THE EFFECTS OF SHELTERWOOD HARVESTS ON BAT POPULATIONS AND FOREST STRUCTURE IN OHIO OAK-HICKORY FORESTS

A Thesis

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By

Marne Avina Titchenell, B.S.

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Master's Examination Committee:

Dr. Roger Williams, Advisor

Dr. Stan Gehrt, Co-Advisor

Dr. Robert Gates

Approved by

____

Advisor
Natural Resources Graduate Program

ABSTRACT

Forest management practices, such as harvesting, can greatly influence bat habitat relationships. Such practices can affect the microclimate and physical structure of the forest, foraging opportunities, and the availability of roost sites and prey. Research in eastern forests is needed to provide managers with the knowledge and skills to properly and effectively manage for bats and their habitat while still achieving forest management goals. One of these goals is the restoration of declining oak communities with regeneration methods, such as shelterwood harvests. This research examined bat activity responses to initial shelterwood harvests with different retention levels (50% and 70%) of the original basal area. Bats were acoustically monitored and captured by the use of mistnets in the summer of June 2006 through August 2006 in harvested and unharvested areas. Overall general activity differed ($p = 0.004$) among harvested and unharvested areas with the greatest amount of activity occurring within the harvested areas. There were no differences in overall bat activity between different retention levels. Red bats (*Lasiurus borealis*), big brown bats (*Eptesicus fuscus*), and silver-haired bats (*Lasionycteris noctivagans*) were detected most in the harvested areas, and had low activity in the unharvested areas. Red bats, big brown bats, and silver-haired bats were detected equally in the two retention levels. Eastern pipistrelles

(*Pipistrellus subflavus*) and myotis (*Myotis sp*.) were detected equally among both retention levels and the unharvested areas. A method was developed to quantify the amount of volume of woody plant material vertically through the forest canopy. The results of this method were compared to overall and species bat activity. Overall bat activity decreased rapidly at volumes exceeding 148.4 meters per hectare (m^3/ha) in the understory (0-3 meters (m) above ground). The probably of detecting a red bat decreased by 50% at volumes exceeding 1500 m^3/ha in the understory to mid-canopy (3-6 m), while big brown and silver-haired bat activity was detected most when volumes at 3-6 m in height were less than 100 m^3/ha. Activity rates of *Myotis* species and eastern pipistrelles were not sensitive to volume of obstruction at any level. Use of additional forest characteristics such as number of snags is recommended. This research suggests that areas harvested for the purposed of restoring oak communities can provide valuable foraging ground for multiple species of bats. Bats require a diversity of landscapes, and harvesting prescriptions should allocate area of high structural density in additions to the land being harvested. This research provides a framework for the management of bat populations in southern Ohio, allowing a unique opportunity for additional rigorous research in the future.

This thesis is dedicated to my parents, who have always given me their support and love through the years, encouraged me to be my best, and given me the faith in myself that enables me to accomplish my goals.

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VITA

October 21, 1980	Born – Toledo, OH
2003	Biological Technician Browns Park National Wildlife Refuge United States Fish and Wildlife Service Maybell, CO
2004	Wildlife Technician Huron-Manistee National Forest USDA Forest Service Oscoda, MI
June, 2004	B. S. Natural Resources The Ohio State University Columbus, OH
2004 – Present	Graduate Teaching Assistant Graduate Research Assistant The Ohio State University Columbus, OH

FIELDS OF STUDY

Major Field: Natural Resources

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INTRODUCTION

Bats belong to an order (Chiroptera) that contains a diversity of species which have highly specialized feeding ecologies that, coupled with their flight ability, is unparalleled among mammals (Kunz 1982, Altringham 1996). Second only to rodents (Order Rodentia) in representing the greatest number of mammalian species in North America, bats fill a number of unique ecological niches such as nocturnal predators, pollinators, and seed dispersers (Arnett 2003, Altringham 1996, Fenton 2001). From their ability of flight to their highly efficient and effective echolocation skills, bats have evolved into a unique order existing of over 1000 living species, which, over the past two decades, has spawned an increase of interest in these flying mammals (Fenton 2001, Altringham 1996).

Interest in bats was aimed at identifying the basic biology and habitat ecology of bats, such as species composition and their response to habitat change based on roost-site selection and frequency of foraging among habitats (Marcot 1996, Miller et al. 2003). Study of bats began not only due to the unique ecology of bats, but also to document suspected population declines in numerous species. These declines, attributed to loss of habitat, pollution, and other anthropogenic related activities, have led to several listings of bat species as endangered or threatened therefore raising concern for both public and private landowners (Miller et al., 2003). Although many studies have provided valuable information, bats remain one of the most complex and difficult groups of wildlife to study (Fenton 1997, Hayes 2003). Therefore, there are numerous areas where information is lacking (Barclay and Brigham 1996, Arnett 2003). One area deals with understanding how bats respond to forest management practices and how these practices influence relationships between bat species and habitats (Marcot 1996, Lacki 1996, Fenton 2001, Arnett 2003).

A diversity of forest harvesting regimes is now being attempted to satisfy biodiversity and community restoration goals (Barclay and Brigham 1996). One example is the use of shelterwood treatments to regenerate and restore oak (*Quercus* sp.) communities. Oak species have been a very important component of the deciduous forests of the eastern United States for at least 10,000 years (Abrams 1992). However, these forests have been shifting from historical dominance by oaks to increasing proportions of red maple (*Acer rubrum*) and other hardwood species (Griffith et al. 1993, Abrams 1998). Periodic fires were common across the forest landscape, which favored regeneration and growth of oaks over more fire-intolerant species such as red maple and American beech (*Fagus grandifolia*) (Abrams 1998). However, the onset of aggressive fire suppression in the early 1900's began shifting forest composition toward the more fire intolerant and shade tolerant species (Abrams 1998). Similar trends in forest composition and structure change can be found due to the suppression of fire in southern Ohio. Although oaks still dominate the overstory in many of Ohio's forests, regeneration on the forest floor is dominated by species such as yellow-poplar (*Liriodendron tulipifera*), maples, and blackgum (*Nyssa silvatica*). Determining ways of restoring oak communities has become an important objective of forest managers in the eastern United States.

The shelterwood method of timber harvesting is one of the best ways to regenerate oaks in eastern deciduous forests of Ohio (Yahner 2000). Carvell and Tryon (1961) indicated that of all the environmental factors at a particular site, light intensity was most strongly correlated with the density of oak seedlings. The shelterwood method is designed to allow more light to reach the canopy floor through a reduction of the canopy (Yahner 2000). Canopy reductions, often at varying levels, undoubtedly affect the structural aspects of the forest thus influencing those wildlife species present.

It has become increasingly important to determine how bats respond to canopy reductions so forest managers are aware of the effects certain oak regeneration methods have on bat populations. Eastern hardwood forests alone account for 51 percent of the total United States forest land, and relatively few studies have been conducted on forest-roosting bats in this region (Allen et al. 1996). All bat species in Ohio rely on forests to satisfy at least one life history requirement, but the majority use forests to meet their entire habitat needs during their active phase of the year (Fenton 1997, Miller et al. 2003). Any knowledge gained will better equip managers with the necessary information to successfully conserve populations of bats while still achieving forest management goals (Marcot 1996, Lacki 1996).

CHAPTER 1

REVIEW OF LITERATURE

Bats belong to the order Chiroptera, a name that originates from the Greek *cheiro* meaning hand, and *ptera* meaning wing (Fenton 2001). True to their name, bats have a unique design involving four elongated fingers with an elastic, muscular membrane stretched between each digit (Fenton 2001). This design is a key component of their lifestyle, allowing them mobility when foraging for food and locating a roost site (Fenton 2001). The availability of roost sites and foraging ground are two important factors that affect presence, abundance, and activity of bats in a particular habitat. Other factors include physical structure of the habitat, such as the horizontal and vertical spatial patterns of trees and other forest vegetation (Hayes and Gruver 2000, Jung et al. 1999, Ford et al. 2005). Another important factor is the specific capabilities of different bat species, such as echolocation call design and morphological differences in body size and wing shape (Krusic and Neefus 1996, Aldridge and Rautenbach 1987, Jones et al. 2000, Menzel et al. 2005).

Many North American bats live in the northern parts of the continent and belong to the family Verspertilionidae (Knopf 1996, Fenton 2001). Bats in this family are typically aerial insectivores that locate and capture prey by echolocation (Broders et al. 2004). The thirteen bat species in Ohio all belong to this family and those that inhabit forests are often found roosting in tree cavities, among the foliage, in crevices between rocks, under exfoliating bark, in hollow trees, and in other protected, secretive places (Knopf 1996). Bats typically inhabit trees that are larger, older, and in the later stages of decay (Barclay and Brigham 1996, Erickson and West 2003). In two separate studies, both Betts (1996) and Vonhof (1996) found big brown bats (*Eptesicus fuscus*) and silver-haired bats (*Lasionycteris noctivagans*) preferred to roost in living and dead trees with large diameters. Northern long-eared bats (*Myotis septentrionalis*) in White Mountain National Forest, New Hampshire, were tracked using radio transmitters to 47 roost sites, 39 (83%) of which, were snag trees (Krusic and Neefus 1996). Roost sites, areas that contained more than one roost tree, were found to have a higher snag basal area (3.9 m^2/ha) than the surrounding forest (Sasse and Pekins 1996).

Snags of higher densities are often found in old growth forests, those that have a heterogeneous, open, and multi-storied physical structure (Barclay and Brigham 1996, Humes et al. 1999). Barclay and Brigham (1996) noted that within various forest stages, old, single-stratum forests and old, multi-stratum forests were among those with the highest bat activity. Levels of higher bat activity were found in the open structure of the mature Douglas-fir (*Pseudotsuga menziessi*) forest type than in the more structurally complex and cluttered western hemlock (*Tsuga heterophylla*) forest type (Bradshaw 1996). In some case, the presence of snags does not imply high bat activity in a particular habitat (Jung et al. 1999). Though snags are important and can be a limiting resource for many bat species, foraging can occur without them. Jung et al. (1999) found snag availability was unimportant in explaining variation in detection rates of bat species among white pine and mixed wood forest stands in central Ontario. This suggests that habitat selection may not always depend solely on the availability of roost sites, but also on the quality of foraging areas.

The quality of foraging grounds to bats depends on many factors, namely the structural complexity of a forest, but also important are the species specific capabilities. Some species prefer to forage in certain habitats such as riparian zones, along forest edges, in wetland areas, old fields, open forests, or structurally complex forests (Barclay and Brigham 1996, Brooks and Ford 2005, Menzel et al. 2005). These preferences may be associated with insect abundance or perhaps more importantly, echolocation call design and morphological differences in body size and wing shape (Krusic and Neefus 1996, Aldridge and Rautenbach 1987, Jones et al. 2000).

Morphological differences between species of bats are commonly described by wing shape and body size (Fenton 2001, Aldridge and Rautenbach 1987, Jones et al. 2000, Menzel et al. 2005). For example, different species of bats have different wing designs, characterized as wing aspect ratios (Fenton 2001, Aldridge and Rautenbach 1987). If a bat has a low aspect ratio, their wings are short and broad. These bats typically forage in denser habitats where their wings allow them to be highly maneuverable (Aldridge and Rautenbach 1987). These bats also tend to have smaller body sizes, such as bats of the genus *Myotis*, which are commonly found foraging in habitats with high amounts of structural clutter (Ford et al. 2005, Jung et al. 1999). A bat with a high aspect ratio has long, narrow wings which enable it to fly faster, but with limited maneuverability. Bats with high aspect ratios are generally found foraging in more open, less structurally dense habitats (Fenton 2001, Aldridge and Rautenbach 1987). These bats, such as big brown and the silver-haired are commonly termed large-bodied bats.

Not only do differences in body size and wind shape influence where bats forage, the echolocation call design of each species is also influential (Aldridge and Rautenbach 1987, Jones et al. 2000). Not all species of bats produce echolocation calls of the same intensity, frequency, and duration (Fenton 2003) and these unique call design are often related to morphology and habitat use (Jones et al. 2000). Large-bodied bats emit calls of high intensity, long duration, and low frequencies. This allows their calls to travel farther and aid in the detection of distant targets, which are ideal in the open habitats they typically forage in (Jones et al. 2000). Small-bodied bats, which forage in dense, cluttered habitats, emit calls of shorter duration and higher intensities (Aldridge and Rautenbach 1987, O'Farrell et al. 1999). This allows these species to precisely locate and separate targets from background noise, such as branches, leaves, and other obstacles that could interfere with echolocation calls (Broders et al. 2004).

These species-specific characteristics such as flight behavior, body size, wing morphology, and echolocation call design, have been used to group certain bat species into guilds (Sherwin et al. 2000, Schnitzler and Kalko 2001, Denzinger et al. 2003). These guilds include gleaners, aerial hawkers, and mixed strategists. Gleaners are species that forage in dense spaces and take food from surfaces. They have low wing aspect ratios, and short, broad wings. These species emit high frequency, low intensity calls of short duration (Sherwin et al. 2000). Aerial hawkers emit intense calls of long duration and high intensity to track flying prey. These species typically forage in open spaces, have high aspect ratios, and long narrow wings (Sherwin et al. 2000). Mixed strategists are those species that alternate between gleaning and aerial feeding and adjust their echolocation calls accordingly (Fenton 2003).

Forest management practices, such as harvesting, can greatly influence bat habitat relationships by altering the physical structure and volume of the forest, thereby influencing foraging opportunities, the availability of roost sites, and insect community composition and abundance (Krusic and Neefus 1996, Fenton 2001, Menzel et al. 2005). Alteration of the forest by harvesting is apparent horizontally, as well as vertically in the understory, mid-canopy, and canopy (Menzel et al. 2005). Forest management practices involving some form of harvesting can be broken down into two categories (Smith et al. 1997, Yahner 2000). The first category, methods of regeneration, refers to treatments of stand and site during the period of regeneration or establishment with the sole purpose of creating environments favorable for the establishment of regeneration (Smith et al. 1997, Yahner 2000). The second category is termed intermediate cutting and refers to treatments at other times during the rotation. These treatments are applied to improve the existing stand or regulate its growth. They are not aimed at regenerating the stand and usually do not yield any product (Smith et al. 1997, Yahner 2000). The focus of this research was on methods of regeneration, and subsequent discussions will center on this category.

Methods of regeneration can be separated into four main treatments, all of which are modeled after natural disturbances and promote regeneration (Smith et al. 1997, Yahner 2000). These treatments are generally termed the selection method, the shelterwood method, the seed-tree method, and the clearcutting method (Smith et al. 1997, Yahner 2000). The selection method involves removing single trees or groups of trees and relying on their replacement by any source of regeneration. Krusic and Neefus (1996) found *Myotis* species (*Myotis sp*.), eastern pipistrelles (*Pipistrellus subflavus*), and eastern red bats (*Lasiurus borealis*) to be most abundant in group selection harvests in New Hampshire's White Mountain National Park. At the Date Creek silvicultural systems research site in northwestern British Columbia, the creation of openings in dense forests was beneficial to bat travel and foraging (Perdue and Steventon 1996). Grindla et al. (1998) noted that bat activity increased in small openings in a harvested experimental forest in British Columbia, Canada, where insect abundance was unaffected by the harvesting. These findings suggest bats use small openings in forest canopies for multiple uses, such as foraging, orientation points while navigating, and corridors for commuting (Perdue and Steventon, Grindal et al. 1998, Verboom and Spoelstra 1999).

The seed-tree method entails the removal of the old stand in a single harvest, leaving only a small number of seed trees left singly or in a group. These remaining trees will then provide the basis of regeneration as a seed source for the reestablishment of the site (Smith et al. 1997, Yahner 2000). Vonhof (1996) speculated that although leaving behind small numbers of trees has been shown to benefit cavity nesting birds, it can not be applied to the management of tree-roosting bats. He also noted that bats were not found roosting in trees left standing after a clearcut in Pend d'Oreille Valley in Southern British Columbia. Vonhof (1996) speculated that the number of trees remaining after a seed-tree cut was too small to meet the needs of bats, and most trees that were left had varying microclimates and provided little protection from predators.

While the seed-tree method leaves a few trees standing, the clearcutting method does not. This method of treatment comprises of the removal of the entire stand in a single harvest (Smith et al. 1997, Yahner 2000). This would include the removal of large, old, and decaying trees where bats prefer to roost (Cline et al. 1980). This type of harvesting can have varying effects on bat habitat and activity, however, it may depend on the species present (Jung et al. 1999). In White Mountain National Park, New Hampshire, bat activity was highest in forest openings resulting from clearcuts (Krusic and Neefus 1996) whereas in southeastern Alaska, bat activity was found to be low in clearcuts (Parker et al. 1996). Using bat detectors, the big brown bat, silver-haired bat, eastern red bat, eastern pipistrelle, and hoary bat (*Lasuirus cinereus*) were recorded most frequently in hardwood regeneration clearcuts in New Hampshire (Krusic and Neefus 1996), while activity of *Myotis* species was low in clearcuts in southeastern Alaska (Parker et al. 1996).

Presence and absence of certain species to structurally different habitats has been explained by the aspect ratios of the species (Aldridge and Rautenbach 1987, Owen et al. 2004). Hoary and silver-haired bats have a high aspect ratio, so they prefer more open areas where they can fly faster without impediments such as numerous trees and hanging branches, called clutter (Owen et al. 2004, Fenton 2001). Also, their echolocation call design is better equipped to handle prey detection at long distances (Jones et al. 2004). *Myotis* species, however, have low aspect ratios, which allow them to maneuver around and between trees and branches found in denser habitats. Clearcutting, in short, may be beneficial to some bats depending on the species being managed for (Owen et al. 2004).

Edge is another factor to consider when comparing different types of silvicultural treatments. A substantial amount of edge habitat is generally created when a forest is clearcut (Smith et al. 1997). Zimmerman and Glanz (2000) noted that bats seemed to prefer edges as opposed to centers of clearcuts in eastern Maine. In terms of foraging and roosting, clearcutting may provide the best of both worlds. Bats are able to forage in the open as well as find roosting trees in the edges of clearcuts (Zimmerman and Glanz 2000). The amount of edge and surrounding landscape can also influence the forest microclimate. Edges bordered by agricultural fields have more extreme changes in microclimate (Gehlhausen et al. 2000). For example, a tree receives more direct sunlight if it is on the edge of an agricultural field as opposed to the forest interior. This can have a direct influence on the temperature of the tree, thereby influencing the tree's quality as a potential roost site.

Clutter is an aspect of all forests that can produce varied levels of bat activity depending on its density. Closely spaced trees and high densities of young even-aged stands are a hindrance to flying bats by impeding detection and capture of prey (Owen et al. 2004). Too much clutter may also increase the risk of predation by obstructing a clear path of escape (Veilleux et al. 2003). Combined with the lack of snags, old, or large decaying trees, these habitats have very low levels of representative bat species (Owens et al. 2004, Patriquin and Barclay 2003). Barclay and Brigham (1996) found that levels of bat activity were highest in open, multi-stratum, old growth forests. Within young, dense stands, intermediate cuts, such as thinning, can be implemented to mimic the multi-stratum physical structure of old growth forests and accelerate the rate of diameter growth (Humes et al. 1999). In western Oregon, bat activity was found to be higher in thinned stands than unthinned stands (Humes et al. 1999). However, the benefits and detriments of highly cluttered habitats on bat activity may better be represented by individual species responses. For example, northern long-eared bats are predominately a forest interior species and rarely forage in open areas. They capture insects in flight, but also by gleaning from vegetation in cluttered habitats (Jung et al. 1999). Due to their ecology, northern long-eared bats are often termed clutter-adapted species (Menzel et al. 2005).

The literature is presently limited regarding the effects of shelterwood harvests on bat habitat or bat populations. Kurta et al. (1999) used radio telemetry to track an eastern pipistrelle to a roost tree in a 6 hectare (ha) shelterwood harvest in Manistee National Forest, Michigan. This bat chose a healthy, white oak (30 cm dbh) with no observable cavities as its roost tree, but remained for only one day. There was no indication of a return to the roost tree or information on additional roosting pipistrelles or other species, which leaves a substantially large gap in the knowledge of bat responses to shelterwood harvests. The shelterwood method involves the removal of the old stand in a series of steps that extend over a relatively short portion of the rotation (Smith et al. 1997). The result is the establishment of an understory under the partial shelter of seed-trees. The initial cut removes a portion of the canopy while retaining trees to meet a specified retention level. In Ohio, regeneration methods for oak species typically call for a 50% sometimes 30% reduction of the canopy (Yahner 2000), or 50% and 70% retention levels.

Oak forests currently occupy 59% of forestland in Ohio (Griffith et al. 1993). These oak forests are valuable habitats and provide roost-sites for several species of Ohio bats (Veilleux et al. 2003, Mager and Nelson 2001). Veilleux et al. (2003) found eastern pipistrelles preferred to roost in oak trees in the forests of Prairie Creek, Indiana. The crown of the oaks made ideal umbrella-like shelters for the bats, while the broad leaves provided shelter from wind, rain, and predators (Veilleux et al. 2003). Red bats in central Illinois were also found primarily roosting in oak trees (Mager and Nelson 2001). It is clear that certain bat species do benefit from oak dominated forests. However, the regeneration layer on the floor of these forests currently has insufficient numbers of oak, thus creating the future possibility of dramatic declines in oak-dominated forests. The small and inadequate presence of oak regeneration in these forests is caused in part by cutting practices that do not provide sufficient light to the forest floor and the absence of fire (Burns and Honkala 1990). The major question in applying shelterwood harvests has therefore revolved around the amount of residual overstory to retain.

