echolocation activity. Northern myotis who appeared physically healthy (no tears in wing membranes and at least 7 grams) were tracked to roost trees in order to collect information about their selected roost sites. They were fitted with 0.03 gram transmitters (Advanced Telemetry Systems, Inc., Isanti, MN) and were tracked the following day.

A total of 22 sites was surveyed during the 2 field seasons (Figure 4). These sites were located within the 5 management zones and were chosen due to their potential for capturing bats within the study area. I had 10 sites located in Zone 1, 7 Sites in Zone 2, 2 sites in Zones 3 and 4, and 1 site in Zone 5. Fewer sites were chosen in Zones 3-5 because they were difficult to get to and had few ideal netting conditions. Research has shown that northern myotis are considered
generalists when it comes to foraging (Fenton 1997); therefore, the study site habitats varied differently from each other in order to adequately survey all potential foraging habitats. Only 1 site occurred on BCCA because as a mature open woodland it was the only area that could serve as a control. A survey session consisted of a 3-night sample period, with a different site surveyed each night. When I resampled a site, I allowed at least 7 days between samples. I visited each netting site 1 to 3 times during the field season.

Mist net data

Upon capture of a bat I recorded: type of species, time of capture, gender, weight, forearm length, reproductive status, and the presence of WNS symptoms which was determined by examining the wings and nose for skin damage caused by the disease. Since we did not have a federal permit, we could only document the presence of the federally endangered Indiana myotis and determine gender and reproductive status but each individual was released immediately without collecting data to avoid potential stress on the animal. All bats, except red bats and Indiana myotis, were fitted with a USFWS metal band when captured. Red bats weren’t equipped with bands due to the potential of them snagging on vegetation, possibly causing harm to the individual (Shelly Colatski, pers. comm.). These bands had a five digit number engraved on them and were placed on the left forearm of females and the right forearm of males (Shelly Colatski, pers. comm.).
Figure 4: Locations of 22 survey sites where mist net and Anabat data were collected in Thousand Hills State Park.
Anabat detector

Echolocation calls were sampled using an Anabat SDII Detector (Titley Electronics, Ballina, New South Wales, Australia) and recorded onto a compact flash card with a Zero-Crossings Analysis Interface Module (ZCAIM; Titley Electronics, Ballina, New South Wales, Australia), a device that stores call files with associated date and time data for later downloading onto a personal computer (Vonhoff and Barclay 1996). Like every sampling method, bat detectors have their bias such as clutter from vegetation, weather conditions, theft, and vandalism. This was controlled by directing or placing the bat detectors at a 45 degrees or higher angle from the ground and pointing away from heavily cluttered stands of vegetation. Weather did not seem to affect the quality of the calls collected. To avoid the detector being vandalized or stolen, I took it down and locked it in a safe place when the survey session was complete. Data recorded by the Anabat were analyzed using Kaleidoscope 2.3.0 (Wildlife Acoustics, MA) with a filter that eliminated any files that did not meet programmed criteria (signals ranged from 16 to 120 kHz, duration of 1 to 500 milliseconds, and had a minimum of two echolocation pulses). The resulting files were automatically identified with Bats of North America 2.2.2 classifier (Wildlife Acoustics, MA). All files that were considered by the program to not be a bat call were labeled as noise and were eliminated from further analyses. Call files that had ≥4 species matching pulses were kept to tabulate species activities at each site. Bat call files were also visually identified by Jason Lane (MDC biologist) and compared to a known call library in order to verify all bat species identification and site activity summaries.
Radio-telemetry

Radio transmitters (Advanced Telemetry Systems, Inc., Isanti, MN) that weighed 0.03 grams were placed on adult northern myotis that weighed greater than 7 grams and showed no visible signs of WNS. The majority of selected bats were females because they are more important to species recruitment and their roost selection mean more to species survival. No bats were tranquilized while attaching a 0.03 gram transmitter. The transmitter was attached by cutting the hair between the scapulae and then secured using Skin Bond® surgical cement (Pfizer Hospital Products Group, Inc., Largo, and Florida) which can hold the transmitter for 3 weeks depending on weather conditions (Sasse and Perkins 1996). Transmitters had a battery life of a week and a half, during which time they sent tracking pulses up to approximately 1.6 km. When tracking bats, I used R2000 ATS receivers (Advanced Telemetry Systems, Inc., Isanti, MN), and folding three-element Yagi antennas to determine the location of roost trees. Universal Transverse Mercator (UTM) coordinates of the roost trees were obtained using a Garmin Global Positioning System (GPS) (Garmin Inc. Olathe, Kansas). Bats were tracked to roost trees during this project and were observed until transmitters fell off the bat or the battery failed.

Roost-tree metrics

When a roost tree was found, I determined the species of the tree and measured the diameter at breast height (DBH) by using a Biltmore stick. The height of each roost tree was determined using a clinometer (Forestry Suppliers, Jackson, MS.), and the canopy cover surrounding the tree was measured with a densiometer (Forestry Suppliers. Jackson MS.). I categorized the amount of canopy cover into 3 categories: <35%, 40-75%, and >75% canopy cover. Elevation of each tree was categorized as: ridge top, mid slope, or bottomland. I also
recorded the distance of each roost tree to nearest water source and distance from capture location using ARC GIS 10.3, (Environmental Systems Research Institute, Inc., Redlands, CA). Once a transmitter was placed on a bat I tracked it to a roost tree for a maximum of 3 days. I also measured the distance from the net it was caught in to the roost tree. If I could not find the roost tree the following day, I traveled the perimeter of the entire lake for a maximum of 3 days until I picked up a signal from the transmitter.

Statistical analysis

The data collected from mist net captures and calls recorded from ANABAT detectors in 2013 (prior to thinning of trees) and 2014 (post tree thinning) were analyzed to see if there was any significant difference in number of individuals surveyed and if there were differences in species assemblage in the 5 managed zones between the 2 years. I analyzed the data by performing a Sign Test for all species captured and echolocation calls recorded to determine if there was a difference in the number of individuals of each species of bat within the differently managed zones. I tracked 16 northern myotis to their selected roost trees and used a Log-likelihood Goodness of Fit Test to determine if there was a difference in roost tree species selection between the 2013 and 2014 field surveys.

RESULTS

Results for 2013

Mist net

Within the 194 net nights that occurred during the summer of 2013, 6 species of bats
were captured in mist nets with a total of 204 individual bats (Table 1). This total consisted of 39 big brown bats, 36 eastern red bats, 34 little brown myotis, 1 Indiana myotis, 15 evening bats, and 79 northern myotis captured with mist nets. The sex ratio was 120 males to 84 females.