The retention of full-crowned oaks in codominant or dominant crown classes must be great enough in number to provide enough shade to inhibit understory competition, yet few enough in number to allow light to reach establishing seedlings (Dey and Parker 1996). There is obviously a trade-off between providing enough light to promote establishment and growth of oak regeneration and limiting the release of understory competition. This makes the initial cut of any shelterwood treatment critical to the overall success of regenerating oak. However, the recommended cutting intensity in the literature is variable and dependent on local conditions. If abundant vegetation is present in the understory, a shelterwood cut that retains 50 percent (%) of the canopy may result in severe understory competition (Sander 1979, Loftis 1983). This could result in increased amounts of clutter for bats. However, if an initial shelterwood cut retains 70% of the canopy, then there may be less understory competition, and accordingly, less clutter. Because varying levels of retention can have very different structural effects on forest stratification, it is important to determine which level is successful in the regeneration of oak species and, of greater importance to this research, how bat populations respond.

Previous research on the effects of silvicultural practices on bats have been concentrated in northwestern North America, with only a few published studies occurring in mixed hardwood forests in the eastern United States and even fewer in Ohio (Miller et al. 2003). Additional research on the effects of different silvicultural practices on bat populations and their habitats is needed to equip managers with the knowledge and skills to properly and effectively manage for the prevention of further declines in the species (Barclay and Brigham 1996, Marcot 1996, Fenton 2001, Lacki 1996). The practice where there is the least amount of research is oak regeneration methods, specifically shelterwood treatments. Because this treatment is being increasingly implemented, it is necessary to determine how bats respond. It is also necessary to determine the direct and indirect effects varying levels of retention have on bat populations and habitat relationships. There is a significant lack of information in these areas and more research will allow managers to move forward with the implementation of practices that will provide valuable habitat to bats while still achieving multiple forest management goals.

CHAPTER 2

A METHOD OF QUANTIFYING FOREST VERTICAL STRUCTURE FOR THE PURPOSE OF EVALUATING BAT HABITAT

2.1 Introduction

Within forest ecosystems, bats were often overlooked faunal assembles until several years ago, when their importance as pollinators, insectivores, and nocturnal predators became known. In addition, population declines attributed to habitat loss, pollution, and stream degradation, have led to several listings of bat species as endangered or threatened, therefore making them a higher priority for both public and private landowners (Miller et al. 2003). Although many valuable studies have been conducted, bats remain one of the most complex and difficult groups of wildlife to study (Fenton 1997, Hayes 2003) and there are numerous areas where information is lacking (Arnett 2003, Barclay and Brigham 1996). One of these areas deals with understanding how bats respond to forest management practices and how these practices influence the habitats bats depend on (Arnett 2003, Fenton 2001, Lacki 1996, Marcot 1996). All thirteen bat species in Ohio rely on forests to satisfy at least one life history requirement, but the majority use forests to meet their entire habitat needs during their active phase of the year (Fenton 1997, Miller and others 2003). For example, bats are often found roosting in tree cavities, among the foliage, in crevices between rocks, under exfoliating bark, and in tree cavities (Knopf 1996). Bat have also been known to use forests for foraging opportunities, protection from predators, commuting corridors, and orientation points while navigating (Perdue and Steventon, Grindal et al. 1998, Verboom and Spoelstra 1999). Therefore, forest management practices may have profound effects on their population status and distribution.

The structural complexity of a forest, such as the amount of clutter (e.g., tree trunks, leaves, branches) significantly influences the foraging activity of bats, which in turn influences the presence of bats in that forest. Owen and others (2004) found that bat species segregated themselves among forests with high and low densities of clutter. These habitat preferences may be derived from high insect populations or perhaps more importantly, the species-specific capabilities (Aldridge and Rautenbach 1987, Krusic and Neefus 1996, Owen et al. 2004). For example, different species of bats have different wing designs which are characterized as wing aspect ratios (Fenton 2001). These aspect ratios are believed to influence flight capabilities as well as energetically and mechanically limit where a certain species can forage (Norberg 1981). If a bat has a low aspect ratio, their wings are short and broad. These bats typically forage in denser habitats where their wings allow them to be highly maneuverable (Aldridge and Rautenbach 1987, Fenton 2001, Nowak 1994). These dense habitats also enable the high frequency echolocation calls emitted by these species to be more effective. A bat with a high aspect ratio has long, narrow wings which enables it to fly faster, but with limited maneuverability. Bats with high aspect ratios are generally found foraging in open areas exhibiting low frequency calls that will travel greater distances (Fenton 2001).

It is apparent that clutter, or structural volume, is an aspect of all forests that can influence levels of bat activity depending on its density. Owen et al. (2004) found that the closely spaced trees and high densities of certain forests can be a hindrance to flying bats by impeding detection and capture of prey. Too much clutter may also increase the risk of predation by obstructing a clear path of escape (Campbell et al. 1996, Vonhof and Barclay 1996). However, due to the morphological differences between species, those with low aspect ratios prefer to forage in cluttered environments as opposed to open habitats (Menzel et al. 2005). The amount of clutter may also vary vertically from the understory up to the upper-canopy, providing different vertical levels of preferred habitat for bats depending on the species (Menzel et al. 2005). When determining the effects of forest harvesting on bat activity, it is necessary to measure the amount of clutter present in an adequate and precise manner.

This research presents the use of a method to quantify forest clutter from the ground upwards through the canopy. Other studies have used a variety of methods to assess clutter. Veilleux and others (2003) defined percent clutter above and below roost trees as the amount of woody material and foliage that broke an imaginary horizontal plane. Kalcounis and Brigham (1995) assigned habitats values one to four, with four being the most cluttered. Broders and others (2004) characterized habitat in one of three clutter categories based on the horizontal distance to the nearest tree. Other studies have simulated clutter in artificial environments (Arlettaz and others 2001, Sleep and Brigham 2003) to determine the effects of varying levels of clutter on foraging bats. The method presented in this study provides a quantitative measurement of clutter (m^3) at various heights by directly measuring the trees present.

2.2 Methods

Data from two oak-hickory forests study areas, located on upland soils in southern Ohio, were evaluated for the application and illustration of this method. One study area was located within Richland Furnace State Forest, Jackson County, Ohio (39˚10'N latitude, 82˚36'W longitude) and the second in Zaleski State Forest, Vinton County, Ohio (39˚15'N latitude, 82˚23'W longitude) (Figure 2.1). Both forests lie within the unglaciated hill country of southern Ohio where the regional topography is characterized by deeply dissected terrain of the Allegheny Plateau (Kerr 1985). This creates a gradient of moisture regimes and subsequent microclimates across the landscape (Kerr 1985). The forests were dominated by upland oak-hickory, which accounted for an average of 88.2% of the total basal area. The remainder was comprised of typical upland hardwood species mix (Table 2.1). Slopes ranged from 10 to 24% with an average of 16%. Aspects averaged southeast (157^o azimuth) and ranged from northeast (43^o azimuth) to southwest (268^o azimuth).

Two different silvicultural treatments were applied, along with a control within each of the forest study areas. These treatments were two shelterwood harvests, each 10 ha in size, that reduced the stand stocking to 50% and 70% stocking of full stocking (100%) (Table 2.2). Both Zaleski and Richland Furnace forest study areas had replicates of each harvest and control, totaling six 10-ha treatment blocks for each forest, for a total of 12 treatment blocks across both forest study areas. To achieve the initial shelterwood cut, a combined crown thinning and low thinning was used to reduce the basal area, favoring dominant and co-dominant oak in the overstory. The control sites experienced no cutting treatments.

Eight vegetation plots were located within each of the 12 treatment sites using a systematic sampling design, for a total of 96 plots between both Richland Furnace and Zaleski forest study areas. Each plot was stratified to measure the overstory (trees greater than or equal to 10 cm dbh), saplings (trees greater than or equal to 1.4 m height and less than 10 cm dbh), and large seedlings (trees 0.3 to 1.4 m height). Overstory, sapling, and large seedling plots were circular and circumscribed about the same center. Overstory, sapling, and large seedling plots were 0.08 ha, 0.04 ha, and 0.02 ha in size. On all woody stems, total height, height to the base of the live crown, maximum crown diameter, and the diameter at a right angle to the axis of the maximum diameter, were measured to the nearest 0.15 m and recorded by species. Crown diameters were measured with a linear tape from dripline to dripline. Height measurements with taken with a clinometer. Field measurement were recorded in English units and later converted to metric for analysis.

2.3 Results

The volume (V) of a cone was used to estimate the crown volume, which has been used successfully in other studies (Karlik and McKay 2002):

$$V = (1/3)(B)(H)(D/2)^2 \quad (1)$$

However, for this study we assumed crown shape to be split into two cones, with the cone base being shared and defined at the crown midpoint. It was assumed that the crown midpoint occurred halfway between the height to the base of the live crown (HL) and the total height of the tree (TH). Accordingly, the measured crown diameter was assumed to be measured at the crown midpoint (Figure 2.2). These assumptions do not affect the calculation of the total crown volume using the standard cone volume equation. The geometric mean of the maximum crown diameter and the diameter at a right angle to the axis of the maximum diameter was used to determine crown diameter (D) in the cone volume calculations. Cone height (H) was determined as the difference between TH and HL.

Zones of vertical forest clutter defined at 0 – 3 m, 3 – 6 m, 6 – 9 m, 9 – 12 m, and 12+ m upwards through the forest canopy were used for this study (Scott 2005). An algorithm using the cone volume equations and the relationship of proportionality was developed to determine how much of the crown volume of a particular tree resided in each of the defined clutter layers. Figure 2.3 gives an example of a tree whose total height lies within the 6 – 9 m strata and live crown base lies within the 0 – 3 m strata.

To determine how much of the total crown volume resides within the 6 – 9 m strata we need to estimate the crown diameter that occurs at the 6 m height using the geometric rule of proportionality. The height of the cone at 6 m and above becomes:

$$TH - 6 \qquad (2)$$

And the height of the cone beginning at the midpoint becomes:

$$(TH - HL)/2 \quad (3)$$

Using the rule of proportionality, we can solve for the crown diameter at 6 m (D_6):

$$D/[(TH - HL)/2] = D_6/(TH - 6) \quad (4)$$

Solving for D_6:

$$D_6 = [D(TH - 6)]/[(TH - HL)/2] \quad (5)$$

We now can substitute the appropriate values into the cone equation to determine the crown volume within the 6 – 9 m strata:

$$V_{6\text{-}9} = (1/3)(B)(TH - 6)\{[(D(TH - 6)]/[(TH - HL)/2)]/2\}^2 \quad (6)$$

Where $V_{6\text{-}9}$ = the cubic meter crown volume of the tree within the 6 – 9 m strata.

In a similar procedure, we now find the volume of the cone that has its base at the 3 m point and extends downward into the 0 – 3 m strata. The height of the cone at the 3 m and below is:

$$3 - HL \quad (7)$$

and the height of the cone from the midpoint downward is

$$(TH - HL)/2 \quad (8)$$

The diameter of the cone at 3 m (D_3) becomes:

$$D/[(TH - HL)/2] = D3/(3 - HL) \quad (9)$$

Solving for D_3:

$$D_3 = [D(3 - HL)]/[(TH - HL)/2] \quad (10)$$

We now can substitute the appropriate values into the cone equation to determine the crown volume within the 0 – 3 m strata:

$$V_{0\text{-}3} = (1/3)(B)(3 - HL)\{[(D(3 - HL)]/[(TH - HL)/2)]/2\}^2 \qquad (11)$$

To find the remaining volume that lies within the 3 – 6 m strata, we subtract $V_{0\text{-}3}$ and $V_{6\text{-}9}$ from the total crown volume:

$$V = [(1/3)(B)(H)(D/2)^2] - (V_{0\text{-}3} + V_{6\text{-}9}) \qquad (12)$$

2.4 Discussion

Algorithms were developed for each stratum and implemented in Statistical Analysis Systems, 2003 (SAS) to calculate total cubic volume per hectare by strata for all plots. Plots were then averaged to obtain total volume per hectare for each stratum in each treatment and control site (Figure 2.4). The 12+ m stratum is represented separately due the large amount of volume within this stratum (Figure 2.4).

This method provides a quantitative approach to estimating the amount of clutter that occurs within a forest, enabling a more rigorous application of statistical analysis. The measurement of three features of a tree—total height, height to the base of the live crown, and crown diameter—are measurements that could be taken in standard inventories. In successive chapters, results obtained from this method will be correlated with the mean number of bat passes per retention harvest and control site to determine how changes in forest structure and clutter density influenced bat activity.

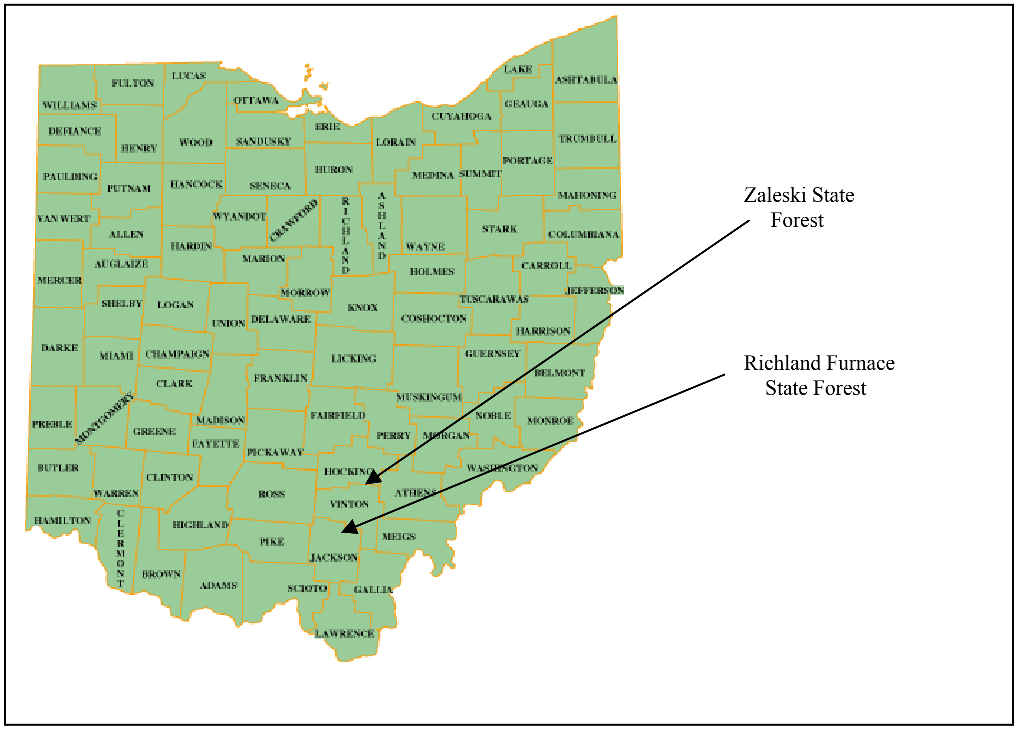

Figure 2.1: Location of oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio.

Upland Oak	Hickory	Mixed Hardwoods	Understory
Quercus alba	*Carya glabra*	*Acer saccharum*	*Amelanchier spp.*
Quercus coccinea	*Carya laciniosa*	*Acer rubrum*	*Carpinus caroliniana*
Quercus prinus	*Carya tomentosa*	*Fagus grandifolia*	*Corylus americana*
Quercus rubra		*Fraxinus americana*	*Hamamelis virginiana*
Quercus velutina		*Fraxinus pennsylvanica*	*Lindera benzoin*
		Liriodendron tulipifera	*Ostrya virginiana*
		Nyssa sylvatica	*Sassafras albidum*
		Populus grandidentata	*Viburnum spp.*
		Prunus serotina	
		Ulmus americana	
		Ulmus rubra	

Table 2.1: List of species present on oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio. Data was collected during June 2006 through August 2006.

Stand Characteristics	50 % Retention (n = 4)		70% Retention (n = 4)		Control (n = 4)	
	Mean	SE	Mean	SE	Mean	SE
Basal Area (m^2/ha)	14.26	1.29	16.15	1.84	24.70	2.41
Trees/ha	88	10.84	121	16.82	381	21.19
Average dbh (cm)	42.95	5.55	38.69	3.36	26.19	2.25
Canopy Closure (%)	64.80	1.9	75.03	3.8	92.63	3.21
Size (ha)	10	-	10	-	10	-
Stocking (%)	42		56		100	

Table 2.2: Stand characteristics post harvesting for oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

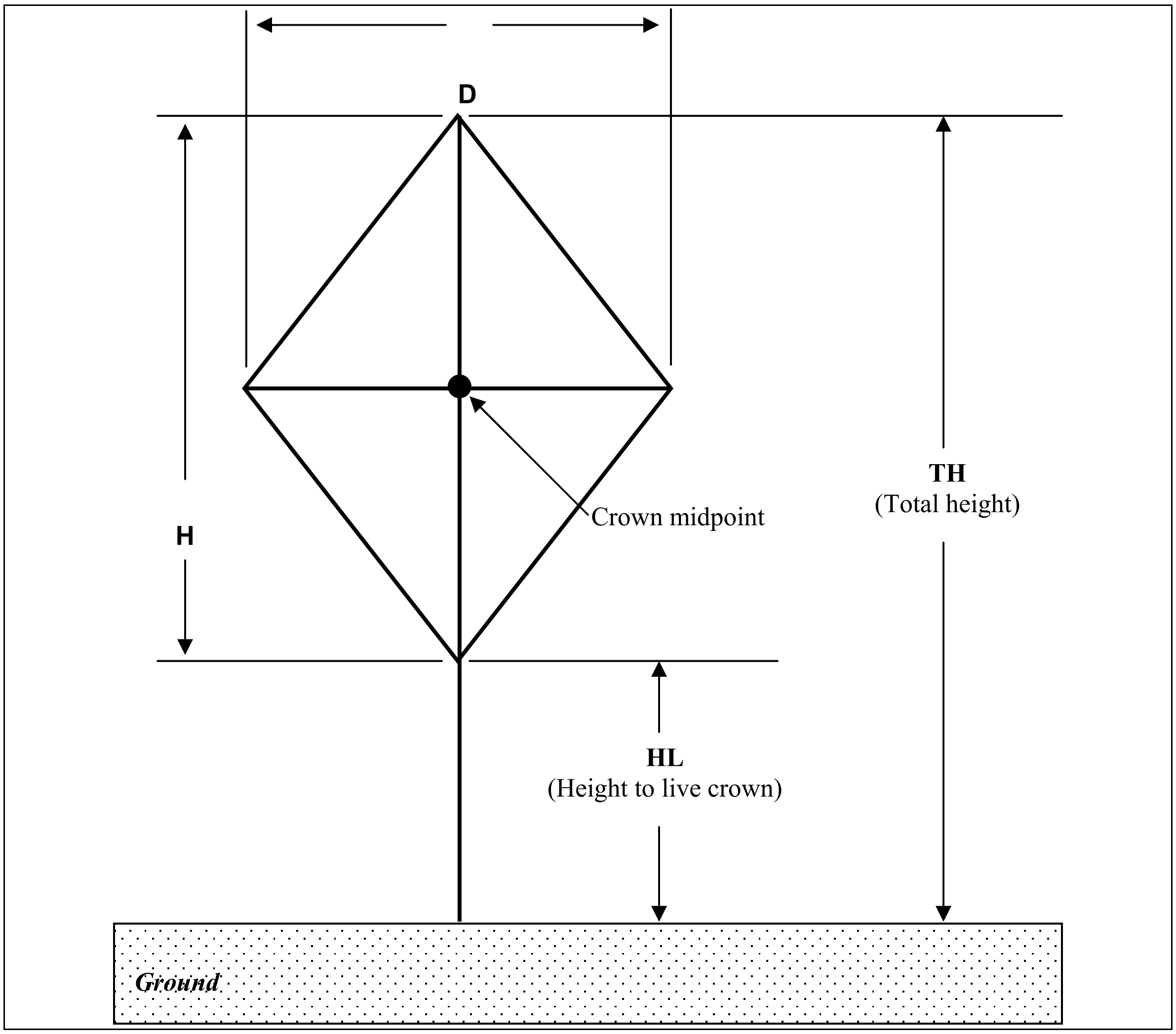

Figure 2.2: Variables and assumptions used in the estimation of total crown volume and the volume that exists in the various vertical strata within oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio.

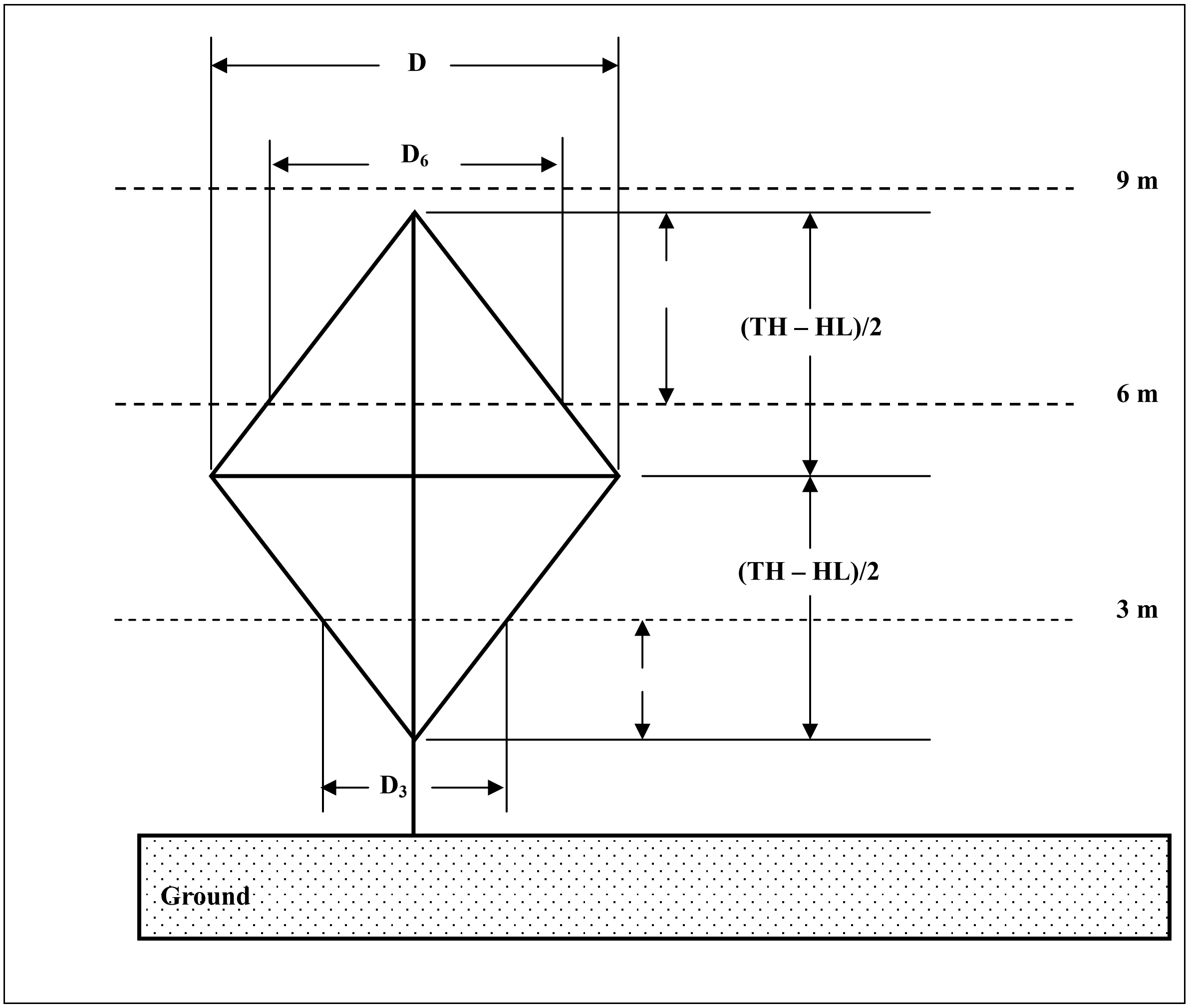

Figure 2.3: Illustration of clutter method using an example of a tree that has a crown occupying the 0-3 m, 3-6 m, and 6-9 m strata in a forest and the corresponding crown dimensions used in the volume per strata estimations.

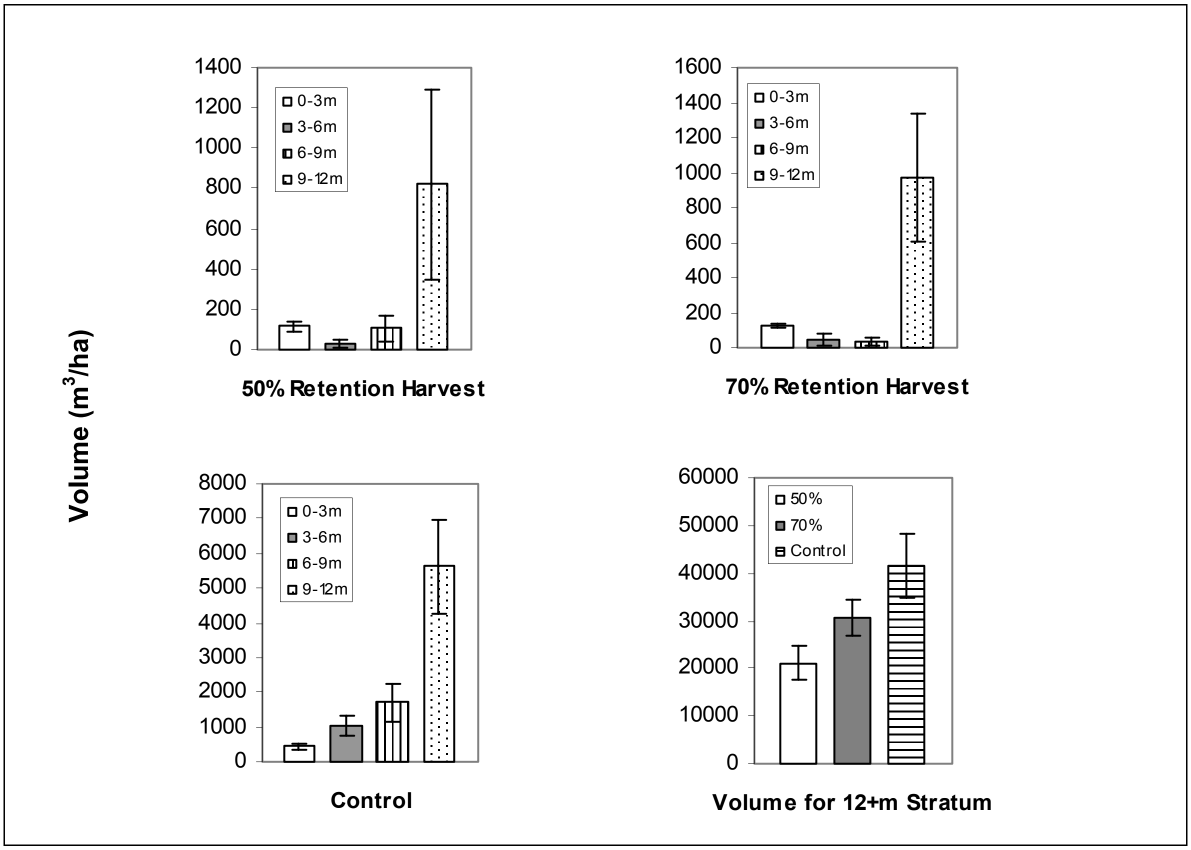

Figure 2.4: Results of clutter method presented as the amount of volume (m^3/ha) (mean and se) within all five strata for the 50% and 70% retention harvests and control sites. Data were collected from two oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio during June 2006 through August 2006.

CHAPTER 3

BAT ACTIVITY IN RESPONSE TO RETENTION HARVESTS OF VARYING INTENSITY IN SOUTHERN OHIO OAK HICKORY FORESTS

3.1 Introduction

Bats are a unique and important component of temperate forest ecosystems that until recently were often overlooked (Fenton 2001, Jung et al. 1999). Due to their role as nocturnal predators and obligate insectivores, bats are believed to aid substantially in regulating insect populations (Jung et al. 1999). Compared to other small mammals, bats have low reproductive rates, are long lived, and have high adult survivorship (Erickson and West 2003, Vaughan et al. 1997). They maintain relatively stable population rates; however, if declines do occur, bats are unable to recover quickly (Vaughan et al. 1997). Unfortunately, this trend had already occurred and several North American bat species are suffering population declines (Vaughan et al. 1997).

Due to these declines, it has become increasingly important to natural resource managers throughout North America to determine the response of bat assemblages to any alterations of habitat that may prove detrimental (Menzel et al. 2005, Miller et al. 2003). Forest management practices such as harvesting, which can occur at multiple levels of severity from clearcutting an entire area to a minor understory thinning, can potentially impact bat populations within a forest (Menzel et al. 2005, Krusic and Neefus 1996, Fenton 2001). Silvicultural practices can influence bat habitat relationships in multiple ways such as changing insect abundance, altering the physical structure of the forest, adjusting the number of available roost sites, or changing the quality of foraging habitat (Jones et al. 2000). Gaps in the knowledge of bat habitat relationship responses to practices such as harvesting is a critical limitation in understanding how to better manage forests for bats (Arnett 2003, Ford et al. 2005).

New emphases are being placed on community restoration of species that were once dominant across the eastern United States (Barclay and Brigham 1996). Oak species (*Quercus sp*.) were once a very prevalent component of deciduous forests, but since the suppression of fire, oak regeneration has shifted from a historical dominance to diminutive regeneration on forest floors (Griffin et al. 1993, Abrams 1998). In southern Ohio, similar trends in forest composition and structural change can be found. Although oaks still dominate the overstory in many of Ohio's forests, regeneration on the forest floor is dominated by species that often out-compete oak seedlings. Ways of restoring oak communities has become an important objective of forest managers in the eastern United States.

The shelterwood method of timber harvesting is a preferred and successful practice used to regenerate oaks in eastern deciduous forests (Yahner 2000). The shelterwood method is designed to allow more light to reach the canopy floor through a reduction of the canopy (Yahner 2000). These reductions in the canopy, often at varying retention levels affect the structural aspects of the forest which can have an impact on those wildlife species present, such as bats. It is important to determine how bats respond to these canopy reductions so forest managers are aware of the effects certain oak regeneration methods have on bat populations. Eastern hardwood forests alone account for 51% of the total United States forest land, and relatively few studies have been conducted on forest-roosting bats in this region (Allen et al. 1996).

Bats are a difficult fauna to study due to the fact that they are nocturnal, fly long distances at great heights, and use a type of communication that is inaudible to humans (Barclay 1999, Vaughan et al. 1997). However, advances have been made in technology that enable researchers to survey and assess bat communities in forested landscapes with the use of Anabat II ultrasonic bat detectors (Titley Electronics, Ballina, New South Wales, Australia) (Broders et al. 2004, Krusic et al. 1996, Zimmerman and Glanz 2000). Ultrasonic bat detectors are receivers which transform bat echolocation calls into sounds audible to humans (Vaughan et al. 1997). Although these systems have been criticized as being less reliable than other models (Fenton 2000), they have been successfully used and recommended for assessing foraging activity patterns for indexing habitat use (Gehrt and Chelsvig 2003, O'Farrell and Gannon 1999, Gehrt and Chelsvig 2004).

The number of recorded passes (a series of bat calls) in an area is used as an indicator of the amount of bat activity. Bats will emit echolocation calls for many reasons such as communication with other bats, mother-young communication, but most importantly, when intercepting and capturing prey (Fenton 2003). High activity rates of bats are positively correlated with aerial insect densities, so areas where bats achieve high rates of insect capture may be good quality habitats (Vaughan et al. 1997). Therefore, the level of bat activity in various habitats can be a good indicator of habitat quality (Jones et al. 2000).

However, certain aspects of bat ecology can influence the amount of activity within a certain habitat. Morphological differences in body size and wing shape, as well as differences in echolocation call designs can impact where a certain bat species forages (Fenton 2001, Aldridge and Rautenbach 1987, Jones et al. 2000, Menzel et al. 2005). This is largely correlated with the amount of structural clutter within a forest. Clutter is any tree, branch, leaf or twig that an echolocation call can bounce off of, or that impedes a bat's flight path (Owen et al. 2004, Fenton 2001). Research has shown that certain species are better adapted for foraging in cluttered areas and others are better adapted to flying in open, less cluttered habitats (Aldridge and Rautenbach 1987, Jones et al. 2000, Menzel et al. 2005). Depending on the physical structure of a forested habitat, clutter can vary from high in a young, dense stand, to very low in a clearcut. Several studies have shown that in general, bats use more open stand types such as those resulting from harvesting or the open understory of a mature forest, rather than structurally cluttered stands (Jung et al. 1999, Loeb and O'Keefe 2006). Because clutter has such a significant impact on the bat population within a forest, it becomes very important to quantify the amount of horizontal and vertical clutter present within a forest, particularly between different levels of harvested and unharvested areas (Owen et al. 2004, Menzel et al. 2005, Aldridge and Rautenbach 1987).

Although research had found the amount of clutter, or structural volume, within a forest has a significant impact on bat activity and species presence (Menzel et al. 2005, Jung et al. 1999, Owen et al. 2004), few have attempted to quantify the amount of volume where bat activity becomes affected. This study aimed to answer questions about the amount (cubic meters per hectare) and height of existing structural volume where changes in bat activity begin to occur. What level of clutter is too high or too low and at what amount does bat activity start to decline? At what height through the forest do reductions become significant? Can volume be measured in only the understory to sufficiently describe the effects it will have on the bat community or does the upper-canopy matter as well? The answers to these questions can provide forest managers with critical information on how to properly manage for bats while still meeting a variety of sustainable use goals. The clutter method developed in Chapter 2, and the amount of activity obtained in the various treatment and control sites were used to answer these questions.

The goal of this research was to determine and describe the short term response of bat populations to initial shelterwood harvests in two southern Ohio oak-hickory forests where restoration of oak communities is a priority for forest land managers. Specific objectives of this study were to 1) quantify the effects of different retention levels on forest structure using a developed method to estimate the amount of volume in predetermined vertical strata, and 2) assess the response of the bat community as a whole to alterations of the canopy, subcanopy, and understory between different harvest levels. It was hypothesized that due to the opening of the canopy and reduction of clutter, activity would be higher in the harvested sites as opposed to the control sites. It was expected that a 70 percent (%) retention harvest would have a higher amount of activity than a 50% retention harvest. This is because a 70% retention harvest would result in a reduction of clutter, becoming more appealing to open habitat foragers, while still retaining enough canopy cover to remain quality foraging habitat for clutter-adapted species. Clutter-adapted species would also be expected to utilize the control sites where no harvesting took place, however, it was predicted that activity would be lowest in the control sites because bat activity in upland sites of high clutter has been found to be low (Menzel et al. 2005, Brooks and Ford 2005).

3.2 Methods

Study Area Description and Site Selection

Two oak-hickory forests located on upland soils in southern Ohio were chosen as study areas. One study area was located within Richland Furnace State Forest, Jackson County, Ohio (39˚10'N latitude, 82˚36'W longitude) and the second in Zaleski State Forest, Vinton County, Ohio (39˚15'N latitude, 82˚23'W longitude) (Figure 3.1). Both forests lie within the unglaciated hill country of southern Ohio where the regional topography is characterized by deeply dissected terrain of the Allegheny Plateau (Kerr 1985). This creates a gradient of moisture regimes and subsequent microclimates across the landscape (Kerr 1985). Both state forests are managed under a multiple-use concept which includes management for wildlife habitat improvement, recreation, watershed management, aesthetics, and forest products. The forests are dominated by upland oak-hickory, which accounted for an average of 88.2% of the total basal area. The remainder consists of typical upland hardwood species (Table 3.1). Both the canopy and understory consist of shade tolerant species such as red maple, yellow poplar, and black gum which allow little to no oak regeneration. Slopes range from 10 – 24% with an average of 16%. Aspects averaged southeast (157^{o} azimuth) and range from northeast (43^{o} azimuth) to southwest (268^{o} azimuth).

Within each of the forest study areas, two different silvicultural treatments were applied, along with a control. These treatments entailed two shelterwood harvests, each comprising 10-ha, that reduced the stand stocking levels to 50% and 70% of full stocking (100%). The retention levels were chosen by forest land managers interested in finding the best level needed to successfully regenerate oak species while still keeping in mind other management objectives. For example, if the 70% retention allowed enough light to reach regenerating oak seedlings while still inhibiting competition, then it would be a more cost effective, aesthetically pleasing approach compared to the 50% retention harvest. It would also be a less intensive harvest and may cause less disruption to local and native wildlife species. However, more sunlight may be needed to successfully regenerate oaks suggesting that the 50% retention level may be necessary. Unfortunately, an increase in the amount of sunlight may allow competitors to over run the site. The chosen retention levels will allow forest managers the opportunity to answer some questions about the level of harvesting needed to restore oak communities while simultaneously determining the response of bats to alterations of the forest habitat.

Both Zaleski and Richland Furnace study areas had one replicate of each retention level and control, totaling six 10-ha treatment sites for each forest, for a total of 12 treatment sites between both forest study areas. To achieve the initial shelterwood cut, a combined crown thinning and low thinning was used to reduce the basal area, favoring dominant and co-dominant oak in the overstory. The control received no cutting treatment and remained intact.

Stand Structure

Eight vegetation plots were located within each of the 12 treatment sites using a systematic sampling design, for a total of 96 plots at both Richland Furnace and Zaleski forest study areas. A systematic sampling design was implemented to establish plot location rather than using a random approach. This was done to ensure plots were evenly distributed over the sites rather than a possible clustering of plots, which could occur in a random approach. Plots were established at a distance of 60 meters (m) apart on transects located 60 m from each other and the edge of other treatment sites or uncut areas. Transects were installed perpendicular to the slope to capture any changes in vegetation as elevation increases or decreases. This sampling design provided a sampling intensity of 6.4%, which is sufficient to describe vegetative compositions for oak forests in southern Ohio (Hutchinson et al. 1999).

Harvesting in Richland Furnace and Zaleski study areas began in June 2005 and ended in March 2006. Vegetation measurements of the harvested sites in both study areas were obtained during June 2006 through August 2006. Control sites were measured during June through August 2005 and 2006. Each vegetation plot was stratified to measure the overstory (trees greater than or equal to 10 cm dbh), saplings (trees greater than or equal to 1.4 m height and less than 10 cm dbh), and large seedlings (trees 0.3 to

1.4 m height). Overstory, sapling, and large seedling plots were circular and circumscribed about the same center. Overstory, sapling, and large seedling plots were 0.08 ha, 0.04 ha, and 0.02 ha in size. For all woody stems, total height, height to the base of the live crown, maximum crown diameter, and the diameter at a right angle to the axis of the maximum diameter, were measured to the nearest 0.15 m and recorded by species. Crown diameters were measured with a linear tape from dripline to dripline. Height measurements were taken with a clinometer. At the four cardinal directions, percent canopy cover was determined using a densitometer. Field measurements were recorded in English units and later converted to metric for analysis.

With the exception of canopy cover and species, the above measurements were used in a method to determine the amount of crown volume (m^3/ha) that existed vertically within each vegetation plot at 1-3 m, 3-6 m, 6-9 m, 9-12 m, and 12+ meters. The method, described in Chapter 2, is based on the measurements of tree height and width, conical crown shapes, and geometric proportionality.

Monitoring Bat Activity

To compare bat foraging activity and species presence across the treatment and control sites, Anabat II broadband ultrasonic bat detectors (Titley Electronics, Ballina, New South Wales, Australia) were used to capture echolocation calls. Because all bat species in Ohio echolocate while in flight (Griffin et al. 1960), bat detectors are an effective monitoring tool (Fenton and Bell 1981, Crome and Richard 1988, Fenton 1988, MacDonald et al. 1994, Krusic et al. 1996). In addition, acoustic monitoring is a sampling system that does not influence bat behavior or generate avoidance responses

(Reynolds 2006). Bats were monitored below the canopy using a passive monitoring approach (detectors were stationary) during the same time frame vegetation measurements were obtained, June 2006 through August 2006.

Two of the 12 treatment or control sites were monitored simultaneously for bat activity each night. A random numbers table was used to generate a random order to determine which two of the 12 treatment or control sites were monitored in a night. After each treatment or control site had been monitored once, the process was repeated until all sites had been monitored. In general, all sites were monitored within one week of each other for each rotation throughout the season (Gehrt and Chelsvig 2003). This monitoring design ensured equal sampling effort among treatment and control sites throughout the season. If inclement weather, such as rain, forced the termination of a monitoring session prematurely, those data were discarded and the site was monitored later in the same week.

All eight of the vegetation plots were used as monitoring stations within each treatment or control site. Monitoring stations were separated by 60 m with a 60 m buffer from edges to ensure independent sampling (Menzel et al. 2002, Krusic et al. 1996). At each monitoring station, a bat detector and cassette recorder with voice-activation mode (Model no. S701, Radio Shack, Athens, Ohio, USA) was placed in a protective box at the plot center. Some studies have shown that echolocation data from certain species of bats recorded directly to a computer are of greater quality than those recorded with tape recorders (White and Gehrt 2001, O'Farrell et al. 1999). However, tape recorders are still an effective method for large scale recording in the field, are sufficient for general measurements of bat activity, and are more cost-effective (White and Gehrt 2001).

Protective boxes were hung from a stable pole approximately 1.5 m from the ground to reduce sound attenuation by understory vegetation. The vertical detection distance of an Anabat bat detector is estimated to be 15 m, indicating that detectors placed 1.5 m above ground would sample bats flying below and within the canopy of most forest stands (Krusic et al. 1996). To maximize the detection of bat passes and minimize external noise such as wind, the bat detectors were set at sensitivity 8 and orientated at a 45˚ angle. The bat detectors were placed facing the interior of the treatment or control site. During a monitoring session, bat detectors were placed at the monitoring stations 30 min prior to sundown, and left to record for 3 hours.

Bat activity is highly variable and in some nights there can be high amounts of activity whereas other nights there may be little or no activity (Hayes 1997). In addition, there may be high activity at one monitoring station and no activity at another in the same night. By surveying each site multiple times with multiple detectors, variation between nights and monitoring stations is minimized (Hayes 1997, Barclay 1999).