<table>
<thead>
<tr>
<th>Zones</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td># of sites in 5 zones</td>
<td>10</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td># of Days Surveyed</td>
<td>31</td>
<td>21</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Big brown bat</td>
<td>20</td>
<td>17</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Eastern red bat</td>
<td>22</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Little brown myotis</td>
<td>15</td>
<td>11</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Indiana myotis</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Evening bat</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Northern myotis</td>
<td>34</td>
<td>25</td>
<td>7</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Male</td>
<td>61</td>
<td>40</td>
<td>5</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Female</td>
<td>40</td>
<td>31</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1: Mist net capture totals for the 6 bat species sampled in the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2013.

*Anabat Detector*

The Anabat Detector recorded 643 echolocation calls, 84 detections were eliminated due to insufficient data for confidence in call identification which resulted in 559 echolocation calls that were analyzed (Table 2) from 9 species (Figures 3 and 4) during the 64 nights within the 22
survey sites. A total of 21 big brown bats, 34 eastern red bats, 48 silver haired bats, 191 hoary bats, 51 little brown myotis, 3 Indiana myotis, 94 evening bats, 100 tri-colored bats, and 17 northern myotis total calls was recorded.

<table>
<thead>
<tr>
<th>Zones</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td># of sites in 5 zones</td>
<td>10</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td># of Days Surveyed</td>
<td>31</td>
<td>21</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Big brown bat</td>
<td>10</td>
<td>7</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Eastern red bat</td>
<td>16</td>
<td>10</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Silver-haired bat</td>
<td>20</td>
<td>15</td>
<td>3</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Hoary bat</td>
<td>110</td>
<td>50</td>
<td>6</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Little brown myotis</td>
<td>16</td>
<td>15</td>
<td>7</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Indiana myotis</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Evening bat</td>
<td>40</td>
<td>20</td>
<td>9</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Tri-colored Bat</td>
<td>41</td>
<td>30</td>
<td>6</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Northern myotis</td>
<td>9</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: Total echolocation calls collected from 9 different species with the Anabat detector in the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2013.

**Roost tree metrics**

In 2013 I attached transmitters to 10 female northern myotis out of the 79 that were captured to track to their roost trees. I was unable to locate 2 of the 10 transmitters, either due to battery failure or dispersal of transmitted bats out of study site. I tracked 8 out of 10 transmitters to 11 trees (Table 3). The selected trees were 5 white oaks, 1 cottonwood, 1 silver maple, 1 red
oak, 2 shagbark hickories, and 1 black walnut (*Juglans nigra*). All trees were mature and possessed snags, loose bark, or cavities where bats could roost. The mean DBH was approximately 58 cm and ranged from 53 to 86 cm. The average height of the trees was 22 m and ranged from 19 to 24 m. The trees were located on ridge tops (4), mid-slopes (6), and bottomland (1). The canopy cover for the area surrounding the roost tree was determined with a densitometer and was considered <75% canopy cover, because little light was reaching the woodland floor. The average distance from the tree to closest water was 167 m and ranged from 32 m to 283 m. The average distance from the tree to where the bat was netted was 206 m with 155 m being the closest and 283 m being the farthest.

<table>
<thead>
<tr>
<th>Bat ID</th>
<th>Gender</th>
<th>Reproductive status</th>
<th>Species of tree</th>
<th>Snag/cavity/loose bark</th>
<th>Dead/alive</th>
<th>Zone</th>
<th>Slope</th>
<th>DBH (cm)</th>
<th>Height (m)</th>
<th>Canopy cover</th>
<th>Distance from water (m)</th>
<th>Distance from net site (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>female</td>
<td>not lactating</td>
<td>silver maple</td>
<td>cavity</td>
<td>dead</td>
<td>1</td>
<td>mid-slope</td>
<td>45</td>
<td>22</td>
<td>&lt;75%</td>
<td>181</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>cavity</td>
<td>alive</td>
<td>2</td>
<td>ridge top</td>
<td>68</td>
<td>19</td>
<td>&lt;75%</td>
<td>283</td>
<td>283</td>
</tr>
<tr>
<td>2</td>
<td>female</td>
<td>lactating</td>
<td>cottonwood</td>
<td>cavity</td>
<td>alive</td>
<td>2</td>
<td>mid-slope</td>
<td>54</td>
<td>24</td>
<td>&lt;75%</td>
<td>271</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>snag</td>
<td>dead</td>
<td>3</td>
<td>ridge top</td>
<td>60</td>
<td>23</td>
<td>&lt;75%</td>
<td>62</td>
<td>156</td>
</tr>
<tr>
<td>4</td>
<td>female</td>
<td>lactating</td>
<td>black walnut</td>
<td>cavity</td>
<td>alive</td>
<td>1</td>
<td>ridge top</td>
<td>86</td>
<td>23</td>
<td>&lt;75%</td>
<td>32</td>
<td>302</td>
</tr>
<tr>
<td>4</td>
<td>female</td>
<td>lactating</td>
<td>red oak</td>
<td>loose bark</td>
<td>alive</td>
<td>1</td>
<td>bottom land</td>
<td>53</td>
<td>22</td>
<td>&lt;75%</td>
<td>242</td>
<td>176</td>
</tr>
<tr>
<td>5</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>snag</td>
<td>alive</td>
<td>4</td>
<td>mid-slope</td>
<td>63</td>
<td>24</td>
<td>&lt;75%</td>
<td>184</td>
<td>155</td>
</tr>
<tr>
<td>6</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>cavity</td>
<td>alive</td>
<td>1</td>
<td>mid-slope</td>
<td>58</td>
<td>24</td>
<td>&lt;75%</td>
<td>172</td>
<td>167</td>
</tr>
<tr>
<td>6</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>cavity</td>
<td>alive</td>
<td>1</td>
<td>mid-slope</td>
<td>58</td>
<td>24</td>
<td>&lt;75%</td>
<td>172</td>
<td>167</td>
</tr>
<tr>
<td>7</td>
<td>female</td>
<td>post lactating</td>
<td>shagbark hickory</td>
<td>loose bark</td>
<td>alive</td>
<td>2</td>
<td>ridge top</td>
<td>40</td>
<td>19</td>
<td>&lt;75%</td>
<td>51</td>
<td>204</td>
</tr>
<tr>
<td>8</td>
<td>female</td>
<td>post lactating</td>
<td>shagbark hickory</td>
<td>loose bark</td>
<td>alive</td>
<td>2</td>
<td>mid-slope</td>
<td>53</td>
<td>23</td>
<td>&lt;75%</td>
<td>195</td>
<td>201</td>
</tr>
</tbody>
</table>

Table 3: Metrics collected from 11 different roost trees used by 8 northern myotis females that were tracked by radio telemetry in Thousand Hills State Park between May 15, and September 15, 2013.