Echolocation Call Analysis

Bat detectors allow researchers to hear and plot time-frequency graphs of otherwise inaudible ultrasonic calls emitted by bats (Zimmerman and Glanz 2000). This provides a way to quantify bat activity at survey points by counting the number of bat passes recorded by the detectors (Zimmerman and Glanz 2000, Thomas and West 1989). Tapes obtained from each monitoring session were analyzed with an Anabat V Zero

Crossing Analysis Interface Module and the computer programs AnaBat6 version 6.3g and AnaLook version 4.9j (Titley Electronics, Ballina, New South Wales, Australia). Passes were identified as being composed of two or more calls (White and Gehrt 2001) and calls separated by >1 second were counted as separate passes (Hayes 1997). Occasionally, multiple bats passed over detectors simultaneously; therefore these were partitioned and considered multiple passes (Gehrt and Chelsvig 2003).

Statistical Analysis

General activity did not differ between months within the treatment and control sites (ANOVA; $F = 0.33$, $p = 0.73$), so the monthly data were pooled within each treatment and control. The total number of bat passes recorded in each of the eight monitoring stations in a night was averaged to obtain the mean number of bat passes per night. Each treatment or control site was monitored multiple nights. The mean number of bat passes for each of those nights was averaged to obtain an overall mean of bat passes for all 12 of the treatment and control sites. A two-way, fixed analysis of variance (ANOVA) with treatment and forest used as main effects and an interaction term was used to determine if bat activity varied among treatment and control sites, and if the pattern of variation was consistent between the two forest study areas. Tukey's multiple mean comparison was used to distinguish which means differed. Significance was determined at $p \leq 0.05$.

Data were analyzed using Statistical Analysis Systems, 2002 (SAS) and Minitab (Minitab Release 14, 2003). A square-root transformation was applied to the mean number of passes per site to meet the assumptions of normality and homogeneity of variances for the analyses (Quinn and Keough, 2002). Normality of the data was assessed by using the Anderson-Darling test for normality ($p = 0.54$) and probability plots. Homogeneity of variances was assessed using Barlett's test ($p = 0.56$) and observation of box plots. The distribution was determined to be normal with minimal skewness (-0.19) and slight kurtosis -1.14). Independence was achieved through replicates of treatment and control sites and adequate spacing between monitoring sites.

Structural volume was analyzed using the clutter method (Chapter 2). Differences in volume between the treatment and control sites and within the five predetermined strata were determined using one way analyses of variance. Tukey's multiple mean comparison was used to distinguish which means differed and significance was determined at 0.05. Assumptions of the analyses were met by log and square root transformations of the variables to meet criteria of normality and homogeneity of variances. Normality of the variables was assessed using the Anderson-Darling test (all variables had $p > 0.4$) and probability tests; equal variances were determined by use of Barlett's test (all variables had $p > 0.3$) and examination of box plots.

To answer questions pertaining to the amount and height of structural volume that influenced bat activity, a candidate set of a priori hypotheses was established based on knowledge of bat habitat relationships. A set of 22 general linear models assuming Gaussian distributions were produced and Akaike's Information Criteria (AIC_c) was used to identify the most parsimonious models and predict variable importance (Burnham and Anderson 2002). Predictor variables were the amount of volume (m^3/ha) in the predetermined strata levels used in the clutter method (Chapter 2), along with basal area and canopy cover. An additional set of predictor variable was created by combining and averaging together combinations of the predetermined strata (Table 3.2) to determine the necessary detail of the volume stratum. For example, the strata of 0-3 m and 3-6 m were combined to form a stratum of 0-6 m. If this stratum is adequate to explain bat activity, then it does not need to be further divided. Because canopy cover and basal area can also reflect the amount of volume within a forest, those variables were analyzed in models not containing volume strata with the exception of the global model. This was done to determine if basal area (m^2/ha) and canopy cover (%) alone were sufficient to describe bat activity. For each model, the AIC_c, the difference between the model with the lowest AIC_c and the AIC_c for the ith model (Δ_i), and Akaike's weights (w_i) were calculated. Models with the lowest AIC_c, $\Delta_i \leq 2$, and the highest weights were considered the best approximating models. Model averaging was used to determine the importance of variables in top models with similar to identical AIC_c scores and weights (Burnham and Anderson 2002). Variable coefficients were then graphed to create a visual representation of the relationship. The response variable, bat activity, and predictor variables were log transformed to meet assumptions of the analysis. Data were analyzed using R statistical package (version 2.5.0, 2007).

3.3 Results

Stand Structure

Differences in structural volume in all five predetermined strata were significant between harvested and unharvested sites with the exception of the 12+ m stratum where the 70% retention harvest was not significantly different from the control (Table 3.3).

Between the 50% and 70% retention harvests, there were no significant differences between structural volumes in any of the strata. However, upon examination of the mean volume for each stratum, the values in the 70% harvest were all greater than that of the 50% harvest, with the exception of the 6-9 m stratum (Table 3.3, Figure 3.2). The control sites had the largest overall total volume followed by the 70% harvest sites, and lastly the 50% harvest sites. Also, the control sites had the largest amount of volume in every stratum. The average volume per plot in the 50% retention harvest was 4414.6 m^3/ha, which was less than the 70% retention harvest which had an average plot volume of 6566.9 m^3/ha. Perceptibly, the control sites once again had the largest per plot volume of 10,081.7 m^3/ha.

Because the amount of volume within the four lower strata between the two retention harvests was similar, the main differences in total volume occurred in the 12+ m stratum (Table 3.3, Figure 3.2). The 12+ m stratum had the greatest amount of volume out of all five strata followed by the 9-12 m stratum within each of the harvested and control sites. Within the control sites, the volume increased with increasing height, whereas in the harvested sites, volume in the 0-3 m stratum was higher than volumes of the 3-6 m and 6-9 m strata (Table 3.3, Figure 3.2).

Basal area and canopy cover were greatest in the control sites followed by the 70%, then 50% retention harvest sites (Table 3.3). There was significant difference between basal area between both retention harvests and control sites. Canopy cover with the 50% and 70% retention harvests was not significantly different; however, mean values were less in the 50%. Canopy cover was significantly higher within the control sites than the harvested sites (Table 3.3). Visually, the retention harvest sites had a more open understory then the control sites and the 50% harvest sites were more open than the 70% sites.

Bat Use of Treatment and Control Sites

Bat activity was monitored for 38 nights during June 2006 through August of 2006 with two treatments being monitored simultaneously each night. As a result, each treatment and control site (n = 12) was monitored between 6-8 total nights and a total of 1824 hours was accumulated for the monitoring season (Table 3.4). Overall, 11,560 bat passes were recorded, the greatest numbers occurring with the harvested sites (Table 3.4).

Total bat activity for all species combined differed significantly between the harvested sites and control sites (ANOVA; $F = 15.44$, $p = 0.004$) and was consistent between the forest study areas ($F = 0.67$, $p = 0.45$). Within the 50% retention harvest sites, a total of 5487 passes (47.5%) were recorded, while a similar 5327 passes (46.1%) were recorded within the 70% retention harvest sites (Table 3.4). Only 746 passes were verified within the control sites, comprising 6.5% of the total passes recorded. Mean number of bat passes per treatment and control were also higher in the harvested sites compared to the control (Figure 3.3). The average number of passes per site (n = 12) ranged from 2 to 38 passes, while the average number of passes between nights ranged from 0 to 64 passes.

Response of Bats to Structural Volume

The model containing variables tridw (0-6 m) and sixup (6-12+ m) and the model containing only tridw were the best predictors of overall bat activity within the harvested and control sites (Table 3.2, Table 3.5). These two models had identical Akaike's weights of 0.17 followed closely by the third model, which was the global model, with a w_i = 0.14. All five predetermined strata, as well as basal area and canopy cover were components of the global model (Table 3.5). All models with $\Delta_i \leq 2$ contained variables accounting for volume within the 0-6 m stratum signifying the importance of this particular height stratum (Table 3.5). The model containing basal area alone had moderate support (Δ_i = 1.98) but the model containing basal area and canopy cover had less support (Δ_i = 2.11). However, both models had equal weights of 0.06. The worst approximating model for predicting bat activity was the model containing only TWLVP (12+ m stratum). Overall, this seemed to be the variable with the least amount of support. All models containing this variable ranked low overall. Models with variables expressing volume in the understory to mid-canopy strata were ranked higher overall.

Model averaging was calculated for variables tridw and sixup and coefficients were graphed to determine the point where bat activity began to drop (Figure 3.4). For variable tridw, the drop off point, or inflection point, is approximately at log (5), which equates to a volume of 148.4 m^3/ha. Variable tridw is the volume for the stratum 0-6 m, and at this height, when the volume is 148.4 m^3/ha, bat activity began to decrease. For the variable sixup (height stratum 6-12+ m), the inflection point was not as clear, but could be interpreted around log (9), which is a volume of approximately 8100 m^3/ha. Both graphical representations of the variable coefficients, however, are negative, meaning that as volume increases, bat activity decreases. Variables tridw and sixup were representative of volume within 0-6 m and 6-12+ m strata, indicating that the division point at 6 m is significantly influential.

3.4 Discussion

The goal of this research was to evaluate the response of bat fauna in southern Ohio oak-hickory forests to changes in forest structure caused by shelterwood harvests of varying retention levels. This was accomplished through a series of objectives. The first objective was to describe the effects each retention level had on forest structure. This was met by the development of a method that estimated the volume (m^3/ha) in five predetermined vertical strata (Chapter 2). The method produced quantitative amounts of volume in each stratum that were then compared between treatment and control sites. Volumes between the 50% and 70% retention harvests were not significantly different in any of the strata, biologically however; mean volumes were generally larger within the 70% harvest. This is consistent with the retention level; more basal area was purposefully retained in the 70% harvest than in the 50% harvest. The one stratum, 6-9 m, which had more volume in the 50% harvest than in the 70%, was due to a plot in a 50% harvest site that had an exceptionally high amount of volume within this stratum. On this plot, there were two snags with diameters of 53 cm, which were only 5 m tall. In the absence of these snags' probably once large crowns, smaller diameter trees that had been suppressed, were growing up around them with crowns within the 6-9 m stratum causing the elevated volume for this plot.

When comparing the harvested treatments to the control, there were significant differences across all strata except the 12+ m stratum. Within this stratum, the 70% retention harvest was not statistically different from the control, but based on the means alone, had >10,000 m^3/ha difference in volume. While statistical difference is important, noting the fact that the means display volume successively increasing as the harvests became less intensive is also important and signifies the practicality and objective of this method.

The strata with the greatest amounts of volume were the 9-12 m and 12+ m, undoubtedly due to the amount of crown volume retained at those heights. Within the control, volume increased vertically up through the canopy. At greater heights, more sunlight becomes available to tree crowns enabling them to grow large, whereas the shaded understory does not receive as much sunlight, therefore producing crowns of smaller volume. Within the harvested sites, however, some of the lowest stratum, 0-3 m, had larger volumes than successive strata. This was cause by several events. One, there was an increase in the amount of sunlight reaching the forest floor. The increase in sunlight resultant from a thinning of the canopy, allowed regenerating species, preferably oak, to grow faster towards establishment. The second reason is that there simply was no merchantable timber within this stratum (0-3 m), however in the successive strata, there was, and it was removed resulting in overall lower volumes.

The second objective of this study was to assess the response of bats to these retention harvests by comparing activity between the two retention harvests and the unharvested control sites. Several hypotheses were formulated, the first being that activity would be higher in the harvested versus control sites. This hypothesis was supported by significantly higher numbers of bat passes in both harvested areas compared to the control. Many studies (Menzel et al. 2005, Grindal and Brigham 1998, Erickson and West 2003) have found bat activity to be significantly higher in harvested areas with low tree density and low structural clutter. This could be due to a couple of reasons, one of which is a greater amount of insect densities within the harvested areas. Insect densities can be an indicator of habitat quality (Vaughan et al. 1997), and some previous studies have documented higher insect abundances in clearings than in forested habitats (De Jong, 1994). Another reason for the greater amount of activity within the harvested sites is the lack of clutter, or structural volume. Clutter can interfere with echolocation calls by creating background noise, as well as obstructing a bat's flight path (Humes et al. 1999). Recall that certain species have adapted to flying in more open areas; those with high aspect ratios. The retention harvests created an open understory and thinned canopy for these species to utilize that previously they could not, due to levels of high structural volume.

It may also have been these reasons of insect density, ease of flight, and echolocation interference that caused the unharvested control sites to have such a low number of bat passes. The second hypothesis expected bat activity to be lower in control sites and this also was supported. Bat activity in the unharvested, structurally cluttered control sites was only 6.5% of the total activity. This could be due to low levels of insect densities, however, without data on insect abundance, it can only be speculated that bats avoided the control areas and preferred the harvested areas because of high insect densities (Menzel et al. 2002). Literature has reported that bat activity is low in upland, closed canopy sites (Menzel et al. 2005, Jung et al. 1999). Brooks and Ford (2005) did not even attempt to survey for bat activity in these habitats because of this knowledge. However, Menzel et al. (2005) did report higher levels of activity above the canopy in upland, closed canopy sites than below. This presents the possibility that there may have been activity within the control sites, but it was undetectable due to the height at which it was taking place. This study placed detectors at ground level only (1.5 m above ground) creating a detectability of roughly 15 m high. If activity was going on above the canopy, the detectors used in this study would not have been able to detect it. Even though activity was low in the control sites, it is still important to remember that bats will fly great distances throughout the night in search of food, and these control sites, while they may not be suitable for feeding, may be suitable for other needs, such as roosting.

The third and final hypothesis devised to explain differences in activity between the treatment and control sites was that more activity was expected within the 70% retention harvest then the 50% retention harvests. This was formulated based on the morphological differences between species of bats. It was expected that the 70% retention harvest would retain enough structural volume to appeal to species with low and high aspect ratios. This hypothesis was not supported, and no significant differences were found between the numbers of passes within the two retention levels. Explanation of this finding can be derived from the examination of the amount of volume present in each of the retention harvests. There was no statistical difference between the amounts of volume between the two harvests in any of the strata. Perhaps bat activity is also reflecting this similarity, and that overall, the creation of an open understory is what is important. Also the fact the bat activity did not respond to the lack of statistical difference in the 12+ m stratum between the 70% retention harvest and the control, also reflects that the open understory is more important. This suggests that opening up the understory is beneficial and that such a distinction between harvesting can be significant when looking at basal area or amount of board feet, but in terms of how a bat views the forest, there may not be much distinction beyond less clutter and more open flight space.

At this point, it becomes important to find answers to the research questions this study proposed about the amount and height of structural volume where changes in bat activity began to occur. It has been established that bat activity is higher in the retention harvests, but it would be highly valuable to find out what it is about the structure of these forests that causes it. The first question proposed was at what height in the forest do reductions in volume start to influence bat activity? Of all the height strata, the strata that changed the most after the harvests were the 3-6 m and 6-9 m. At the 3-6 m, the volume was approximately 27 times higher in the control sites than in the harvests and in the 6-9 m stratum, the volume was 24 times higher. Compared to the other strata, volumes were only four to six times higher in the control than in the harvests. These two strata also had the largest f-values as well as smallest p-values between harvested and control sites.

There is definitive evidence that these two height strata are impacting the structure of the forest, as well as bat activity. Through an evaluation of 22 proposed models, the models containing the variables tridw and sixup were found to be the best at describing bat activity in the harvested and unharvested sites. Tridw was a combination of the 0-3 m and 3-6 m strata, and was obtained by averaging the volume of these two strata. There was very little volume within the 3-6 m stratum, so by averaging this with the 0-3 m strata, the average is being pulled down making the 3-6 m stratum (SIX) influential. The variable sixup, which is an average of the 6-9 m, 9-12 m, and 12+ m strata, is being influenced by the 6-9 m stratum (NINE), which is pulling down the average. Overall, the height strata that were most affected by harvesting also appeared in the top models, which provides evidence of their importance.

As tridw appeared in the top two models as being the best at predicting bat activity, there is sound evidence that at heights up to 6 m, bat activity is influenced. Reynolds (2006) also found approximately 50% of all bat passes were recorded at a heights of 7 m. The model analysis provided a top model and influential height, but what is the volume at that height and how much is too high or too low? Graphing tridw showed a negative relationship between the amount of volume and bat activity and at 148.4 m^3/ha, activity began to decrease substantially. The amount of volume in the 0-6m stratum in the 50% and 70% retention harvests were less than this at 73.5 m^3/ha and 84.6 m^3/ha respectively. In the control, the volume was much higher at 736.2 m^3/ha, indicating that the amount of volume in the control is too high to warrant much activity.

The graph for sixup, unfortunately, gave a less clear representation of the amount of volume where bat activity begins to decline at heights from 6-12+ m, but could be interpreted at around 8100 m^3/ha. This was less than the volume at this height stratum in the 70% retention harvest and control, but only slightly greater than the 50% retention harvest, which had a volume of 7410.1 m^3/ha. The reason this variable is showing a straighter line, indicating little influence on bat activity, is because it is included in the model with the tridw variable. The variable tridw is having such a strong influence on the model that is it overpowering any influence from the sixup height stratum.

The final question this study aimed to answer was can volume be measured in only the understory and mid-canopy to sufficiently describe the effects it will have on the bat community or does the upper-canopy matter as well? There have been several indications that the understory played a larger role than the upper-canopy. First, analysis of the amount of volume at different heights showed that volume in the understory to mid-canopy was reduced the most by harvesting (3-6 m and 6-9 m). This was also reflected in the amount of bat activity as these two strata were present in the top models predicting bat activity, expressed as tridw and sixup. Also, variables representing volume within the understory to mid-canopy are continually present in the models with the highest w_i and $\Delta_i \leq 2$ also indicating these heights are important in predicting bat activity. Conversely, strata representing volume within the upper-canopy, 12+ m (TWLVP) is present most often in the bottom models. Also, the largest difference in volume between the two harvests occurs at the 12+ m stratum, and even though these strata have almost no statistical difference ($p = 0.467$), they are still ~9600 m^3/ha apart in volume. Even though bat activity is not outwardly reflecting this stratum, it is still accounted for within the top models, and is reiterating the strong influence that a reduction of structural volume has on bat activity. This statement is also reiterated in the presence of the global model being the third highest ranked model.

Previous studies have used basal area, canopy cover, and a variety of other forest characteristics such as number of snags and tree density, as variables to predict bat activity (Jung et al. 1999, Loeb and O'Keefe 2006). Basal area and canopy cover were placed alone in models to determine if they were better at explaining bat activity than volume. Basal area alone was one of the top six models with $\Delta_i \leq 2$, and basal area + canopy cover was right below it, but did not have a high enough Δ_i to be considered one of the best approximating models. Basal area was also represented in the third highest model, the global model. This would suggest that basal area is important in describing high levels of bat activity by representing a thinning of the forest, but still not as influential as the lower volume strata. In the future, however, it may be beneficial to include additional forest characteristics such as number of snags and tree density to see if any of these in combination with volume could provide an even better model for predicting bat activity.

3.5 Management Implications

Community restoration is an important objective of forest managers, specifically oak species regeneration in forests of southern Ohio through the use of shelterwood harvesting. These harvests retain large diameter oak trees for regeneration of oak seedlings on the forest floor, while creating an open understory to mid-canopy by removing smaller diameter trees. The analysis of total bat activity suggests this type of harvesting yields high amounts of bat activity, thereby providing quality foraging habitat.

There were no significant differences in activity between the two retention levels, suggesting the less intensive 70% retention level, if successful in regenerating oak species, be used in the future.

In conclusion, the understory to mid-story height strata of 0-6 m (tridw) and 6-9 m (SIX) appeared to be the most influential and are important strata to measure in the future. However, the upper-canopy stratum should not be ignored due to its importance in representing a large reduction of volume between harvested and unharvested sites. Also, more research on the amount of activity occurring above the canopy should be considered. In addition, the harvested sites retain little to no snags. Erickson and West (2003) found the removal of snags may have the greatest influence on bats by reducing potential roost sites. Kalcounis-Ruppell et al. (2005) also stated that bats selected roost trees that were tall, had large diameters, and were present in forest stands with open canopies and high numbers of snags per hectare. This suggests that shelterwood harvests, which retain large diameter trees, could provide optimal habitat for bats if snags were also retained. It is imperative, however, to consider the entire forest community and other wildlife species needs before a management objective is subscribed. While results of this study suggest an open understory highly beneficial in supporting a health bat community, it is also imperative that habitats with higher amounts of structural volume, such as the control sites, be retained to provide roosting sites for bats as well as nesting areas for other species such as migrating songbirds. Forest management practices that create structural and biological complexity will provide quality foraging and roosting habitat for a variety of bat species, while still meeting the needs of community restoration.

3.6 Caveats

Caution should always be used in extending inferences from data collected in acoustical monitoring surveys due to limitations of the equipment. For example, bat detectors do not allow researchers to distinguish between multiple passes by a single bat or single passes by several bats. Therefore, the number of bat passes recorded by the detectors can not be used as a direct measurement of the abundance of bats and inferring abundance from activity should be forewarned. However, Gehrt and Chelsvig (2004) did determine a relationship between minimum abundance and activity levels. Also, high activity rates of bats are positively correlated with aerial insect densities (Dai Fukui et al. 2006), so areas where bats achieve high rates of insect capture may be good quality habitats (Vaughan et al. 1997). Therefore, the level of bat activity in various habitats can be a good indicator of habitat quality (Jones et al. 2000). This information can be used to support general deductions made based on measured of activity from data collected acoustically.

Great attempts were made to limit sources of bias by standardizing monitoring protocol and sampling in replicate areas as well as multiple nights. However, habitat characteristics were different between treatment and control sites which could lead to potential differences in probability of detection. Because the amount of clutter influences the call structure of certain species, care must be made in evaluating data in these situations.

In addition, recent literature has indicated that above-forest canopy activity in upland sites for large-bodied bats can be considerably higher than that of below canopy activity. This could potentially lower the value of upland forest sites, such as the control sites in this study, to bat populations and considerations should be made in the future concerning monitoring at various heights throughout and above the canopy.

Finally, species-specific effects may have been masked by pooling all the species together in a general activity analysis. In the subsequent chapter, effects on individual species are examined and evaluated.

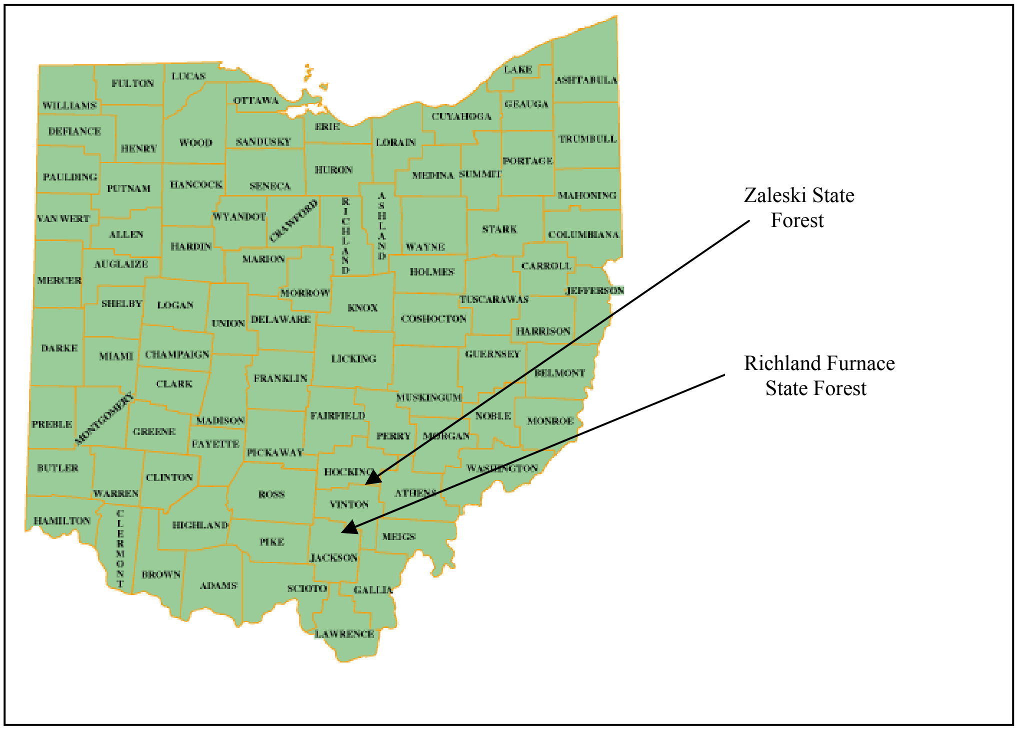

Figure 3.1: Location of oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio.

Upland Oak	**Hickory**	**Mixed Hardwoods**	**Understory**
Quercus alba	*Carya glabra*	*Acer saccharum*	*Amelanchier spp.*
Quercus coccinea	*Carya laciniosa*	*Acer rubrum*	*Carpinus caroliniana*
Quercus prinus	*Carya tomentosa*	*Fagus grandifolia*	*Corylus americana*
Quercus rubra		*Fraxinus americana*	*Hamamelis virginiana*
Quercus velutina		*Fraxinus pennsylvanica*	*Lindera benzoin*
		Liriodendron tulipifera	*Ostrya virginiana*
		Nyssa sylvatica	*Sassafras albidum*
		Populus grandidentata	*Viburnum spp.*
		Prunus serotina	
		Ulmus americana	
		Ulmus rubra	

Table 3.1: List of species present on oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio. Data was collected during June 2006 through August 2006.

Variable	Definition
ba	Basal area (m^2/ha)
cc	Canopy cover (%)
	Volume (m^3/ha) in stratum:
TRI	0-3m
SIX	3-6m
NINE	6-9m
TWLV	9-12m
TWLP	12+m
	Average volume (m^3/ha) in strata:
tridw	0-3m and 3-6m
triup	3-6m, 6-9m, 9-12m, and 12+m
sixdw	0-3m, 3-6m, and 6-9m
sixup	6-9m, 9-12m, and 12+m
ninedw	9-12m and 12+m
nineup	0-3m, 3-6m, 6-9m, and 9-12m
sixm	3-6m and 6-9m
ninem	6-9m and 9-12m

Table 3.2: Variables measured and used in regression analysis at bat monitoring sites located in Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio during June 2006 through August 2006.

	50% Retention (n = 4)		70% Retention (n = 4)		Control (n = 4)		ANOVA[a]	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**F**	**P**
Basal Area (m^3/ha)	12.99A	0.34	17.42B	0.67	24.70C	1.23	50.53	0.0001
Canopy Cover (%)	64.08A	1.90	75.03A	3.80	92.63B	3.21	20.96	0.0004
Volume Strata								
0-3m	117.48A	26.20	123.31A	14.40	443.68B	73.30	16.98	0.0009
3-6m	28.36A	17.80	45.87A	34.60	1028.63B	289.00	12.65	0.0024
6-9m	105.45A	65.50	35.17A	18.20	1713.02B	554.00	6.90	0.0153
9-12m	820.33A	475.00	975.55A	366.00	5626.58B	1341.00	10.39	0.0046
12+m	21,001.24A	3587.00	30,629.65AB	3763.00	41,596.78B	6748.00	4.39	0.0467
TOTAL	22,072.85		31,809.56		50,408.69			

[a] 1-way ANOVA across 2 treatments and control

Table 3.3: Structural characteristics for oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006. Mean values followed by the same letter are not significantly different across rows (Tukey's, p > 0.05, means and SE are from untransformed data).

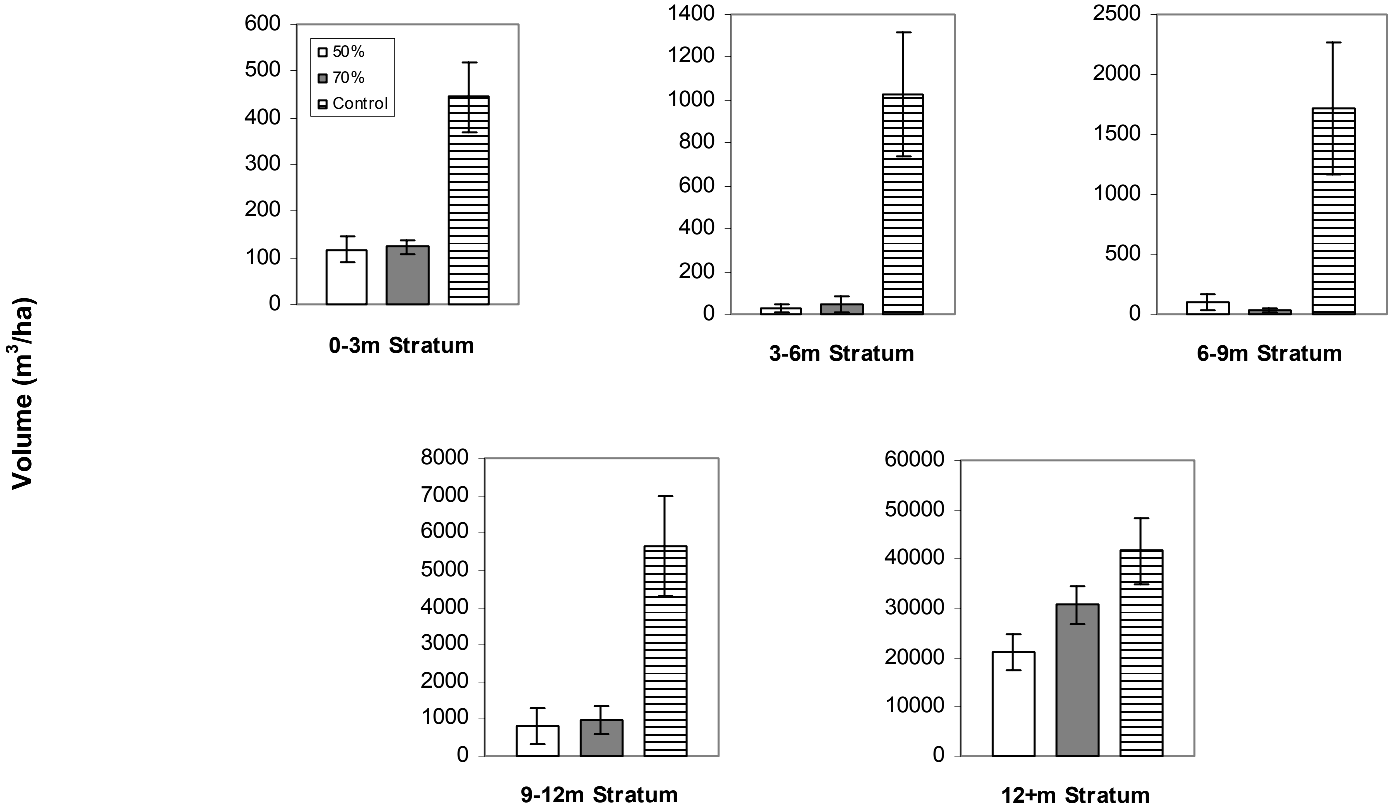

Figure 3.2: Results of clutter method presented as the amount of volume (m^3/ha) (mean and se) within all five strata for the 50% and 70% retention harvests and control sites. Data were collected from two oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio during June 2006 through August 2006.

Acoustical Monitoring Summary	50 % Retention (n = 4)	70% Retention (n = 4)	Control (n = 4)	TOTAL
Total no. passes	5487	5327	746	11,560
Hours/treatment	600	648	576	1824
Nights monitored/treatment	25	27	24	76
Mean no. passes/treatment	1327	1332	187	
Mean no. passes/night	219	197	31	

Table 3.4: Acoustical monitoring summary of bat activity recorded in oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio. Data were collected during June 2006 through August 2006.

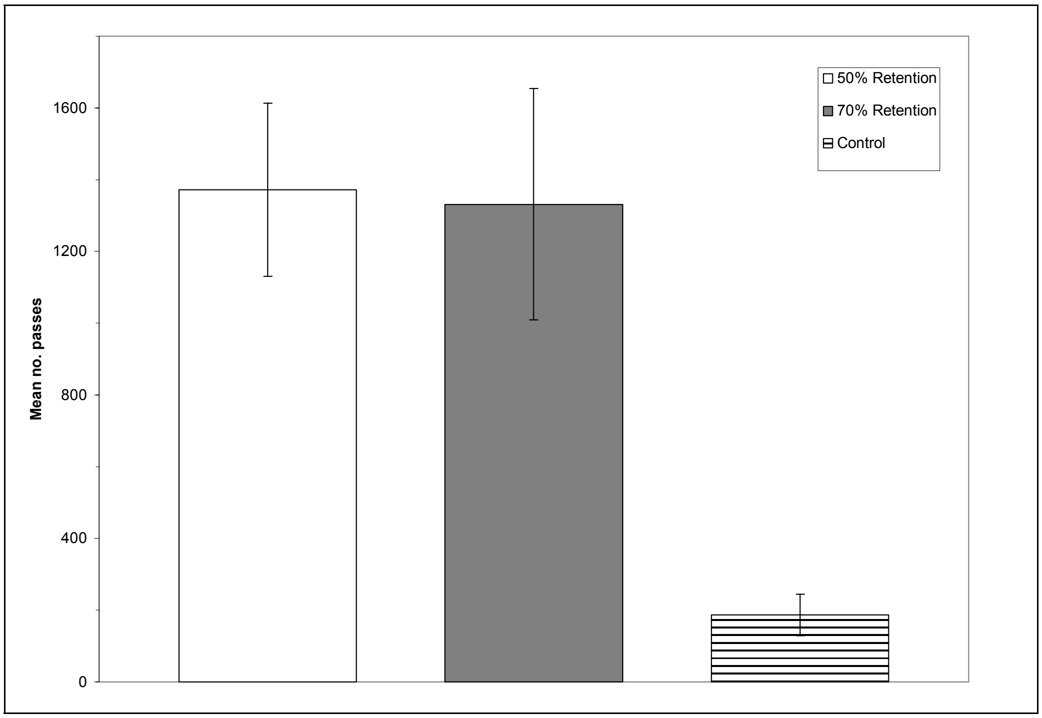

Figure 3.3: Total bat activity for all species combined (mean no. passes and se) within each treatment and control collected from two oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio during June 2006 through August 2006.

Model	k	AIC_c	Δ_i	w_i
tridw + sixup	3	285.50	0.00	0.17
tridw	2	285.53	0.03	0.17
ba + cc + TRI + SIX + NINE + TWLV + TWLVP	8	285.96	0.46	0.14
TRI + SIX	3	286.67	1.17	0.10
nineup + NINE + tridw	4	286.74	1.24	0.09
ba	2	287.48	1.98	0.06
ba + cc	3	287.61	2.11	0.06
TWLVP + ninem + tridw	4	287.65	2.15	0.06
SIX	2	288.56	3.07	0.04
TRI + SIX + NINE	4	288.69	3.19	0.04
TRI	2	290.11	4.62	0.02
triup + TRI	3	290.14	4.64	0.02
nineup + sixm + TRI	4	290.29	4.79	0.02
nineup + sixdw	3	292.40	6.91	0.01
sixdw	2	292.45	6.95	0.01
TWLVP + TWLV + sixdw	4	294.57	9.08	0.00
ninedw	2	294.69	9.19	0.00
TWLVP + ninedw	3	295.83	10.33	0.00
totalv	2	301.60	16.10	0.00
nineup	2	303.33	17.83	0.00
TWLVP	2	305.50	20.00	0.00
Null model	1	309.84	24.34	0.00

Table 3.5: Number of estimated parameters (k), small sample Akaike's Information Criteria (AIC_c), difference between model AIC_c and that of the best model (Δ_i), and Akaike's weight (w_i) for Gaussian regression models to predict bat response to forest structure and volume data collected from Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

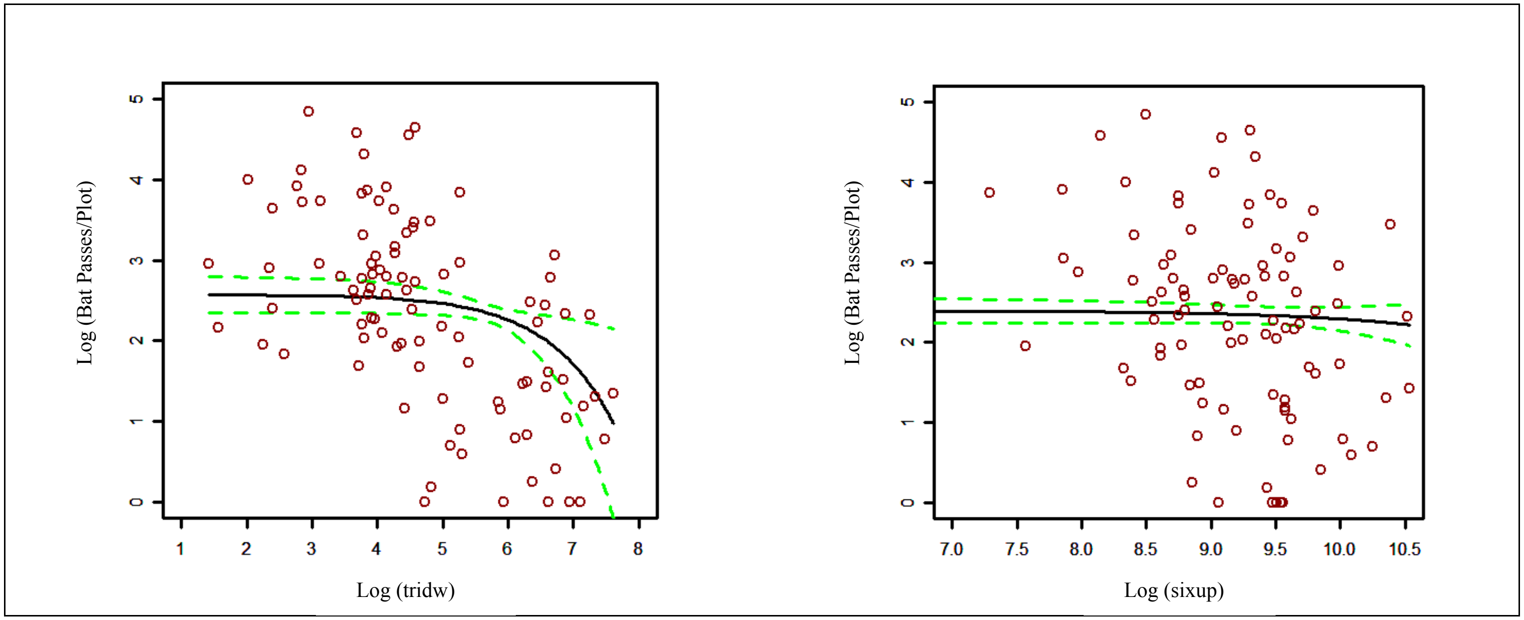

Figure 3.4: Results of model averaging of variables tridw (0-6 m) and sixup (6-12+ m) with log number of bat passes per plot on the y-axis, and log of volume (m^3/ha) on the x-axis. Confidence intervals set at 95% are represented by the green dashed lines. Data were collected from Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

CHAPTER 4

SPECIES PATTERNS OF BAT ACTIVITY IN RESPONSE TO RETENTION HARVESTS IN SOUTHERN OHIO

4.1 Introduction

It has been well researched and documented that bats can be partitioned by dietary and habitat resources based on echolocation call design and morphological differences between species (Fenton 2001, Aldridge and Rautenbach 1987, Jones et al. 2000, Menzel et al. 2005). These morphological differences can dictate where certain species are likely to be present more than others. While studies that determine general bat activity are important in creating an overall picture of resource use in a certain habitat (White and Gehrt 2001), considering individual species of bats can provide additional insight into bat habitat relationships (Menzel et al. 2005).

Morphological differences between species of bats are commonly described by wing shape and body size (Fenton 2001, Aldridge and Rautenbach 1987, Jones et al. 2000, Menzel et al. 2005). For example, different species of bats have different wing designs which are characterized as wing aspect ratios (wing length/wing width) (Fenton 2001, Aldridge and Rautenbach 1987). If a bat has a low aspect ratio, their wings are short and broad which allow them to forage in denser habitats where their wings allow them to be highly maneuverable (Aldridge and Rautenbach 1987). Bats are also characterized by body size, or wing loading (mass/2 x wing area). Bats with low aspect ratios also tend to have smaller body sizes or low wing loadings, for example, bats belonging to the genus *Myotis* such as the Indiana bat (*Myotis sodalis*), little brown bat (*Myotis lucifugus*), northern long-eared myotis (*Myotis septentrionalis*). These species are commonly found foraging in habitats with high amounts of structural clutter (Ford et al. 2005, Jung et al. 1999). Structural clutter is any tree, leaf, branch, etc. that can impede a bat's flight path or an echolocation call can bounce off of (Owen et al. 2004, Fenton 2001). A bat with a high aspect ratio has long, narrow wings which enable it to fly faster, but with limited maneuverability. Bats with high aspect ratios are generally found foraging in more open, less structurally dense habitats (Fenton 2001, Aldridge and Rautenbach 1987). These bats, such as big brown (*Eptesicus fuscus*) and silver-haired (*Lasionycterus noctivagans*) are commonly termed large-bodied bats, or bats with high wing loadings. Other species in Ohio that are large-bodied are the red bat (*Lasiurus borealis*) and the hoary bat (*Lasiurus cinereus*).

Where a bat can forage depends more on its wing morphology and body size, but a bat's ability to successfully forage within that habitat depends also on its echolocation call design (Aldridge and Rautenbach 1987). Not all species of bats produce echolocation calls of the same intensity, frequency, and duration (Fenton 2003) and often times, these unique call designs are related to morphology and habitat use (Jones et al. 2000). Large-bodied bats emit calls of high intensity, long duration, and low frequencies. This allows their calls to travel farther and aid in the detection of distant targets, which are ideal in the open habitats they typically forage in (Jones et al. 2000). Small-bodied bats, which forage in dense, cluttered habitats, emit calls of shorter duration and higher frequencies (Aldridge and Rautenbach 1987, O'Farrell et al. 1999). This allows for these species to precisely locate and separate targets from clutter, such as branches, leaves, and other obstacles that could interfere with echolocation calls (Broders et al. 2004).

Silvicultural practices such as timber harvesting, can potentially impact bat populations within a forest (Menzel et al. 2005, Krusic and Neefus 1996, Fenton 2001). Not only can these practices change insect abundances, adjust the number of available roost sites, and change the quality of foraging habitat, but they can alter the amount of clutter, or structural volume, present within the forest (Jones et al. 2000). Because clutter has such a significant impact on the bat fauna present within a forest, it becomes important to achieve a quantification of the amount of clutter horizontally and vertically present within a forest, particularly between various levels of harvested and unharvested areas (Owen et al. 2004, Menzel et al. 2005, Aldridge and Rautenbach 1987).