**Results for 2014:**

**Mist net:**

Within the 176 net nights during the summer of 2014, 6 species of bats were collected in the 5 managed zones for a total of 98 individual bats (Table 4). This total consisted of 10 big
brown bats, 24 eastern red bats, 17 little brown myotis, 8 evening bats, 7 tri-colored bats, and 32 northern myotis. The sex ratio was 65 males to 33 females.

<table>
<thead>
<tr>
<th>Zones</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td># of sites in 5 zones</td>
<td>10</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td># of Days Surveyed</td>
<td>30</td>
<td>18</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Big brown bat</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Eastern red bat</td>
<td>10</td>
<td>11</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Little brown myotis</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Indiana myotis</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Evening bat</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tri-colored bats</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Northern myotis</td>
<td>19</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Male</td>
<td>34</td>
<td>19</td>
<td>3</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Female</td>
<td>19</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4: Mist net capture totals for the 7 species sampled within the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2014.

**Anabat Detector**

The Anabat Detector recorded 330 echolocation calls and 143 detections were eliminated due to insufficient data for confidence in call identification which resulted in 187 echolocation calls that were analyzed (Table 5) from 9 species. A total of 2 big brown bats, 11 eastern red bats, 22 silver haired bats, 61 hoary bats, 31 little brown myotis, 1 Indiana myotis, 36 evening bats, 10 tri-colored bats, and 13 northern myotis was recorded.
Table 5: Total echolocation calls collected from 9 different species with the Anabat detector in the 5 managed zones in Thousand Hills State Park between May 15, and September 15, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Zones</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td># of sites in 5 zones</td>
<td></td>
<td>10</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td># of Days Surveyed</td>
<td></td>
<td>30</td>
<td>18</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Big brown bat</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Eastern red bat</td>
<td></td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Silver-haired bat</td>
<td></td>
<td>10</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Hoary bat</td>
<td></td>
<td>25</td>
<td>17</td>
<td>8</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Little brown myotis</td>
<td></td>
<td>11</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Indiana myotis</td>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Evening bat</td>
<td></td>
<td>15</td>
<td>10</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Tri-colored bat</td>
<td></td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Northern myotis</td>
<td></td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

In 2014, 8 northern myotis (2 males, 6 females) out of the 32 that were netted were tracked to 8 different trees (Table 6). I chose 2 males in this field season due to the small number of females captured. The 8 bats were successfully tracked to 5 white oak trees, 2 shagbark hickories, and 1 cottonwood. Locations of the 8 trees varied topographically, 5 were mid slope, 2 were on ridge tops, and 1 was in the bottomland. The canopy cover for all trees was considered <75% due to the fact that very little solar exposure was reaching the woodland floor. All trees
were mature and possessed snags, loose bark, or cavities where bats could roost. The average DBH was 63 cm with 91 cm being the largest and 53 cm being the smallest. The average height of the trees was 22 m with 24 m being the tallest and 17.4 m being the shortest. The average distance from the tree to the closest water source was 153 m with 45 m being the closest and 230 m being the farthest. The average distance from the tree to where the bat was netted was 184 m with 133 m being the closest and 258 m being the farthest.

<table>
<thead>
<tr>
<th>Bat ID</th>
<th>Gender</th>
<th>Reproductive status</th>
<th>Species of tree</th>
<th>Snag/cavity/loose bark</th>
<th>Dead/alive</th>
<th>Zone</th>
<th>Slope</th>
<th>DBH (cm)</th>
<th>Height (m)</th>
<th>Canopy cover</th>
<th>Distance from water (m)</th>
<th>Distance from net site (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>female</td>
<td>not lactating</td>
<td>white oak</td>
<td>cavity</td>
<td>alive</td>
<td>1</td>
<td>mid-slope</td>
<td>66</td>
<td>24</td>
<td>&lt;75%</td>
<td>130</td>
<td>188</td>
</tr>
<tr>
<td>10</td>
<td>female</td>
<td>not lactating</td>
<td>white oak</td>
<td>cavity</td>
<td>alive</td>
<td>1</td>
<td>mid-slope</td>
<td>56</td>
<td>23</td>
<td>&lt;75%</td>
<td>230</td>
<td>148</td>
</tr>
<tr>
<td>11</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>snag</td>
<td>dead</td>
<td>1</td>
<td>mid-slope</td>
<td>55</td>
<td>22</td>
<td>&lt;75%</td>
<td>160</td>
<td>198</td>
</tr>
<tr>
<td>12</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>snag</td>
<td>dead</td>
<td>2</td>
<td>ridge top</td>
<td>64</td>
<td>22</td>
<td>&lt;75%</td>
<td>45</td>
<td>139</td>
</tr>
<tr>
<td>13</td>
<td>female</td>
<td>lactating</td>
<td>white oak</td>
<td>cavity</td>
<td>alive</td>
<td>2</td>
<td>mid-slope</td>
<td>61</td>
<td>22</td>
<td>&lt;75%</td>
<td>198</td>
<td>200</td>
</tr>
<tr>
<td>14</td>
<td>female</td>
<td>post lactating</td>
<td>shagbark hickory</td>
<td>loose bark</td>
<td>alive</td>
<td>3</td>
<td>mid-slope</td>
<td>61</td>
<td>24</td>
<td>&lt;75%</td>
<td>130</td>
<td>133</td>
</tr>
<tr>
<td>15</td>
<td>male</td>
<td>N/A</td>
<td>shagbark hickory</td>
<td>loose bark</td>
<td>alive</td>
<td>2</td>
<td>ridge top</td>
<td>53</td>
<td>17</td>
<td>&lt;75%</td>
<td>150</td>
<td>210</td>
</tr>
<tr>
<td>16</td>
<td>male</td>
<td>N/A</td>
<td>cottonwood</td>
<td>snag</td>
<td>alive</td>
<td>1</td>
<td>bottom land</td>
<td>91</td>
<td>24</td>
<td>&lt;75%</td>
<td>180</td>
<td>258</td>
</tr>
</tbody>
</table>

Table 6: Metrics collected from 8 roost trees used by the 8 northern myotis that were tracked by radio telemetry in Thousand Hills State Park between May 15, and September 15, 2014.

**Total data collected from 2013 and 2014**

**Mist net:**

A total of 370 net nights occurred during the 2 summers of 2013 and 2014. Seven bat species were captured with a total of 302 individual bats sampled in the 5 zones (Figures 5-10). This total consisted of 49 big brown bats, 60 eastern red bats, 51 little brown myotis, 1 Indiana myotis, 23 evening bats, 7 tri-colored bats, and 111 northern myotis. I only had 1 recapture out
of the 241 bats captured and it was netted in the exact same spot on the same date from the previous year.