A wide range of forest management practices is being used in attempts to achieve goals of biodiversity and community restoration (Barclay and Brigham 1996). For the past 100 centuries, oak species (*Quercus sp*.) have been an important component of the deciduous forests of the eastern United States (Abrams 1992). However, these forests have been shifting from the historical dominance by oaks to higher proportions of red maple (*Acer rubrum*) and other hardwood species (Griffith et al. 1993, Abrams 1998). In southern Ohio, similar trends in forest composition and structure change can be found, and although oaks still dominate the overstory in many of Ohio's forests, regeneration on the forest floor is dominated by species such as yellow-poplar (*Liriodendron tulipifera*), maples and blackgum (*Nyssa silvatica*). It has become an important objective of forest managers in the eastern United States to determine ways of restoring oak communities.

In eastern deciduous forests of Ohio, forest managers are implementing the shelterwood method of timber harvesting to regenerate oak species (Yahner 2000). Through a reduction of the canopy and understory, this method is designed to allow more light and permit faster growth of oak seedlings on the forest floor (Yahner 2000). These reductions in the canopy are examples of how the structural clutter within a forest can be altered. Due to population declines in several bat species, such as the Indiana bat (*Myotis sodalis*), it has become vital to determine how bats respond to these canopy reductions. Relatively few studies have been conducted on forest-roosting bats within eastern hardwood forests where silvicultural practices aimed at oak regeneration are being implemented. Information is needed to equip forest managers with the proper tools to manage for both threatened populations of bats and oaks.

In Chapter 3, total bat activity was analyzed without respect to different species. In this chapter, bat species were examined individually to further accomplish the goal of this research; to determine and describe the immediate response of bats to initial shelterwood harvests in two southern Ohio oak-hickory forests where restoration of oak communities is a priority for forest land managers. Information on forest structure, obtained from the clutter method (Chapter 2), will be used once more to examine the species-specific responses to the alterations of the canopy, subcanopy, and understory within and between each treatment.

Previous studies have determined that vegetation density is a key factor in explaining the presence and absence, as well as level of activity of certain bat species (Menzel et al. 2005, Jung et al. 1999, Loeb and O'Keefe 2006). In Chapter 3, the amount of vegetation density, or structural volume, where bat activity becomes affected was determined for overall bat activity. Chapter 4 aimed to answer questions about the amount (cubic meters per hectare) and height of existing structural volume where changes in individual species activity began to occur. What level of clutter was too high, or too low to warrant activity of certain species? At what height vertically through the canopy did reductions become significant and was that height species dependent? At what volume did activity levels of certain species drop by 50%? Any attempts made to answer these types of questions can provide guidelines to forest managers on how to best manage for certain species of bats.

It was hypothesized that species-specific activity among open habitats (retention harvests) and cluttered habitats (control sites) would be predictable based on differences in morphology and echolocation call design. It was predicted that small bodied bats such as *Myotis* species and eastern pipistrelle (*Pipistrellus subflavus*) would predominate in the highly cluttered control sites whereas larger bodied species such as big brown and silver-haired bats would be more active in the open understories of the harvested sites. Although red bats (*Lasiurus borealis*) emit medium to high level frequency calls, they are large-bodied and have been found to frequent recently harvested areas, (Ford et al. 2005, Jung et al. 1999, Menzel et al. 2002), therefore it was predicted that this species would be detected more in the harvested areas. Finally, it was expected that the larger bodied bats, such as big brown and silver-haired bats would exhibit high levels of activity within the more open understories of the 50% retention harvest compared to the 70% retention harvest.

4.2 Methods

Study Area Description and Site Selection

Two oak-hickory forests, one located within Richland Furnace State Forest, Jackson County, Ohio (39˚10'N latitude, 82˚36'W longitude) and the second in Zaleski State Forest, Vinton County, Ohio (39˚15'N latitude, 82˚23'W longitude) served as the study areas for this research (Figure 4.1). Both state forests are managed under a multi-use concept which includes management for wildlife habitat improvement, recreation, watershed management, aesthetics, and forest products. These forests, dominated by upland oak-hickory, which accounted for an average of 88.2 % of the total basal area, are the same that were studied in Chapter 3. Species consisted of chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), northern red oak (*Quercus rubra*), bitternut hickory (*Carya glabra*), and mockernut hickory (*Carya tomentosa*). The remainder is comprised of typical upland hardwood species such as red maple, American beech (*Fagus grandifolia*), black gum, and yellow poplar, most of which are shade tolerant species. The understory consists of species such as red maple, sassafras (*Sassafras albidum*), American hornbeam (*Carpinus caroliniana*), and spice bush (*Lindera benzoin*) with little to no oak regeneration.

Within each of the forest study areas, bat species activity was monitored within two different silvicultural treatments and a control. These treatments entailed two shelterwood harvests that reduced the stand stocking to 50% and 70% of full stocking (100%) (Chapter 3, Table 4.1). The retention levels were chosen by forest land managers interested in finding the best level needed to successfully regenerate oak species while still keeping in mind other management objectives, such as wildlife species needs and aesthetics. Both Zaleski and Richland Furnace study areas had one replicate of each retention level and control, totaling six 10-ha treatment sites for each forest, for a total of 12 treatment sites between both forest study areas. Harvesting took place in June 2005 through March 2006, and favored dominant and co-dominant oak in the overstory creating an open understory with canopy cover highest in the control sites where basal area was not reduced (Chapter 3).

Stand Structure

Methods used to determine stand structure and results were described in detail in Chapters 3, and will be briefly summarized here. Eight vegetation plots were located within each of the 12 treatment sites using a systematic sampling design, for a total of 96 plots at both Richland Furnace and Zaleski forest study areas. Plots were established at a distance of 60 meters (m) apart on transects located 60 m from each other and the edge of other treatment sites and uncut areas. Each vegetation plot was stratified to measure the height, height to live crown, and crown width of all woody species within the overstory, sapling layer, and understory. Vegetative measurements of the harvested sites in both study areas were obtained in June 2006 through August 2006. Control sites were measured from June through August 2005 and 2006.

Chapter 2 described in detail a method that was used to determine the amount of crown volume (m^3/ha) that existed vertically within each vegetation plot at 1-3 m, 3-6 m, 6-9 m, 9-12 m, and 12+ meters. Using this method, there was determined to be structural differences between the harvested and control sites in all predetermined strata except the 12+ m stratum (Chapter 3, Table 4.1). Between the 50% and 70% retention harvests, there was no statistical difference in volume between each of the strata. However, the mean volumes for the majority of the strata within the 50% sites were lower than the mean volume of the 70% retention harvest sites (Table 4.1). The control sites had the greatest amount of total volume as well as the greatest amount of volume in each stratum compared to the harvested sites. Within the control sites, the volume increased with increasing height, whereas in the harvested sites, volume in the 0-3 m stratum was higher than volumes of the 3-6 m and 6-9 m strata (Table 4.1). The 3-6 m and 6-9 m strata were the most changed after harvesting, undergoing reductions of 24 to 27 times less than the volume of those strata in the control sites. Chapter 3 found these strata to be highly influential in predicting the amount of overall bat activity with all species taken into account. It is important, however to determine species response to these structural volumes and if their individual capabilities based on morphology and echolocation call structure alter the influential strata and mean volumes.

Monitoring Bat Activity

The number of recorded passes (a series of bat calls) in an area was used as an indicator of the amount of bat activity. Bats will emit echolocation calls for many reasons such as communication with other bats, mother-young interactions, but most importantly, when intercepting and capturing prey (Fenton 2003). High activity rates of bats are positively correlated with aerial insect densities (Dai Fukui et al. 2006), so areas where bats achieve high rates of insect capture may be high quality habitats for bats (Vaughan et al. 1997). Therefore, the level of bat activity in various habitats can be a good indicator of habitat quality (Jones et al. 2000).

To compare bat foraging activity and species presence across the treatment and control sites, Anabat II broadband ultrasonic bat detectors (Titley Electronics, Ballina, New South Wales, Australia) were used to record echolocation calls. Because all bat species in Ohio echolocate while in flight (Griffin et al. 1960), bat detectors are an effective monitoring tool (Fenton and Bell 1981, Crome and Richard 1988, Fenton 1988, MacDonald et al. 1994, Krusic et al. 1996). In addition, acoustic monitoring is a sampling system that does not influence bat behavior or generate avoidance responses (Reynolds 2006). Species were monitored below the canopy using a passive monitoring approach during the same time frame vegetation measurements were obtained, June 2006 through August 2006.

Two of the 12 treatment or control sites were monitored simultaneously for bat activity each night. A random numbers table was used to generate a random order to determine which two of the 12 treatment of control sites were monitored in a night. After each treatment or control site had been monitored once, the process was repeated until all sites had been monitored. In general, all sites were monitored within a week of each other for each rotation throughout the season (Gehrt and Chelsvig 2003). This monitoring design ensured equal sampling effort among treatment and control sites throughout the season. If weather forced the termination of a monitoring session prematurely, those data were discarded and the site was monitored later in the same week.

Within each treatment or control site, all eight of the vegetation plots were used as monitoring stations. Monitoring stations were separated by 60 m from each other with a 60 m buffer from edges to ensure independent sampling (Menzel et al. 2002, Krusic et al. 1996). At each monitoring station, a bat detector and cassette recorder with voice-activation mode (Model no. S701, Radio Shack, Athens, Ohio, USA) was placed in a protective box at the plot center. Bat activity is highly variable and in some nights there can be high amounts of activity whereas other nights there may be little to no activity (Hayes 1997). In addition, there may be high activity at one monitoring station and no activity at another in the same night. This sampling design allowed for multiple sites to be monitored multiple nights by multiple detectors, which minimized variation in activity between nights and monitoring stations (Hayes 1997, Barclay 1999).

The protective boxes were hung from a stable pole approximately 1.5 m from the ground to reduce sound attenuation by understory vegetation. The vertical detection distance of an Anabat bat detector is estimated to be 15 m, indicating that detectors placed 1.5m above ground would sample bats flying below and within the canopy of most forest stands (Krusic et al. 1996). To maximize the detection of bat passes and minimize external noise such as wind, the bat detectors were set at sensitivity 8 and orientated at a 45 degree angle. The bat detectors were placed facing the interior of the treatment or control site. During a monitoring session, bat detectors were placed at the monitoring stations 30 min prior to sundown, and left to record for 3 hours.

Mist-netting also was conducted during June 2006 through August 2006 to provide additional species richness information by allowing for the identification of species present within the forest study areas. Certain species of bats, such as those belonging to the genus *Myotis*, are difficult to separate by their echolocation call designs alone. By capturing these bats separation of species was possible, and inferences made from acoustical monitoring data were used with a higher degree of confidence than would occur without capture data (Murray et al. 1999, O'Farrell and Gannon 1999, Gannon et al. 2003). Mist-netting was conducted 2-3 nights per week within the two forest study areas in sites other than those being monitored acoustically the same night. Treatment or control blocks were randomly selected without repetition to ensure equal sampling effort. Nets were opened at 30 minutes prior to sunset and remained open for 3 hours. Nets were checked at 5-10 minute intervals with a red filter light to reduce anxiety.

Echolocation Call Analysis and Species Identification

Tapes obtained from each monitoring session were analyzed with an Anabat V Zero Crossing Analysis Interface Module and the computer programs AnaBat6 version 6.3g and AnaLook version 4.9j (Titley Electronics, Ballina, New South Wales, Australia). Passes were identified as being composed of two or more calls (White and

Gehrt 2001) and calls separated by >1 second were counted as separate passes (Hayes 1997). Occasionally, multiple bats passed over detectors simultaneously; therefore these were partitioned and considered multiple passes (Gehrt and Chelsvig 2003).

There are several sequences of echolocation calls such as search-phase calls used to detect prey, approach-phase calls used in pursuit, and terminal used just before capture (Murray et al. 2001). Search-phase calls exhibit consistency in structure throughout the call sequence, have species specific characteristics, and are emitted most often so they are easily encountered in the field. Because of this, search-phase calls are ideal for use in species identification (Fenton and Bell 1981). Passes consisting of four or more search-phase calls of good quality were selected for species identification. Prior to selection, passes were eliminated of extraneous noise and made suitable for the process of identification by use of the filter function in Analook 4.9j. The filter function quantifies the selection of identifiable calls thereby eliminating subjectivity among researchers (Britzke and Murray 1999). Species were then identified by qualitatively examining the slope and curvature of the call, and quantitatively by evaluating the minimum and mean frequencies and duration of each call sequence. Knowledge on individual species calls was obtained from a call reference library (Gehrt and Chelsvig 2004).

Differentiating between species can be challenging due to the accuracy of detection, which can be affected by the direction the bat is facing while echolocating, the direction of the detector's microphone, attenuation, or Doppler shift (Betts 1998). Also, there are some species that share similar call structures which can lead to misclassification if care is not taken. White and Gehrt (2001) stated that multiple species of *Myotis* and pipistrelles detected in northeastern Illinois were misclassified due to their similar call structures. Betts (1998) found univariate analysis of call parameters ineffective at separating big brown bats and silver-haired bats and that experienced observers misclassified 30% of all calls by these two species. Yates and Muzika (2006) found that one method of minimizing errors in classification of recorded calls to species is to combine similar species into groups or clades. Therefore, species with similar call structures, habitat partitioning, and morphological similarities were assembled into species groups. Big brown bats and silver-haired bats formed one species group (EPLA) while members of the genus *Myotis* (little brown bat, northern long-eared bat, and Indiana bat) and eastern pipistrelles formed another group (MYPI). These groups were unique amongst others in the forest community, identification of calls was justifiable, and species were correctly classified using these groups.

Statistical Analysis

The mean number of calls per night for each species or species group was averaged across multiple nights to obtain an overall mean for all 12 of the treatment and control sites. Two factor analyses of variances (ANOVA's) with treatment and forest used as main effects and an interaction term were used to determine if species/groups activity varied among treatment and control sites, and if the pattern of variation was consistent between the two forests study areas. Tukey's multiple mean comparison was used to distinguish which means differed ($p \leq 0.05$).

Data was analyzed using Statistical Analysis Systems, 2002 (SAS) and Minitab (Minitab Release 14, 2003). Mean number of passes per species or group per site was transformed to the fourth power to meet the assumptions of normality and homogeneity of variances for the analyses (Quinn and Keough, 2002). Normality of the data was assessed by using the Anderson-Darling test for normality ($p = 0.15$) and probability plots. Homogeneity of variances was assessed using Barlett's test ($p = 0.59$) and observation of box plots. The distribution was determined to be normal with slight skewness (-0.11) and little to no kurtosis -0.79). Independence was achieved through replicates of treatment and control sites and adequate spacing between monitoring sites.

Structural volume was analyzed using the clutter method (Chapter 2). Differences in volume between the treatment and control sites and within the five predetermined strata were determined using one way analyses of variance. Tukey's multiple mean comparison was used to distinguish which means differed and significance was determined at 0.05. Assumptions of the analyses were met by log and square root transformations of the variables to meet qualifications of normality and homogeneity of variances. Normality of the variables was assessed using the Anderson-Darling test and probability tests; equal variances were determined by use of Barlett's test and examination of box plots.

To answer questions pertaining to the amount and height of structural volume that influenced individual species activity, the candidate set of a priori hypotheses used in Chapter 3 were again used. Logistic regression and Akaike's Information Criteria (AIC_c) were used to identify the most parsimonious models and predict variable importance (Burnham and Anderson 2002) for each species or species group. Predictor variables were the amount of volume (m^3/ha) in the predetermined strata levels used in the clutter method (Chapter 2), along with basal area and canopy cover. An additional set of predictor variables was created by combining and averaging together combinations of the predetermined strata (Table 4.2) to determine the necessary detail of the volume stratum. For example, the strata of 0-3 m and 3-6 m were combined to form a stratum of 0-6 m. If this stratum is adequate to explain bat activity, then it does not need to be further divided. Because canopy cover and basal area can also reflect the amount of volume within a forest, those variables were analyzed in models not containing volume strata with the exception of the global model. This was done to determine if basal area (m^2/ha) and canopy cover (%) alone were sufficient to describe species activity. For each model, the AIC_c, the difference between the model with the lowest AIC_c and the AIC_c for the *i*th model (Δ_i), and Akaike's weights (w_i) were calculated. Models with the lowest AIC_c, $\Delta_i \leq 2$, and the highest weights were considered the best approximating models. Model averaging was used to determine the importance of variables in top models with similar to identical AIC_c scores and weights (Burnham and Anderson 2002). Coefficients of the variables were then graphed to create a visual representation of the relationship. Data were analyzed using R statistical package (version 2.5.0, 2007).

4.3 Results

Bat Species Composition

Bat activity was monitored for a total of 1824 hours and 6-8 monitoring nights per treatment or control site. Of the 11,560 passes recorded, only 796 passes (6.8%) were identified to three species or species groups (red bats, big brown/silver-haired bats, and *Myotis* species (little brown bats, Indiana bats, and northern long-eared bats)/eastern pipistrelle bats). Red bats constituted 45% (358) of the total calls identified to species (Table 4.3). The species group EPLA (big brown and silver-haired bats) comprised 40% (321), and the species group MYPI (*Myotis* sp. and eastern pipistrelles) constituted 15% (117) of total calls identified to species (Table 4.3). *Myotis* sp. and eastern pipistrelles were detected in 92% of all 12 treatment and control sites, whereas red bats and the species group EPLA were detected in 67% of all sites (Table 4.3). Out of 96 monitoring stations, *Myotis* and eastern pipistrelles were detected at 39 (41%) stations. Red bats were detected at 45 stations (47%) and big brown and silver-haired bats were detected at 67 stations (70%) (Table 4.3).

Mistnetting was conducted during 14 nights from June 2006 through August 2006 for a total of 42 hours, and 47 bats captured of five different species. Of the 47 bats caught, 14 were northern long-eared myotis, 13 were red bats, 8 were eastern pipistrelles, 7 were big brown bats, and 5 were little brown bats. Nets were placed where bats were most likely to be captured. Sometimes, this was not in the harvested sites as the open understories made it very easy for bats to detect and avoid the nets. Most often nets were placed above streams with overhanging branches, or along roadways or skidder trails left from harvesting.

Species Use of Treatment and Control Sites

Red bats and the big brown and silver-haired species group were detected only in the 50% and 70% retention harvested sites. Big brown and silver-haired bats were detected in all of the monitoring stations within the harvested sites (Appendix C), whereas red bats were detected in greater numbers at fewer monitoring stations (Appendix B). The *Myotis* and eastern pipistrelle species group was detected in both retention harvests and the control sites, at all sites but one control site (Appendix D).

Red bat activity was significantly different between harvested and control sites (ANOVA; $F = 12.35$, $p = 0.004$) and was consistent between the forest study areas ($f = 2.37$, $p = 0.174$) (Table 4.4). There was no statistical difference in activity between the 50% and 70% retention harvest sites, however, 63% of red bat passes were in the 50% harvest sites compared to 37% in the 70% retention harvest sites (Table 4.4, Figure 4.2). Activity of the species group containing big brown and silver-haired bats was also significantly different between harvested and control sites (ANOVA; $F = 7.96$, $p = 0.013$) and consistent between forest study areas ($f = 0.13$, $p = 0.884$) (Table 4.4), but there was a higher percentage of passes recorded in the 70% retention harvest sites (59%) compared to the 50% sites (41%) (Figure 4.2).

There was no significant difference in the *Myotis* and eastern pipistrelle species group activity between harvested and control sites, or between the 50% and 70% retention harvest sites (ANOVA; $F= 0.92$, $p = 0.527$). However, the mean number of passes was lowest in the control sites (0.07 passes/site), and roughly equal between the two treatments. Within the 50% harvest, 0.20 passes were detected per site, and within the 70% harvest, 0.24 passes were detected per site (Table 4.4).

Response of Species to Structural Volume

The model that contained the variable ninedw (Table 4.2, Table 4.5) was the best predictor for red bat activity within the harvested sites ($w_i = 0.34$). The only other model that had $\Delta_i \leq 2$ was the model containing the variables ninedw and TWLPV (Table 4.5). The worst approximating model for predicting red bat activity was TWLPV, however, this variable combined with others that represent that lower volume strata appeared higher up in the model set. Models containing the variables basal area and canopy cover appear lower down in the model set as did the global model (Table 4.5).

Model averaging was calculated for variables ninedw and TWLPV and the coefficients were graphed to determine levels of declining red bat activity (Figure 4.3). For both these variable, there was a negative relationship between the amount of volume and the probability of detecting a red bat. For the variable ninedw, when structural volume between 0 and 12 m is at zero, there is a 30% chance of detecting a red bat (Figure 4.3). When the volume within that height stratum increases to 1500 m^3/ha, the chance of detecting a red bat pass decreases by 50%. At 4000 m^3/ha, there is no chance of detecting a red bat (Figure 4.3). The graph representing the variable TWVLP is less descriptive than that of ninedw, but still represents a decline in red bat detection rates as structural volume increases (Figure 4.3).

The best approximating model for predicting activity of the species group containing big brown and silver-haired bats contained the variable SIX, which represents the structural volume within 3-6 m. This model had the highest w_i of 0.54 and was the only one with $\Delta_i \leq 2$ (Table 4.6). This variable was consistently present in the top models signifying its importance. Once again, the model with the lowest Akaike's weight contained the variable TWLVP. Models that were higher up in the red bat model analysis were lower in the big brown and silver-haired bat model analysis; however, the best approximating model for both represents the understory to mid-canopy volume strata (Table 4.6).

The variable SIX was graphed and its influence ascertained using model averaging. The graph shows a very negative relationship between big brown and silver-haired bat detection and the amount of volume present within 3-6 m (Figure 4.4). At a volume of zero, there is approximately a 65% chance of detecting a big brown or silver-haired bat (Figure 4.4). The probability of detection declines by 50% at a slight increase of volume to 100 m^3/ha. At 250 m^3/ha, the probability of detecting a big brown or silver-haired bat drops to zero (Figure 4.4).

The species group of *Myotis* sp. and eastern pipistrelle bats was not sensitive to the predictor variables. The presence of the null model as the second best approximating model indicates this (Table 4.7). Also, the fact that the models are declining according to the amount of variables within in them also signifies an insignificant relationship between the variables and activity of *Myotis* and eastern pipistrelle bats (Table 4.7).

4.4 Discussion

It was hypothesized that species-specific activity would be predictable based on differences in morphology, described by aspect ratios and wing loadings, and echolocation call design. Except for *Myotis* species and eastern pipistrelles, the remaining species were distributed among measures of structural volume as their body size and echolocation call design would indicate. Big brown and silver-haired bats have high wing loadings and aspect ratios making them equipped for faster flight in open habitats, such as the retention harvest sites. Their echolocation call structure is based on low frequency calls that travel longer distances in the open habitats they prefer to forage in. Results of this research found that big brown and silver-haired bat were detected most in the open understories of the retention harvest sites and not in the highly cluttered control sites. Similarily, Brooks and Ford (2005) found activity of big brown bats to be high in open habitats and low in closed canopy sites. Silver-haired bats have been found to prefer large diameter trees and open understories within cut stands, and were detected more in stands with these characteristics than unlogged stands (Jung et al. 1999).

The model analysis for the big brown and silver-haired bat species group identified the volume height strata of 3-6 m to be very influential in predicting detection of these species. This height stratum is one of two strata that were most reduced by harvesting. The other stratum was 6-9 m which also appeared higher up in the model set for the big brown and silver-haired bat species group. The probability of detecting a big brown or silver-haired bat declined by 50% at a volume of 100 m^3/ha. Within both retention harvests, the volume of the 3-6 m stratum was well below 100 m^3/ha, however, the volume for this stratum in the control sites was greater at 1028 m^3/ha. The sharp decline of the graph indicates that very little increase in the volume within this height stratum will result in low detection probabilities of big brown and silver-haired bats. These results coincide with big brown and silver-haired bats preferring habitats with open understories, represented here by the 3-6 m height stratum, and will avoid areas with high amounts of structural volume. As the amount of volume within the understory increases to over 250 m^3/ha, big brown and silver-haired bats will not be detected, just as they were not detected in the control sites.

Like big brown and silver-haired bats, red bats also have high aspect ratios and wing loadings suggesting a preference towards open habitats (Aldridge and Rautenbach 1987). Unlike big brown and silver-haired bats, red bats have relatively high frequency calls which would aid in foraging in cluttered habitats. Previous literature, however, has detected high amounts of red bat activity within recently harvested areas (Menzel et al. 2002, Ford et al. 2005). Jung et al. (1999) found selectively logged sites to be important foraging habitat for red bats, and Elmore et al. (2005) detected high amounts of red bat activity within the open canopies of intensively managed pine stands. Therefore, this study hypothesized that red bats would be detected more in the 50% and 70% retention sites than the control sites due to their morphology rather than their echolocation call structure. This was supported by high numbers of passes within the harvested sites, and no recorded passed within the control sites.

Elmore et al. (2005) found that red bats are fast fliers and concentrate foraging activity from below tree top level down to only inches above the ground. This would suggest that the more open the understory to mid-canopy is, the easier it will be for these fast fliers to forage. The model analysis for red bats found the height stratum that was most influential on red bat activity was from 0-12 m. This stratum would encompass all volume present within the forest from below the canopy to inches above the ground. The graph displaying the relationship between red bat activity and volume in the ninedw stratum displayed that when understory volume is around 1500 m^3/ha, the chance of detecting a red bat declines by 50%. Within the 50% retention harvest sites the average volume for 0-12 m was 267.9 m^3/ha, and for the 70% retention harvest sites the volume was slightly higher at 295 m^3/ha. Both harvests had volumes within this height stratum low enough to detect red bats. The control sites, however, had a volume of 2203 m^3/ha. This indicates that within the control sites, the chance of detecting a red bat declines by over 60%. At 4000 m^3/ha, there is no chance of detecting a red bat. The understory volume in the control is not above 4000 m^3/ha, which indicates there is a low chance of detecting bats within the control sites.

The variable ninedw encompasses the two height stratum that were most reduced after harvesting again reflecting the importance of general understory volume reduction to bats with high aspect ratios and wing loadings. On the other hand, the model analysis for red bats also found the height stratum TWLVP to be influential in predicting activity. However, when the coefficient was graphed, the relationship depicted was close to a straight line which indicated little influence on red bat activity. When this variable was graphed alone without the influence of the variable ninedw, the resulting relationship was a steady decrease in the probability of detecting a red bat as the amount of volume increased. This suggests that when this variable is included within the same model as ninedw, its influence is lessened compared to ninedw. The height stratum 12+ m did appear in several other top models and again represents the preference of red bats to habitats with less structural volume and canopy cover.

Unfortunately, the analysis for *Myotis* sp. and eastern pipistrelles was not very conclusive. This species group proved ubiquitous, occurring in both the retention harvest sites as well as the control sites. Species detection rates were not responsive to the volumes in the predetermined or averaged height strata. Perhaps the inclusion of additional forest characteristics such as average diameter and number of snags would create a more successful model to predicting small-bodied bat activity. The hypothesis that species with low wing loadings and aspect ratios prefer cluttered habitats was not supported by this research. In fact, when looking at the mean number of passes per treatment and control site, *Myotis* sp. and eastern pipistrelles were detected more within the harvested sites than the control sites. This could be due to eastern pipistrelle and little brown bat's generalist nature. Eastern pipistrelles have been found foraging in a wide range of land types including harvested and unharvested forest stands (Menzel et al. 2002, Vaughan et al. 1997). Ford et al. (2005) also found little brown bats and eastern pipistrelles absent from areas of high structural volume and favoring habitats with openings, indicating that prey abundance influences more than morphological adaptations would suggest. The open understories and canopies of the 50% and 70% retention harvest sites may have provided these species with a less energetically expensive opportunity to forage.

Even though activity of the *Myotis* and eastern pipistrelle species group was higher in the harvested sites, it was still the only species/group detected within the control sites. This could be due to northern long-eared bats, a species that prefers structurally cluttered habitats and has been found to be related to greater canopy cover and higher tree densities (Jung et al. 1999, Ford et al. 2005). Other *Myotis* species as well as eastern pipistrelles and red bats have been found to forage in cluttered habitats; however, very little activity overall was detected within the control sites. This suggests that the control sites within these forests of southern Ohio may be too cluttered for the majority of species living there. However, there has been recent research indicating bats with high aspect ratios and wing loadings have been detected within and above the canopy of cluttered habitats (Menzel et al. 2005). It is a possibility that there was activity occurring above the canopy in the control sites, but was unable to be detected by below canopy monitoring. This should be taken into consideration and studies that include monitoring at heights within the upper canopy and above should be implemented (Menzel et al. 2005).

When comparing species activity between the two harvests sites, there were no statistical differences within any of the species between retention harvest treatments. It was expected that species with high aspect ratios and wing loadings would prefer the 50% retention harvest sites due to lower levels of structural volume than the 70% retention harvest sites. Harvesting down to 70% of the original basal area did create more structural volume within the understory to mid-canopy. The difference, however, was not great enough to detect significant changes in species preferences between the two treatments. When looking at mean number of passes alone between the two sites, the *Myotis* species and eastern pipistrelle group was approximately equal. Red bats had a higher mean number of passes within the 50% retention harvest sites than big brown bats. This could again be attributed to red bats use of the forest from the understory up through the canopy, as reflected in the model analysis as 0-12+ m being most influential in predicting red bat presence. The 50% retention harvest had the least amount of structural volume from the top of the canopy down to inches above the ground.

Big brown and silver-haired bats had a greater mean number of passes within the 70% retention harvest sites than the 50% harvest sites. Looking through the data on a plot by plot basis, this could be attributed to a high number of calls on one specific plot within a 70% retention harvest site. This specific plot had only 3 overstory trees, compared to an average of 8 overstory trees per plot, and relatively no understory. This resulted in a low amount of structural volume for this plot compared to other plots within the area. This could be the reason for the high levels of big brown and silver-haired activity within the 70% retention harvests. A nearby roost tree could be another possible explanation for the high activity within this plot. The fact that the big brown and silver-haired bat group was detected in 92% of the retention harvest sites suggests that overall, these species were frequently and consistently using these habitats.

Overall, the quantity of passes identified to species was low compared to previous literature. Gehrt and Chelsvig (2004) identified 73% of recorded passes, while Ford et al. (2005) identified 80% of total recorded passes. Anabat II bat detectors coupled with tape recorders have been found reliable when used to assess foraging activity patterns of overall bat activity without separating species (Gehrt and Chelsvig 2003, O'Farrell and Gannon 1999). The majority of passes recorded within both the harvested and unharvested sites in this study, however, lacked the structure and clarity needed to be separated by species. Because of this, and previous research found on the difficulties of distinguishing certain species calls (Betts 1998, White and Gehrt 2001), a rigorous filtering system was used to identify those passes suitable for identification. It is the author's belief that accurate and precise identification of fewer passes is far superior to identification of many passes made without complete certainty. For future research interested in identifying species, it is recommended that systems other than tape recorders be coupled with Anabat II detectors, such as CF-ZCAIM data storage units or a laptop computer. These systems have been show to record calls of high quality (Johnson et al. 2002).

Despite the low number of identifiable passes, those passes that were identified were consistent with species captured in mistnets. Hoary bats were not caught or identified to species despite the fact that this species has been detected in temperate forest of this region in previous studies (Ford et al. 2005, Gehrt and Chelsvig 2004). Within the harvested areas, there were some passes that had a low enough frequency to possibly be from a hoary bat, but the call structures were of poor quality. Kalcounis et al. (1999) found hoary bat activity to be higher above than within the forest canopy. As mentioned before, above canopy activity was not monitored in this study and its occurrence should not be overlooked.

4.5 Management Implications

Bats of southern Ohio are quickly gaining recognition as an important fauna within the community. Forest managers interested in silvicultural prescriptions aimed at community restoration are faced with the challenge of considering all organisms' needs and life requirements. This study has investigated at bat species responses to retention harvests implemented to restore oak seedlings to the forest community. The results show that a matrix of habitats at different levels of structural volumes is preferred, and that no single structure or volume is optimal for all bat species. A combination of dense hardwood, open understories, and thinned canopies were ideal and were used most intensively by the bats of this area. Further recommendation would include examination of various patch sizes of retention harvests, as well as the surrounding landscapes effect of species needs.

This study attempted to answer questions about the amount and height of structural volume, i.e. clutter, where species activity was negatively or positively influenced. The amount and height of structural volume was dependent on species, however, additional research is required on small-bodied bats. Placement of detectors at different heights throughout the understory and canopy would also provide addition insight into foraging patterns of these species. This research provided valuable insight into foraging activity of several northeastern bat species living in oak-hickory forests of southern Ohio and can further serve as a template for additional studies involving vertical monitoring and telemetry.

4.6 Caveats

There has been much debate on the most effective, rigorous, and accurate method of acoustic species identification (O'Farrell 1999, Barclay 1999). Inability to correctly identify species can lead to management decisions based on limited and inaccurate information. The method used in this study was predominately qualitative supported by information from reference call libraries. A rigorous and highly conservative approach at selecting calls for analysis, as well as grouping species as suggested by Yates and Muzika (2006) yielded successful identification of call sequences. Had a less conservative approach be taken, and species identified individually as opposed to groups, there may have been an increase in the number of passes to be analyzed, but at the cost of misclassified calls, which would have been unacceptable.

Despite attempts made to limit sources of bias by standardizing monitoring protocol and sampling in replicate areas as well as multiple nights, habitat characteristics were nonetheless greatly different between treatment and control sites which could lead to potential differences in probability of detection. Because the amount of clutter influences the call structure of certain species, care must be made evaluating data under these situations. Therefore, levels of bat activity were not compared across species within similar habitats, but effects of different habitats on each individual species were evaluated.

Also, limitations of acoustical surveying such as the inability to distinguish between sexes, which could provide information on habitats containing maternity colonies, is a bias that may never be overcome. With temporal biases, however, adjustments can be made. The focus on summer activity may present an incomplete picture of habitat use by bats in respect to migratory species such as silver-haired bats, which are more common in spring and early fall. Research has also found that the endangered Indiana bat's foraging activity shifted to forested habitats in the early to mid-fall (Kiser and Elliot 1996). Monitoring surveys should be adapted to include monitoring in spring and continuing throughout fall.

In addition, recent literature has indicated that above-forest canopy activity in upland sites for large-bodied bats can be considerably higher than that of below canopy activity. This could potentially lower the value of upland forest sites, such as the control sites in this study, to bat populations and considerations should be made in the future concerning monitoring at various heights throughout and above the canopy.

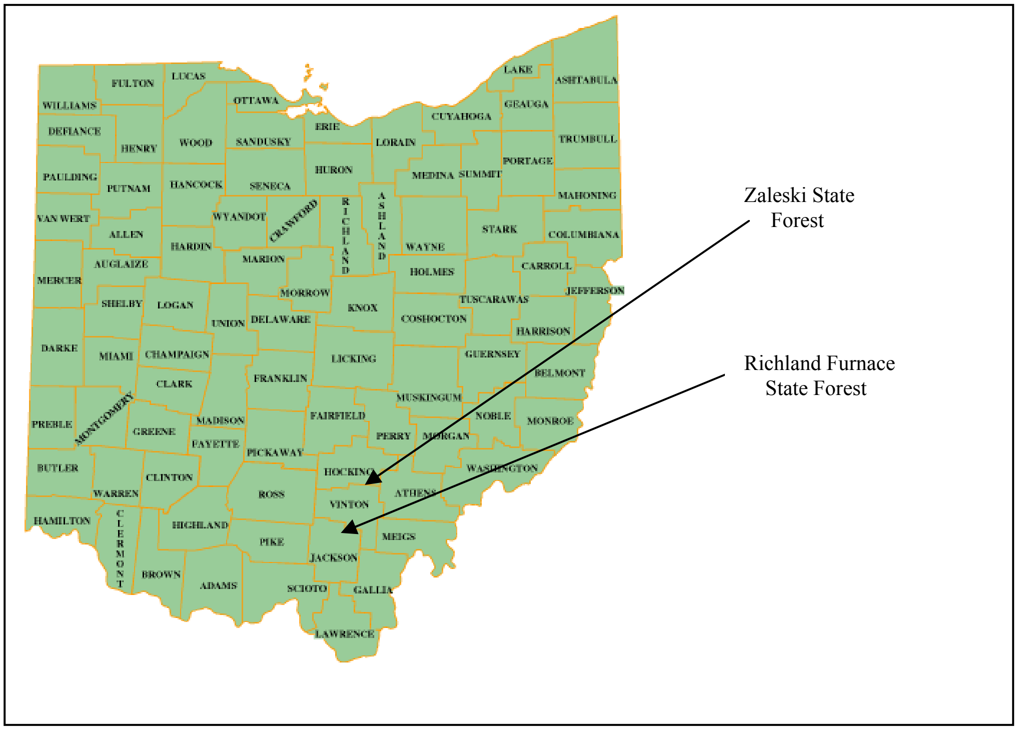

Figure 4.1: Location of oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio.

	50% Retention (n = 4)		70% Retention (n = 4)		Control (n = 4)		ANOVA[a]	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**F**	**P**
Basal Area (m^3/ha)	12.99A	0.34	17.42B	0.67	24.70C	1.23	50.53	0.0001
Canopy Cover (%)	64.08A	1.90	75.03A	3.80	92.63B	3.21	20.96	0.0004
Volume Strata								
0-3m	117.48A	26.20	123.31A	14.40	443.68B	73.30	16.98	0.0009
3-6m	28.36A	17.80	45.87A	34.60	1028.63B	289.00	12.65	0.0024
6-9m	105.45A	65.50	35.17A	18.20	1713.02B	554.00	6.90	0.0153
9-12m	820.33A	475.00	975.55A	366.00	5626.58B	1341.00	10.39	0.0046
12+m	21,001.24A	3587.00	30,629.65AB	3763.00	41,596.78B	6748.00	4.39	0.0467
TOTAL	22,072.85		31,809.56		50,408.69			

[a] 1-way ANOVA across 2 treatments and control

Table 4.1: Structural characteristics for oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006. Mean values followed by the same letter are not significantly different across rows (Tukey's, p > 0.05, means and SE are from untransformed data).

Variable	Definition
ba	Basal area (m^2/ha)
cc	Canopy cover (%)
	Volume (m^3/ha) in stratum:
TRI	0-3m
SIX	3-6m
NINE	6-9m
TWLV	9-12m
TWLP	12+m
	Average volume (m^3/ha) in strata:
tridw	0-3m and 3-6m
triup	3-6m, 6-9m, 9-12m, and 12+m
sixdw	0-3m, 3-6m, and 6-9m
sixup	6-9m, 9-12m, and 12+m
ninedw	9-12m and 12+m
nineup	0-3m, 3-6m, 6-9m, and 9-12m
sixm	3-6m and 6-9m
ninem	6-9m and 9-12m

Table 4.2: Variables measured and used in regression analysis at bat monitoring sites located in Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio during June 2006 through August 2006.

Species	Passes	Sites (%)	Stations (%)
Lasiurus borealis	358	8 (67)	45 (47)
Eptesicus fuscus/Lasionycteris noctivagans	321	8 (67)	67 (70)
Myotis spp./Pipistrellus subflavus	117	11 (92)	39 (41)

Table 4.3: Number of passes identified to species, and the number of treatment or control sites and monitoring stations at which at least one pass was identified to species, during monitoring conducted from June 2006 through August 2006 in Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio.

Species	Control (n =4)		50% Retention (n = 4)		70% Retention (n = 4)		ANOVA[a]	
	Mean	SE	Mean	SE	Mean	SE	*F*	P
LABO[b]	0.00A	0.00	1.09B	0.79	0.60B	0.32	12.35	0.004
EPLA[c]	0.00A	0.00	0.64B	0.11	0.82B	0.51	7.96	0.013
MYPI[d]	0.07A	0.04	0.20A	0.10	0.24A	0.18	0.92	0.527

[a] 1-way ANOVA across 2 treatments and control
[b] *Lasiurus borealis*
[c] *Eptesicus fuscus/Lasionycteris noctivagans*
[d] *Myotis spp./ Pipistrellus subflavus*

Table 4.4: Species activity (mean passes/site) compared across treatment and control sites (n=12) on oak-hickory forest sites located at Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected from June 2006 through August 2006. Species means followed by the same capital letter are not significantly different across treatments and control (Tukey's, p > 0.05, means and SE are from untransformed data).

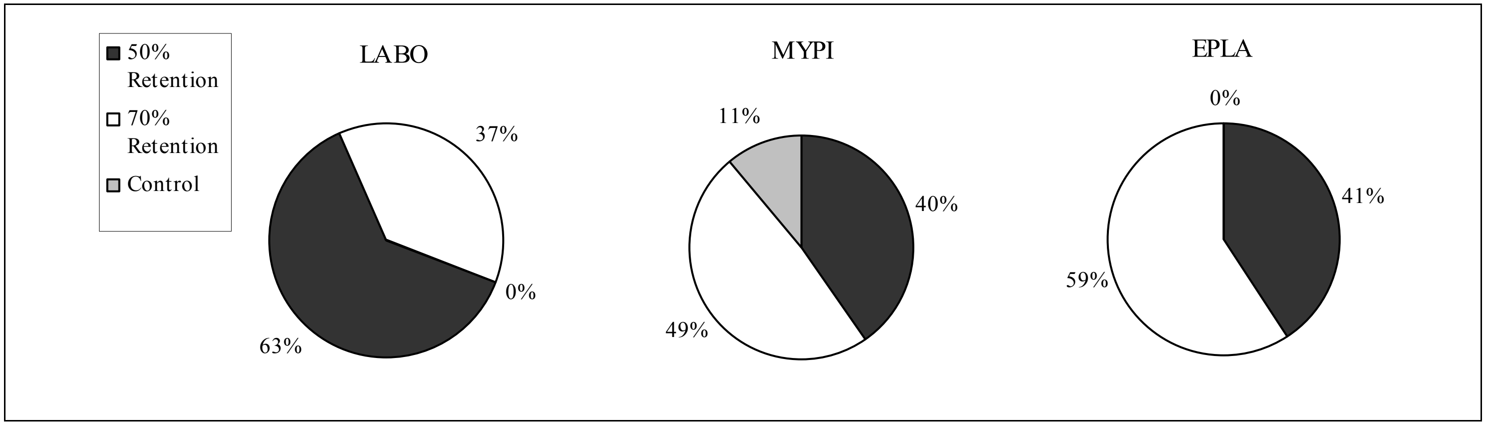

Figure 4.2: Comparison of total number of passes of red bats (LABO), *Myotis* sp. and eastern pipistrelle bats (MYPI), and big brown and silver-haired bats (EPLA) among 50% and 70% retention harvest and control sites recorded during June through August 2006 in oak-hickory forests located in Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio.