Figure 5: Mist net capture totals for 9 bat species collected in Zone 1 in 2013-2014 (May 15-September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 6: Mist net capture totals for 9 bat species collected in Zone 2 in 2013-2014 (May 15-September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].
Figure 7: Mist net capture totals for 9 bat species collected in Zone 3 in 2013-2014 (May 15 through September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 8: Mist net capture totals for 9 bat species collected in Zone 4 in 2013-2014 (May 15 through September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].
Figure 9: Mist net capture totals for 9 bat species collected in Zone 5 in 2013-2014 (May 15-September 15) at Thousand Hills State Park [big brown bat (EPFU), eastern red bat (LABO), hoary bat (LACI), silver haired bat (LANO) evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 10: Total number of individuals collected in between May 15 through September 15 2013, and 2014 for the 10 Sites in located in Zone 1, 7 Sites in Zone 2, 2 Sites in Zones 3 and 4, and 1 Site in Zone 5.
Anabat detector

The Anabat detector was set for a total of 610 hours from May 15 through September 15 in 2013 and 2014 while I was sampling bats that were collected from the mist nets. Within those 121 days, a total of 973 calls were recorded across the 5 management zones (Figures 11-16), 746 were deemed suitable for further analyses. Of those 746 calls, I identified 9 species of bats that consisted of 23 big brown bats, 45 eastern red bats, 252 hoary bats, 70 silver hair bats, 82 little brown myotis, 4 Indiana myotis, 130 evening bats, 110 tri-colored bats, and 30 northern myotis calls.

Figure 11: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May-September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].
Figure 12: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May-September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 13: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May-September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].
Figure 14: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May-September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Figure 15: Number of total vocal calls recorded for the 9 bat species collected in 2013-2014 (May-September) at Thousand Hills State Park. [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].
Figure 16: Total number of calls recorded in between May 15 through September 15 2013, and 2014 for the 10 Sites in located in Zone 1, 7 Sites in Zone 2, 2 Sites in Zones 3 and 4, and 1 Site in Zone 5.

**Roost tree metrics**

I tracked 16 different bats to 19 different trees between 2013 and 2014 (Figure 17). The tree species used most often were white oak trees (10), shagbark hickory (4), cottonwood (2), silver maple (1), black walnut (1), and red oak (1). Although no data were recorded on surrounding trees, they seemed to have smaller DBH. All structures that was found on the roost tree such as cavities, snags, and loose bark was located below the canopy level. The average distance from roost tree to water was similar as well with 167 m average for 2013 and 153 m average for 2014.
Figure 17: Map depicting 19 locations of roosting trees located by radio tracking 16 different bats in 2013-2014.

**Statistical analysis results for 2013 and 2014**

Fewer bats were surveyed (through mist netting and Anabat detection) in 2014 than in 2013. Using the statistical Sign Test to analyze the data, I determined that there was a significant difference in total species recorded for both mist net captures and echolocation calls collected after forest management techniques were conducted in January 2014 (Sign Test, p < 0.05).
**Mist net Sign Test results**

Significant difference in number of bats mist netted between 2013 and 2014 occurred in Zones 1 (p<.001), 2 (p<0.001), and 5 (p=0.039) were significantly different (Sign Test). In Zone 1, significant differences existed between number of bats caught in 2013 and 2014 for big brown bats (p<0.004), eastern red bats (p<0.05), and northern myotis (p=0.053). In Zone 2 significant differences existed between number of bats caught in 2013 and 2014 for the big brown bat (p < 0.007) and the northern myotis (p< 0.009). In Zone 3, 4, and 5 there was no significant difference between the species in 2013 and 2014 (Sign Test, p>0.05).

<table>
<thead>
<tr>
<th>Zone</th>
<th>P Value</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.267</td>
<td>0.307</td>
<td>0.039</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: P-values associated with Sign Tests to determine whether there were significant differences in the 5 different Zones between 2013 and 2014.

<table>
<thead>
<tr>
<th>Species</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPFU</td>
<td>0.004</td>
<td>0.007</td>
<td>0.5</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>LABO</td>
<td>0.050</td>
<td>0.690</td>
<td>N/A</td>
<td>0.25</td>
<td>N/A</td>
</tr>
<tr>
<td>NYHU</td>
<td>0.423</td>
<td>0.687</td>
<td>1</td>
<td>0.5</td>
<td>N/A</td>
</tr>
<tr>
<td>MYSO</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>MYLU</td>
<td>0.424</td>
<td>0.118</td>
<td>0.5</td>
<td>0.375</td>
<td>0.125</td>
</tr>
<tr>
<td>PESU</td>
<td>.0125</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>MYSE</td>
<td>0.053</td>
<td>0.009</td>
<td>0.070</td>
<td>0.145</td>
<td>0.125</td>
</tr>
</tbody>
</table>

Table 8: P-values associated with Sign Tests to determine whether there were significant differences in number of bats captured per species between 2013 and 2014 [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].
Anabat Sign Test results

There were significant differences in number of detections in each zone between 2013 and 2014 (Table 9; Sign Test, p<0.05), with the p values being 0.009 for Zone 1, 0.005 for Zone 2, 0.027 for Zone 3, 0.001 for Zone 4, and 0.008 for Zone 5. In Zone 1, the Sign Test showed significant differences in the big brown bat (p<0.01), eastern red bat (p<0.01), silver-haired bat (p<0.006), tri-colored bat (p<0.006), and the evening bat (p<0.001). For Zone 2, the Sign Test showed significant differences for hoary bat (p<0.006) and the tri-colored bat (p<0.002). In zones 3 and 4 there was a significant difference in the number of tri-colored bats (Sign Test, p<0.03 and p<0.0002, respectively). For Zone 5, the Sign Test showed a significant difference in the tri colored bat (p<0.01) and the evening bat (p<0.02), the Sign Test showed that there was significance in calls collected for 2013 and 2014 (p<0.007).
Table 9: P-values associated with Sign Tests to determine whether there were significant differences in number of calls collected per species between 2013 and 2014 [big brown bat (EPFU), eastern red bat (LABO), silver hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].

Roost tree metrics  Log-likelihood Goodness of Fit results

The number of roosts of northern myotis were significantly different among the 6 species of trees used in 2013 and 2014 (Log-likelihood Goodness of Fit, G= 16.114, p<0.05).

From this study, northern myotis utilized white oak species more than other tree species.

DISCUSSION

The 2 objectives for this project were to assess the impact woodland restoration techniques have on bats and to describe roost trees of northern myotis in THSP. During this project, I recorded all 9 species of bats known from the THSP area in 2013 and 2014. In 2013 I
netted 204 individual bats from 6 species and in 2014 I netted 98 individuals from 6 species. With the Anabat detector, I recorded 9 species for both years but had a greater sample size in 2013 with 643 calls recorded compared to 330 in 2014. The numbers for both years followed a similar pattern between months, the number of species netted was high in the beginning of May and June when streams held water but declined through July as creeks dried up, pushing bats to other areas to forage. There was an increase in bat captures during mid-August to early September which is most likely evidence of migration activity (Cryan 2003).

To collect data for this project, I used Anabat detectors and mist nets to sample the bat community. Each method used for surveying bats had strengths and weaknesses. The strength of mist netting is the ability to record information such as gender, size, weight, and reproductive status of individuals. The primary weakness of mist netting is that bats could fly over or around the mist net set up. Bats were noticed flying over the mist nets multiple times during this field study due to high canopy areas. Anabat detectors may be a useful tool for determining the presence or presumed absence of a species in the field, however, data cannot be used to determine population number. When a single bat makes multiple passes in front of the unit, each call sequence generated is counted as an individual call. Mist nets placed within a closed canopy area caught bats using flyways. Mist nets placed in areas with high canopies and no low lying branches had fewer captures. This was due to nets being set in an area where bats had ample opportunity to fly over and around the nets. The use of both methods was important to get a better understanding of all bat species using the area, especially is sites where high canopies or cluttered vegetation existed, the use of both tools was necessary to provide the information needed.

The sites selected for placement of mist nets and Anabat detectors likely influenced
which species were found. I netted mostly in forest interiors which might explain why northern myotis, which tends to forage in areas over wooded edge habitat, was my most caught species (Sasse and Perkins 1996). Likewise, I usually placed the detector in open areas rather than cluttered areas to reduce the amount of “noise” being collected, which could explain why hoary bat calls were collected the most due to the fact that they forage in open canopy areas (Barclay et al. 1999). I collected very few northern myotis calls because they are gleaners and emit very low amplitude calls that attenuate quickly making it hard for the Anabat detector to detect its calls.

Within the different zones, Zone 1 (Fig. 16) had the largest number of mist net captures and calls collected for both years because it had ideal netting conditions, such as streams and trails, which made good flight corridors for setting up nets. Although Zone 1 had the highest number of captured bats, Site 11 located in Zone 2 (Fig. 18) had the overall largest number of collected bats probably because it was located at the edge of where the tree thinning practices were finished and it had a pond, providing excellent foraging grounds after the streams dried up late in the summer.
I banded 241 bats between 2013 and 2014 field surveys. Site 11 is the only location of recapture. I can’t make any conclusions based on such a small sample size of recaptures; however, only 1 recapture may indicate that THSP has a large number of bats. Lack of suitable mist netting sites due to few flyways and high branching could have also played a factor to why I had only 1 recapture. Since the majority of woodland restoration was focused more in the center of the managed zones, sites 1, 2, 3, 10, 11, 12, 13, 14, 15 and 16 were not affected by woodland restoration practices directly because restoration practices were more focused on ridge tops than areas located closer to Forest Lake. Site 12 had 0 mist net captures due to inclement weather which impacted my totals. I believe in the absence of inclement weather I would have captured more bats in Zone 2 because on the nights with clear weather I averaged 2.4 bats a night. The proximity to a creek should have increased the numbers of bats documented. I caught less bats in nets set along the lake than expected, bats were foraging over the lake rather than the nearby...
shore. Nets set in woodland interiors caught more bats than those set by the lake due to my ability to adequately cover flyways. Site 7 was at the edge of an area that had restoration work done in 1993 and bordered that which was done in 2014. The habitat was similar to Zone 2 with scattered mature trees and thick patches of saplings growing on the woodland floor.

**Reasons for declines**

Precipitation and temperature could have affected the number of bats captured in 2013-2014. Bats limit travel from their roost trees when temperatures fall below 10° Celsius or when raining because few insects are active during these conditions (Robbins et al. 2008). In 2014, rain occurred 21 of the 51 days I netted compared to 10 days of rain that occurred during my survey nights in 2013. Temperatures fell below 10°Celsius for 10 survey nights in 2014 compared to 7 nights in 2013.

White-nose syndrome could also explain why I sampled fewer individuals in 2014. An estimated 80% decline (USGS 2015) in total bat populations has occurred since 2006 and fatalities are increasing every year. Although none of the bats sampled at THSP showed any visible signs of WNS, the caves in which they hibernate could harbor the fungus which could have killed a large portion of the population that exists at THSP. Further assessment needs to be conducted to decide whether this could be a contributing factor in their decline.

Although it is highly unlikely, woodland management techniques that were performed between the two survey years could have contributed to the decline in bats sampled. Sign Tests for mist net captures and Anabat calls show that there was a reduction in numbers of big brown bats, red bats, silver-haired bats, hoary bats, Indiana myotis, little brown myotis, evening bats, and the northern myotis. The one bat that did not show any significant difference was the tri-
colored bat which may be due to its small sample size or because they thrive better in early successional forest growth stages (Loeb and O’Keefe 2006).

Roost tree selection of the northern myotis did not seem to change between seasons as white oak trees that possessed either snags or cavities seemed to be the most used species in both years. The 2 male northern myotis that were selected were found in trees that had very different characteristics. One male was roosting in 1 of the tallest trees documented during the survey and the other was found roosting in 1 of the shortest trees documented. All females picked trees similar in height and size throughout the 2 study seasons. Yet, one thing that was common among both genders was that all roosting cavities or snags were below the canopy level. Northern myotis might be roosting below canopy level to reduce the risk of colliding into a tree or shrubs for juvenile bats that are learning how to fly. Seventeen out of the 19 trees that were recorded were found before August 15th. Although no exit counts were conducted, these trees could be maternity trees due to the fact that northern myotis maternity season ends around mid-August (USFWS 2015). The 2 other trees were found after August 15th, so it was presumed that these were just roosting trees. Another trend that was prevalent in all the roost trees was canopies that had very little solar exposure located on ridge tops or mid-slope. As long as trees with hollow crevices or snags are present in the area, northern myotis may utilize them for maternity colonies. Solar exposure does not seem to be a major factor in tree selection.

Since the 2014 survey was conducted directly after woodland restoration practices, I expect the mosaic of the landscape will continue to fluctuate and the habitat for bats will increase, providing foraging and roosting habitat for bats in the future. A heterogeneous landscape composed of open woodland stands may be identical to a natural woodland landscape for faraging. I predict as the woodland matures and trees grow larger, northern myotis
populations will increase because during my study I tracked northern myotis to trees that seemed
to have larger DBH than surrounding trees. Proper girdling and prescribed burning will help
create new snags that will benefit maternity colonies. I caught the most bats throughout the study
area in Site 11, probably due to the presence of the pond, and I therefore believe that maintaining
water sources is crucial for providing foraging areas for bats as well as for hydration. I
recommend focusing conservation efforts on regenerating forest interior patches by the use of
woodland restoration practices. Promoting tree growth will be the key to maintaining multiple
maternity colonies for the northern myotis in Thousand Hills State Park.

These results may provide some insight into the initial responses of 9 species of bats to
woodland restoration practices that may be used in future years at THSP. Understanding bat
requirements, such as foraging and roosting habitat, is necessary for land managers to properly
manage woodlands and forests for bat conservation. Although fewer individuals were sampled in
2014, I sampled bats throughout the study site, including areas where woodland restoration
practices occurred, which may be an indication that bats are utilizing both disturbed and
undisturbed areas for foraging. Woodland restoration practices have the potential to increase
roosting habitat for northern myotis in Thousand Hills State Park. The open understory created
by tree thinning will provide a new area for foraging bats. As the disturbed area continues to
regenerate new growth, more and more forest-roosting bat species may begin to roost within the
area. For now, the newly created disturbed area has roosting conditions conducive for habitat
specialist bats such as the northern myotis. It is studies like this that will be key in protecting this
species survival. On April 2, 2015 the northern myotis conservation status changed to threatened
due to the large impact of WNS on northern myotis populations (USFWS 2015). It is imperative
to understand the foraging and roosting needs of this species of conservation concern so that we can manage for it properly.
LITERATURE CITED


Colatskie, S. 2014. Personal communication. Email correspondence sent by S. Colatskie, Ecologist, Missouri Department of Conservation to C. Zimmerman, Student, University of Central Missouri. (sent 12/5/2014)


Kiser, J. D., and C. L. Elliot.1996. Foraging habitat, food habits and roost tree characteristics of the Indiana myotis (Myotis sodalis) during autumn in Jackson County, Kentucky. Final Report to the Kentucky Department of Fish and Wildlife Resources, Frankfort, Kentucky Pp. 65.


U.S. Fish and Wildlife Service, White-Nose Syndrome.org (http://whitenosesyndrome.org/)

USGS Fort Collins Science Center, WNS page (http://www.fort.usgs.gov/WNS/)


APPENDIX

Habitat Types

**Dry-mesic loess/glacial till savannah**

Dry-mesic loess/glacial till savannahs are described as grasslands interspersed with trees and are maintained by fire. This type of habitat can occur on broad ridges. They can be distinguished from grassland and woodlands by a tree canopy cover of 10-50 percent. White oak trees are the most common tree species for this type of habitat with big blue stem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and Indian grass (*Sorghastrum nutans*) being the common plant species covering the ground floor. Sites which contained this habitat type include 7, 11, and 15. Further down the slopes is where the landscape changed into more dry woodland type of habitat.

**Dry-mesic loess/glacial till woodland**

Dry-mesic loess/glacial till woodlands are found in the dissected plains of Missouri located on mid- and upper-backslopes and ridges. The tree canopy is moderately tall, 18-27 m, with 50-80% canopy cover. Some of the dominant plant species include white oak, shagbark hickory, fragrant sumac (*Rhus aromatica*), tick trefoil (*Desmodium glutinosum*), hog-peanut (*Amphicarpaea bracteata*) and various sedges (*Caryx* spp.; Nelson 2005). Sites which contained this habitat type include 3-7, 9,10,13,14,16,18,19,21,22.

**Dry-mesic sandstone woodland**

This community occurs on narrow ridges and mid- and lower-backslopes of Missouri. Slopes can be gently sloping to steep (3-35%). Canopy trees are tall (18-27 m) with a canopy cover that ranges from 50-80%. Dominant plants include white oak, fragrant sumac, tick trefoil,
and hog peanut (Nelson 2005). Sites 1, 2, 8, and 17 for this study area are considered a dry-mesic sandstone woodland habitat.

**Streambank**

This type of community is found along the stream and can hold water seasonally or all year round. The soils of the stream bank and stream floor are variable and can be sand, clay, or silt. The banks of the stream for this area are moderately steep due to seasonal high velocity floods that occur throughout the year. Dominant species for this region include silver maple, cottonwood, black willow (*Salix nigra*), river oats (*Chasmanthium latifolium*), and yellow iron weed (*Verbesina alternifolia*; Nelson 2005). Sites which contained this habitat type include 1-3, 10,12,13,17,19,21,22. This type of habitat was most ideal for capturing bats due to the water source which attracted bat species who prefer to feed on aquatic insects.

**Marsh**

This type of community is an inundated wetland with seasonal or permanent fluctuating water levels characterized by herbaceous vegetation adapted to saturated or flooded soil conditions. River bulrush (*Bolboschoenus fluviatilis*), cattails (*Typha latifolia*), cottonwood, and willow trees are the common species noticed for this type of habitat (Nelson 2005). Sites 3 and 20 are considered to be this type of habitat.

**SITE DESCRIPTIONS:**

All sites were chosen in areas with potential for high success rates for both mist nets and recording bat calls. Each site description details the landscape surrounding the site and describes what nets were used and where the Anabat detector was placed for each particular site. Each site was used 2-3 times per season and after each night of sampling the nets were boiled and bleached to prevent the spread of WNS.
Zone 1

Site 1

Site 1 was located in a lower perennial stream bank within a dry-mesic sandstone woodland setting. The woodland understory surrounding the creek was covered with vegetation such as poison ivy (*Toxicodendron radicans*) and various sedges. White oak, red oak, and cottonwood trees were the dominant tree species in the area. The creek flow was a slight trickle so I set the mist nets perpendicular over the creek. The Anabat detector was placed on the sandbar along the stream bank and set at a 45° angle to increase the chance of picking up echolocation calls. Since the canopy cover was tall (12 m) and the water level was low, a double high mist net system with a single high mist net directly in front of it was necessary for this site. I used 2 double high net systems for this area where one net was placed under a bridge and another was placed 20 m north.

Site 2

This site was located near the same perennial stream as Site 1 but further north. The habitat was dry-mesic sandstone woodland. I chose this site because 2 tributaries flowed into the main creek. The vegetation around it was a mix with wood nettle (*Laportea canadensis*) and hog peanut. Trees that occurred in this area were mainly white oak with a few cottonwoods and silver maple scattered along the bank edge. Since there were 3 separate flyways, I used 3 nets placing 2 of the 6 m nets at each of the openings of the tributaries that opened into the main creek and placed a 9 m net perpendicular over the main creek. The canopy cover was moderately short so I used only single high nets for this site. I placed the Anabat 20 m south of the site along the bank of the creek.
Site 3

This site was located where Gill branch creek empties into the lake. The habitat slowly transformed from a mesic woodland setting to a marsh as it got closer to the lake. River birch (*Betula nigra*) trees on both sides of the creek created a flyway for foraging bats. Ground cover was mostly woodland brome (*Bromus pubescens*) and river oats. Two 12 m nets were placed perpendicular over the creek 15 m apart. The Anabat detector was placed 20 m south along the creek with the microphone facing the opposite direction of the nets.

Site 4

This site was located within the woodland interior on a ridge top in a dry-mesic loess/glacial till woodland. The dominant tree species were white oak, post oak (*Quercus stellata*), and red oaks. The canopy cover was moderately tall and the woodland floor was mainly hog peanut and tick trefoil. I set 3 mist nets up at this site. One was a 9 m double-high mist net system that was set up between 2 trees while 1, 6 m net was placed between 2 trees with low lying branches. The Anabat detector was set in an area that had low lying vegetation and was placed 10 m east from the nets’ site.

Site 5

This site was on a ridge top in dry-mesic loess/glacial till woodland community where woodland restoration practices had occurred. To the east of the ridge top it began to slope and turn into dry-mesic sandstone woodland because bare rock structures were exposed on the ground floor. White oak, red oak, and hickories were the dominant tree species for this area. I used 3 mist nets, 2, 6 m nets and a 9 m net were placed in small gaps between the trees. The Anabat detector was placed on a log 15 m west of the mist nets and was facing the opposite direction of the nets.
Site 6

This was a dry-mesic loess/glacial till woodland community. Numerous moderately steep hills occurred in this area so I placed my nets on one of the ridgetops. The surrounding trees were dominated by red and white oaks with few silver maple and hickory species scattered in between. A 9 m double high mist net system was necessary for this area due to high canopy cover. The Anabat detector was located on the ridge top in a clearing with little vegetation on the forest floor.

Site 7

This particular site was located on an old fire line in dry-mesic loess/glacial till woodland on the perimeter with small patches of dry-mesic loess/glacial till savannah communities within and surrounding the fire lane. The site was mixed with mature white oaks whose bark started to pull away from the trunk towards the canopy. Younger saplings were thick and covered the woodland floor. The fire line had grasses such as woodland brome (Bromus pubescens) and little bluestem (Schizachyrium scoparium). This site was far from any available water sources. Two 6 m nets and a 9 m net were placed in small gaps between trees. The Anabat detector was placed on a stump that was above the vegetation, 15 m north of the mist nets facing away from the net site.

Site 8

This site was a dry-mesic sandstone woodland community that occurred on a slightly sloped hill. This site was located on a hiking trail 20 m west of Forest Lake. This site was abundant with younger oak and hickory species with low lying branches making it perfect for single high net systems. The hiking trail was 1.5 m wide so I used 3 single high nets in this area which consisted of 2, 6 m long net and 1, 12 m long net and set them perpendicular along the
trail. Each net was set where the shortest canopy spots occurred. Tick trefoil was abundant in this area so I had to remove some of it to reduce clutter 15 m east of my netting site to place the Anabat detector.

**Site 9**

This site was located in a dry-mesic loess/glacial till woodland community that was on the edge of a ridge top. Tick trefoil, black berry bushes (*Rubus fruticosus*) and Virginia creeper (*Parthenocissus quiquefolia*) covered the woodland floor where red oak species surrounded the net site area. Further down the slope tree species transitioned from red oaks to white oaks. I set up 2, 6 m mist nets in this area. One was located mid-slope in between 2 trees with low lying branches. The other was located on the ridge top in the old fire trail. The Anabat detector was placed 20 m north of the mist net in a patch of bedded down grasses.

**Site 10**

This area was located over a dry-mesic loess/glacial till woodland creek that cut through 2 hills and a washed out pool that ran into Forest Lake. The pool was not very deep and had low lying dead trees that had fallen across the creek. The trees in this area were all tall and similar in size and the woodland floor was mixed with Virginia creeper and wood nettle. The goal for this site was to trap bats that were entering or leaving the lake. Bulrush and cattails were surrounding the edge of stream bank so I used a 12 m double high net system, which was set perpendicular to the entrance of the flyway. The Anabat detector was located on the bank of the lake 15 m north of the double high net system.
**Zone 2**

**Site 11**

This site was located in between a hiking trail and an old farm pond. Two communities were present within this site. On the south side of the pond was a dry-mesic loess/glacial till woodland where woodland restoration occurred and north of the pond was dry-mesic loess/glacial till savannah. The habitat surrounding the pond consisted of wetland vegetation such as bulrush and cattails. The canopy cover was tall so a double high net system was necessary for this site. Two, 18 m nets were placed parallel to the pond dam and a 6 m net was placed perpendicular over the hiking trail. When the net system was set up the double high and 6 m single high met and formed an L-shape netting system. The Anabat detector was placed on the trail 15 m west of the nets and was set along the hiking trail.

**Site 12**

This site was located near the lake in a dried up creek bed. The habitat type surrounding the stream bank were sedges and river oats covering the woodland floor with black willow (*Salix nigra*), silver maple, and cottonwood trees being the most common tree species. Canopy cover was slightly open and had about 30% sunlight coming through during daylight hours. The understory was generally open with the exception of a few patches of woody shrubs like flowering dogwood (*Cornus florida*) and vines such as Virginia creeper and summer grape (*Vitis aestivalis*). The creek floor was bedrock so placing metal stakes to stabilize the mist net poles in the creek would not work with the tools I possessed. Therefore, I used 2 of the 12 m nets that I could stake up against the edge of the bank so the poles would stand in an upright position for the study time. The 2 single high nets were placed 10 m apart from each other and were...
perpendicular to the creek bed. The Anabat detector was placed 15 m west of the nets and was placed 2 m off the bank of the dried up creek.

Site 13

This site was on the ridge top where the perennial stream bed began to form. The area surrounding the stream was considered a dry-mesic loess/glacial till woodland. The canopy was open with large post oak and white oak trees with an abundance of sapling oak trees covering the ground floor. Traveling through this area was difficult but there was an open patch where I set up 2.6 m nets and formed a double high mist net system that faced perpendicular to the beginning of the creek. The Anabat detector was placed mid-ridge alongside of the creek, 15 m east of the nets.

Site 14

This site was located on the bottom of a hill 20 m away from Forest Lake within dry-mesic loess/glacial till woodland community with oak and hickory trees spaced close together. Single high nets were necessary for this site so I used 3 nets: 6, 9 and 12 m nets spaced 10 m apart in a flight corridor in between the row of trees. The Anabat detector was placed 15 m south of the nets on the bank of Forest Lake to pick up any calls over the lake.

Site 15

This site was located in dry-mesic loess/glacial till savannah habitat with clusters of oak trees spaced sporadically. I chose to set up my nets in a cluster of trees that looked like a potential flight corridor. I used a 12 m double high net system and placed a 6 m net 10 m east of the double high net. Both nets were placed under low hanging branches of the oak trees. I set the Anabat detector in the savannah 15 m away from the mist nets facing away from the trees.
Site 16

This site was located in dry-mesic loess/glacial till woodland on the northwest end of the peninsula in between 2 wooded hills. The timber was mature and evenly distributed with fragrant sumac (*Rhus aromatica*) and poison ivy being the common plants growing on the woodland floor. Very limited sunlight reached this site due to the dense canopy cover. I chose to use 3 nets for this site which consisted of 2, 6 m nets and a 9 m net. I placed the nets perpendicularly along a dried up tributary and spaced them 10 m apart. The Anabat detector was placed in the dried up creek connected to the tributary.

Site 17

This site was located in a dry-mesic sandstone woodland setting with tall red oaks being the dominant species along a small stream at the bottom of 3 hills. Rock was exposed on some of the hill sides and hog peanut covered the ground floor. One, 6 m double high net system was placed perpendicular over the stream and 1 single high 9 m net was placed mid-slope in between 2 red oaks. The Anabat detector was placed on the stream bank 15 m east of the double high net system.

Zone 3

Site 18

This site was located on the eastern side of Forest Lake within a dry-mesic loess/glacial till woodland with oak and hickory trees spaced close together surrounding the perimeter. Black walnut trees were also scattered throughout this community. I set my nets in a gap between 2 clusters of trees. I set a 9 m double high net system and a single 6 m net 10 m to the east of the double high system. The Anabat detector was placed on the wooded edge at a 45°angle and was facing towards the woods.
Site 19

This was located to the west of Site 18 but was located in a streambed within a dry-mesic loess/glacial till woodland. The area was slightly hilly on both sides of the stream bed and banks were heavily eroded on each side of the tributary so I placed a 6 m double high net system perpendicular to the stream. The vegetation was thick with sedges and grasses on the west side of the stream but the east side was relatively open so I decided to place the Anabat detector on the east side of the bank in an open patch of wooded timber 10 m away from the net site.

Zone 4

Site 20

This site was located in a marsh type habitat where black willow trees and cattails were abundant. I chose this site for the abundance of aquatic insects and mosquitoes that were in the area. Since there was very little canopy cover and the marsh was so wide I chose to use an 18 m double high mist net system that was placed over a stagnant pool of water. I placed the Anabat detector on the bank of the marsh facing the water in the opposite direction of the nets.

Site 21

This site was on the border of Big Creek Conservation Area (MDC) which is dry-mesic loess/glacial till woodland with mature trees in the area. The area I selected was in a low water level stream bed with river birch trees arching over the creek that created a flyway into which bats would funnel. Only single high nets were necessary for this site due to the low canopy cover. Two, 9 m nets and a 6 m net were placed 15 m apart perpendicular to the stream. The Anabat detector was placed 15 m away on the north side of the creek bank and faced the opposite direction of the nets.
Zone 5

Site 22

This site was our control site and was located on Big Creek Conservation Area (MDC) which is considered old growth woodland. The community was dry-mesic loess/glacial till woodland with mature oak, walnut, and hickory tree species in the area. This site was located along a stream bed where vegetation on the banks was sporadic and canopy cover was high. I used a 9 m double high net system and a single high 12 m net which were placed perpendicular to the creek where a large gap between trees could fit a 12 m net. The Anabat detector was placed 15 m north of the nets on a log that was above the ground vegetation.
APPENDIX II

<table>
<thead>
<tr>
<th>Species</th>
<th>Avg. forearm length (mm)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Avg. weight (g)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPFU</td>
<td>48.7</td>
<td>46</td>
<td>50</td>
<td>18.8</td>
<td>17.7</td>
<td>19.4</td>
</tr>
<tr>
<td>LABO</td>
<td>38.5</td>
<td>36</td>
<td>44</td>
<td>11.9</td>
<td>10.9</td>
<td>12.3</td>
</tr>
<tr>
<td>LACI</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>LANO</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>MYLU</td>
<td>34.4</td>
<td>33</td>
<td>36</td>
<td>7.3</td>
<td>6.9</td>
<td>7.9</td>
</tr>
<tr>
<td>MYSO</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>NYHU</td>
<td>35.6</td>
<td>34</td>
<td>37</td>
<td>8.7</td>
<td>8.3</td>
<td>10.2</td>
</tr>
<tr>
<td>PESU</td>
<td>32.3</td>
<td>31</td>
<td>33</td>
<td>6.7</td>
<td>6.4</td>
<td>6.9</td>
</tr>
<tr>
<td>MYSE</td>
<td>34.4</td>
<td>33</td>
<td>35</td>
<td>7.9</td>
<td>7.6</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Data collected from the 9 different species of bats throughout the 2 field seasons, [big brown bat (EPFU), eastern red bat (LABO), silver-hair bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown myotis (MYLU), tri-colored bat (PESU), and northern myotis (MYSE)].
APPENDIX III

<table>
<thead>
<tr>
<th>Species</th>
<th>Total number of individuals captured</th>
<th>Male</th>
<th>Female</th>
<th>Adult</th>
<th>Juvenile</th>
<th>Pregnant</th>
<th>Lactating</th>
<th>Post-lactating</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPFU</td>
<td>49</td>
<td>33</td>
<td>16</td>
<td>43</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>LABO</td>
<td>60</td>
<td>35</td>
<td>25</td>
<td>47</td>
<td>13</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>LACI</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>LANO</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>MYLU</td>
<td>51</td>
<td>30</td>
<td>21</td>
<td>42</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>MYSO</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>NYHU</td>
<td>23</td>
<td>16</td>
<td>7</td>
<td>18</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PESU</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>MYSE</td>
<td>111</td>
<td>67</td>
<td>44</td>
<td>93</td>
<td>18</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
</tbody>
</table>

Data collected from the 9 different species of bats throughout the 2 field seasons. [big brown bat (EPFU), eastern red bat (LABO), silver haired bat (LACI), hoary bat (LANO), evening bat (NYHU), Indiana myotis (MYSO), little brown bat (MYLU), tri-colored bat (PESU), northern myotis (MYSE)].