Model	k	AICc	Δ_i	w_i
ninedw	2	99.99	0.00	0.34
TWLVP + ninedw	3	101.85	1.86	0.13
sixdw	2	102.16	2.17	0.11
TWLVP + ninem + tridw	4	102.75	2.76	0.09
TWLVP + TWLV + sixdw	4	103.13	3.13	0.07
nineup + sixdw	3	103.22	3.22	0.07
tridw	2	104.43	4.44	0.04
sixup + tridw	3	104.95	4.95	0.03
nineup + sixm + TRI	4	105.26	5.27	0.02
nineup + NINE + tridw	4	105.36	5.36	0.02
SIX	2	106.01	6.02	0.02
TRI + SIX + NINE	4	106.18	6.19	0.02
TRI + SIX	3	106.42	6.43	0.01
TRI	2	107.10	7.11	0.01
triup + TRI	3	107.64	7.65	0.01
ba	2	108.40	8.40	0.01
ba + cc + TRI + SIX + NINE + TWLV + TWLVP	8	110.29	10.30	0.00
ba + cc	3	110.53	10.53	0.00
totalv	2	113.14	13.14	0.00
nineup	2	114.23	14.24	0.00
TWLVP	2	116.15	16.16	0.00
Null model	1	117.94	17.95	0.00

Table 4.5: Number of estimated parameters (k), small sample Akaike's Information Criteria (AIC_c), difference between model AIC_c and that of the best model (Δ_i), and Akaike's weight (w_i) for logistic regression models to predict red bat (*L.borealis*) response to forest structure and volume data collected from Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

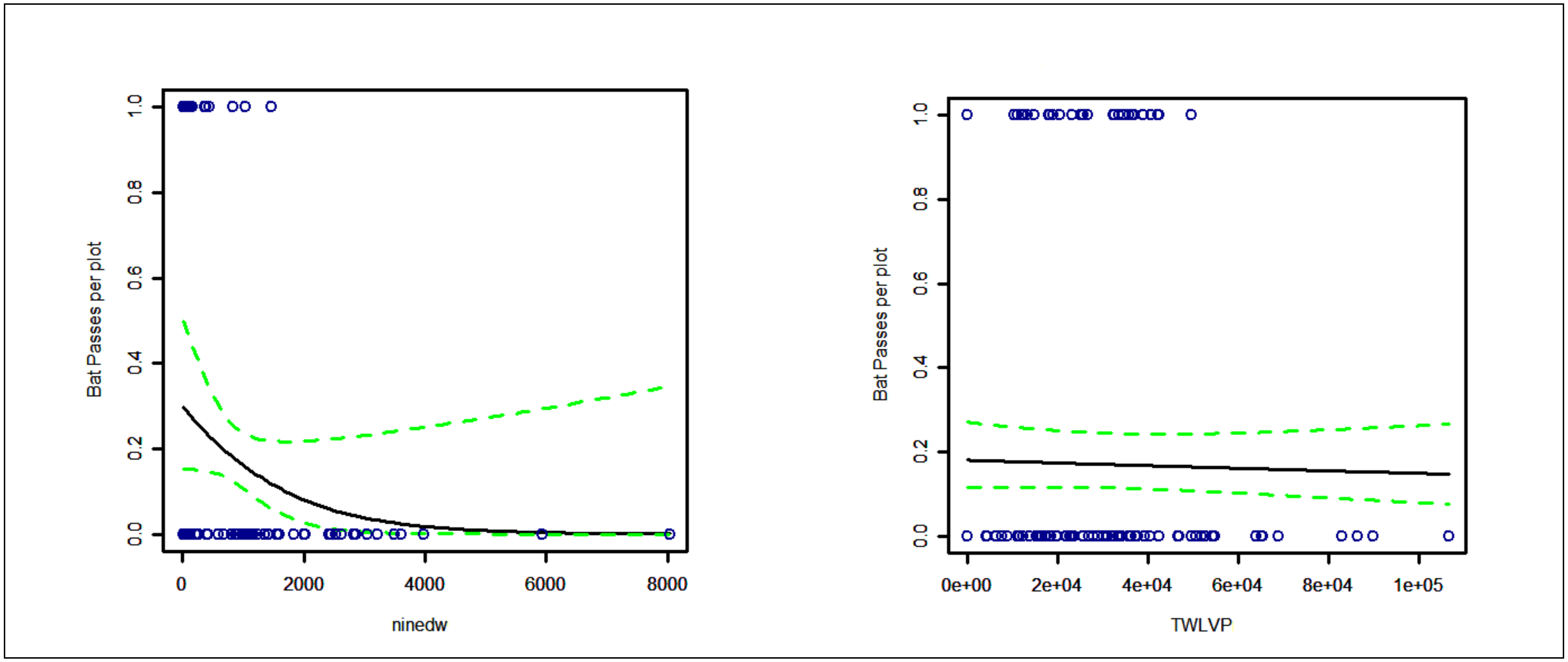

Figure 4.3: Results of model averaging of variable ninedw (0-12 m) with probability of red bat (*L. borealis*) passes per plot on the y-axis, and volume (m^3/ha) on the x-axis. Confidence intervals set at 95% are represented by the green dashed lines. Data were collected from Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

Model	k	AICc	Δ_i	w_i
SIX	2	80.31	0.00	0.54
TRI + SIX	3	82.45	2.13	0.19
TRI + SIX + NINE	4	83.26	2.95	0.12
sixdw	2	84.81	4.49	0.06
nineup + sixdw	3	86.48	6.17	0.02
ba + cc + TRI + SIX + NINE + TWLV + TWLVP	8	86.62	6.31	0.02
nineup + NINE + tridw	4	88.12	7.81	0.01
nineup + sixm + TRI	4	88.35	8.03	0.01
TWLVP + TWLV + sixdw	4	88.56	8.25	0.01
tridw	2	89.28	8.97	0.01
sixup + tridw	3	90.61	10.29	0.00
TWLVP + ninem + tridw	4	91.28	10.97	0.00
ba + cc	3	96.01	15.69	0.00
ninedw	2	103.74	23.43	0.00
TWLVP + ninedw	3	105.43	25.12	0.00
TRI	2	105.53	25.21	0.00
triup + TRI	3	105.87	25.56	0.00
ba	2	106.44	26.13	0.00
totalv	2	124.63	44.32	0.00
nineup	2	126.92	46.61	0.00
TWLVP	2	129.77	49.45	0.00
Null model	1	134.08	53.77	0.00

Table 4.6: Number of estimated parameters (k), small sample Akaike's Information Criteria (AIC_c), difference between model AIC_c and that of the best model (Δ_i), and Akaike's weight (w_i) for Gaussian regression models to predict big brown (*E. fuscus*) and silver-haired (*L. noctivagans*) bat response to forest structure and volume data collected from Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

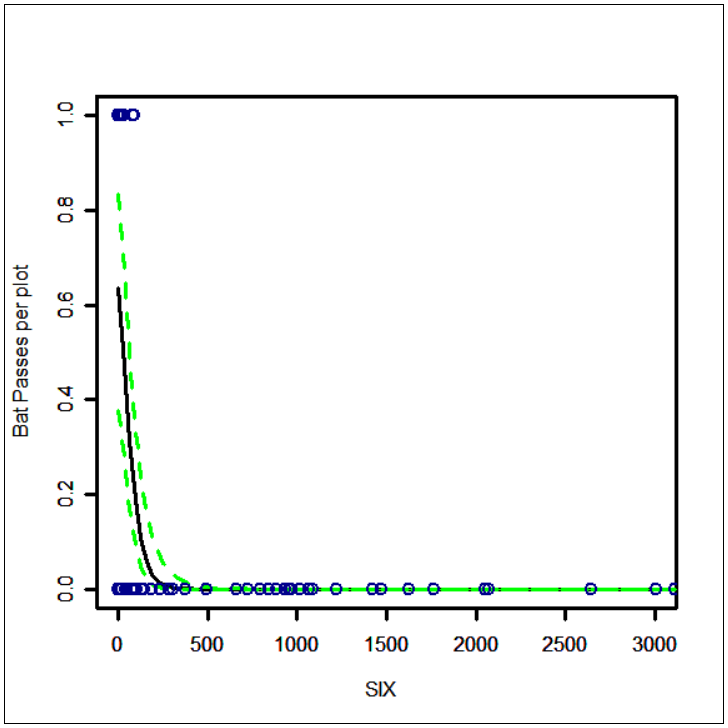

Figure 4.4: Results of model averaging of variable SIX (3-6 m) with probability of big brown (*E. fuscus*) and silver-haired (*L. noctivagans*) bat passes per plot on the y-axis and volume (m^3/ha) on the x-axis. Confidence intervals set at 95% are represented by the green dashed lines. Data were collected from Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

Model	k	AICc	Δ_i	w_i
ba	2	123.76	0.00	0.17
Null model	1	124.25	0.49	0.13
tridw	2	125.46	1.70	0.07
ba + cc	3	125.47	1.71	0.07
SIX	2	125.55	1.79	0.07
TRI	2	125.57	1.81	0.07
sixdw	2	125.85	2.09	0.06
totalv	2	126.05	2.29	0.05
TWLVP	2	126.07	2.31	0.05
nineup	2	126.10	2.34	0.05
ninedw	2	126.22	2.46	0.05
TRI + SIX	3	127.55	3.79	0.03
sixup + tridw	3	127.56	3.80	0.02
triup + TRI	3	127.68	3.92	0.02
nineup + sixdw	3	127.92	4.16	0.02
TWLVP + ninedw	3	128.18	4.42	0.02
TWLVP + ninem + tridw	4	129.32	5.56	0.01
nineup + NINE + tridw	4	129.54	5.78	0.01
TWLVP + TWLV + sixdw	4	129.59	5.83	0.01
TRI + SIX + NINE	4	129.60	5.84	0.01
nineup + sixm + TRI	4	129.85	6.09	0.01
ba + cc + TRI + SIX + NINE + TWLV + TWLVP	8	135.87	12.11	0.00

Table 4.7: Number of estimated parameters (k), small sample Akaike's Information Criteria (AIC_c), difference between model AIC_c and that of the best model (Δ_i), and Akaike's weight (w_i) for Gaussian regression models to predict *Myotis sp*. and eastern pipistrelle (*P. subflavus*) bat response to forest structure and volume data collected from Richland Furnace State Forest, Jackson County, Ohio and Zaleski State Forest, Vinton County, Ohio collected during June 2006 through August 2006.

CONCLUSION

Bats are now recognized as an important component of forest ecosystems and their needs are increasingly incorporated into forest management plans. Information on species habitat relationships is needed for sound management decisions. In the eastern temperate forests of Ohio, community restoration is a top priority on many managers' lists. They are implementing silvicultural practices that alter the forest structure in ways that can influence a number of wildlife species. This research has examined the effects of retention harvests aimed at regenerating oak species on bat populations in southern Ohio oak-hickory forests.

The overall response of the bat population to these harvests was positive. Activity rates were much higher in harvested versus unharvested areas. Between the two harvests, there was no difference in the amount of bat activity suggesting the preferred treatment for restoring oak species be determined by the success of oak regeneration. Bats generally preferred a less cluttered, open understory for ease of flight and prey capture. They responded most to a decrease in structural volume within 0-6 meters (m), and were not present in areas of the forest where that volume exceeded approximately 150 cubic meters per hectare (m^3/ha).

Examination of individual species also displayed a preference to the retention harvests. Big brown (*Eptesicus fuscus*), silver-haired (*Lasionycteris noctivagans*), and red bats (*Lasiurus borealis*) were detected most in habitats suited to their morphology and echolocation call design. *Myotis* species (*Myotis sp*.) and eastern pipistrelles (*Pipistrellus subflavus*) displayed a more generalist nature, suggesting an appreciation for multiple habitats. Individual species responded differently, however to volume at different heights up through the canopy. Big brown and silver-haired bats were strongly influenced by the understory height strata of 3-6 m. In areas with volumes slightly higher than 100 m^3/ha in this stratum, activity rates decreased sharply. Red bats were not influenced by a single stratum, but mostly by the entire understory to mid-canopy volume, from 0-12 m. As this volume approached 1500 m^3/ha, activity rates for this species declined.

The height strata used in the model analysis were chosen in order to determine the level of detail needed to measure volume within the forest when compared to bat activity. The analysis of overall bat activity, as presented in Chapter 3, did not indicate a level of detail, since both averaged volume strata variables (i.e. tridw) and single stratum variables (i.e. SIX) were present in top models. Red bats general preference for an open understory was reflected in the ninedw height stratum. This suggests that it is not necessary to measure volume throughout the canopy in 3 m intervals such as 0-3 m, 3-6 m, and 6-9 m, but in a single stratum capturing the average understory to mid-canopy volume. With the species group containing big brown and silver-haired bats, the top model and successive models all contained single stratum variables, indicating that when looking for clutter influences on big brown or silver-haired bats, a more detailed approach is needed to measure volume.

In conclusion, the bat population in these southern Ohio oak-hickory forests gained quality foraging habitat from the retention harvests, however, certain species are well adapted for areas with higher amounts of structural volume, such as northern long-eared bats (*Myotis septentrionalis*) and these habitats should also be considered important. In addition to northern long-eared bats, species with high aspect ratios may also use unharvested areas for roosting sites; therefore a matrix of habitats is needed to support a healthy bat community. This study has provided significant insight into the foraging activity of several northeastern bat species, but can also serve as a template for future studies involving telemetry to gain more information on the roosting habits of these species. In the future, it is the hope of the author that this information can be used by forest managers to determine how changes in structural volume due to silvicultural practices outside of retention harvests influence the bat species present within the forest ecosystem. If the level of volume within the forest can be determined, then forest managers will already have a general idea on how bat species will respond without having to complete extensive monitoring. With additional information on the vertical distribution of bat species throughout the forest paired with information obtained by this research, perhaps some of the gaps in the knowledge of bats responses to forest management prescriptions can be bridged.

APPENDIX A

TOTAL ACTIVITY BY PLOT

ZA [a]70[b]1[c]	6/14/07	6/27/06	6/30/06	7/8/06	7/20/06	8/1/06	8/22/06
plot 1	34	2	14	30	190	41	16
plot 2	33	20	9	121	27	45	122
plot 3	18	12	16	61	88	15	11
plot 4	79	0	25	26	83	5	0
plot 5	2	5	1	1	0	13	34
plot 6	15	0	10	87	12	4	0
plot 7	0	2	0	0	9	5	15
plot 8	2	29	2	18	73	16	119

ZA702	6/8/06	6/20/06	7/26/06	7/28/06	8/9/06	8/15/06	8/23/06
plot 1	2	1	22	9	11	0	2
plot 2	4	16	7	1	2	4	36
plot 3	9	0	4	35	12	6	19
plot 4	2	0	13	0	13	5	4
plot 5	6	0	2	0	37	1	8
plot 6	5	4	17	6	85	8	15
plot 7	20	3	15	1	15	1	45
plot 8	19	6	34	6	156	30	97

ZA503	6/5/2006	6/20/2006	7/6/2006	7/10/2006	8/1/2006	8/25/2006
plot 1	30	3	3	46	17	64
plot 2	12	1	0	23	0	0
plot 3	6	2	4	107	43	85
plot 4	48	0	3	3	16	33
plot 5	16	4	5	27	47	10
plot 6	11	1	1	2	0	11
plot 7	11	2	0	7	8	25
plot 8	74	35	1	17	8	157

ZA504	6/14/2006	6/30/2006	7/8/2006	7/28/2006	8/9/2006	8/21/2006	8/22/2006
plot 1	40	0	6	8	0	0	1
plot 2	29	7	2	16	4	2	1

plot 3	13	11	2	6	58	0	0
plot 4	2	0	0	2	13	0	0
plot 5	4	0	0	1	0	4	1
plot 6	170	18	32	11	126	127	239
plot 7	3	8	10	16	7	0	63
plot 8	42	0	20	9	20	8	9

ZACON	**6/13/2006**	**6/27/2006**	**7/10/2006**	**7/26/2006**	**8/11/2006**	**8/21/2006**
plot 1	0	5	0	2	0	0
plot 2	0	2	0	14	1	0
plot 3	0	0	0	0	0	0
plot 4	3	0	0	0	0	0
plot 5	0	0	0	0	0	0
plot 6	2	0	9	0	0	0
plot 7	0	0	5	7	7	5
plot 8	4	1	10	20	20	4

ZACON2	**7/18/2006**	**7/20/2006**	**8/11/06**	**8/15/06**	**8/23/06**	**8/25/2006**
plot 1	6	0	13	0	0	0
plot 2	0	13	0	3	0	0
plot 3	35	20	0	0	0	0
plot 4	34	14	0	2	0	0
plot 5	0	0	0	0	0	0
plot 6	13	0	0	0	0	7
plot 7	2	54	0	0	0	0
plot 8	26	94	0	0	2	0

RF501	**6/21/2006**	**7/19/2006**	**7/24/2006**	**7/31/2006**	**8/10/2006**	**8/26/2006**
plot 1	9	72	34	6	1	3
plot 2	32	8	5	9	38	9
plot 3	0	6	67	10	13	14
plot 4	1	0	28	0	2	4
plot 5	3	63	14	8	6	1
plot 6	112	10	132	9	3	4
plot 7	32	24	312	221	162	4
plot 8	177	9	125	147	0	125

RF502	**6/12/2006**	**6/15/2006**	**7/24/2006**	**7/27/2006**	**8/10/2006**	**8/16/2006**
plot 1	10	4	26	8	0	44
plot 2	12	10	78	70	0	76
plot 3	15	2	17	33	5	1
plot 4	83	0	32	85	23	20
plot 5	3	56	85	69	2	6
plot 6	6	0	8	6	6	53
plot 7	2	3	42	13	0	98
plot 8	5	16	31	30	8	21

RF703	6/6/2006	6/26/2006	7/17/2006	7/27/2006	8/8/2006	8/18/2006	
plot 1	57	0	56	35	15	109	
plot 2	12	0	7	2	0	16	
plot 3	5	3	28	38	15	85	
plot 4	7	1	38	0	1	21	
plot 5	9	3	3	0	1	22	
plot 6	5	3	30	6	26	7	
plot 7	5	0	0	0	0	8	
plot 8	17	0	9	10	4	0	

RF704	6/15/2006	6/28/2006	7/9/2006	7/19/2006	8/2/2006	8/18/2006	8/24/2006
plot 1	5	8	52	15	35	45	0
plot 2	126	61	65	117	143	0	5
plot 3	16	4	29	34	15	13	0
plot 4	36	0	27	106	189	54	14
plot 5	0	2	17	2	2	22	5
plot 6	17	56	35	223	112	1	218
plot 7	0	1	10	0	2	45	15
plot 8	15	4	25	13	9	39	0

RFCON	6/12/2006	6/21/2006	7/9/2006	7/25/2006	7/31/2006	8/16/2006	8/24/2006
plot 1	77	0	12	13	0	0	5
plot 2	7	0	0	10	1	2	4
plot 3	9	0	0	4	1	1	0
plot 4	0	0	0	0	1	1	0
plot 5	0	0	0	0	0	0	0
plot 6	6	7	0	2	1	0	0
plot 7	7	0	1	0	0	1	0
plot 8	16	0	9	0	0	0	0

RFCON2	7/17/2006	7/25/2006	8/2/2006	8/8/2006	8/26/2006
plot 1	0	1	0	0	0
plot 2	3	9	0	1	0
plot 3	1	0	2	0	1
plot 4	0	5	0	1	0
plot 5	0	0	1	4	0
plot 6	0	0	0	0	0
plot 7	13	33	2	6	1
plot 8	23	0	0	0	0

[a] **RF** = Richland Furnace, **ZA** = Zaleski

[b] **50, 70, CON** = 50 and 70% retention harvests, control sites

[c] **1,2** = replicated of each treatments or control site

APPENDIX B

Lasiurus borealis ACTIVITY BY PLOT

ZA[a]70[b]1[c]	**6/14/07**	**6/27/06**	**6/30/06**	**7/8/06**	**7/20/06**	**8/1/06**	**8/22/06**
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	6	0	1	0
plot 3	0	0	0	0	1	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	0
plot 8	0	3	0	0	0	0	0

ZA702	**6/8/06**	**6/20/06**	**7/26/06**	**7/28/06**	**8/9/06**	**8/15/06**	**8/23/06**
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	2	0	0	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	0
plot 8	0	0	0	3	0	0	0

ZA503	**6/5/2006**	**6/20/2006**	**7/6/2006**	**7/10/2006**	**8/1/2006**	**8/25/2006**	
plot 1	0	0	0	4	0	0	
plot 2	0	0	0	0	0	0	
plot 3	0	0	0	0	0	0	
plot 4	0	0	0	0	0	0	
plot 5	0	0	0	0	0	0	
plot 6	0	0	0	0	0	0	
plot 7	0	0	0	0	0	0	
plot 8	0	0	0	0	0	0	

ZA504	**6/14/2006**	**6/30/2006**	**7/8/2006**	**7/28/2006**	**8/9/2006**	**8/21/2006**	**8/22/2006**
plot 1	0	0	5	0	0	0	0
plot 2	2	0	0	0	0	0	0

plot 3	0	1	0	0	27	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	0
plot 8	6	0	0	0	0	0	0

ZACON	**6/13/2006**	**6/27/2006**	**7/10/2006**	**7/26/2006**	**8/11/2006**	**8/21/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	0	0	0	0
plot 5	0	0	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	0	0	0	0	0	0

ZACON2	**7/18/2006**	**7/20/2006**	**8/11/06**	**8/15/06**	**8/23/06**	**8/25/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	0	0	0	0
plot 5	0	0	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	0	0	0	0	0	0

RF501	**6/21/2006**	**7/19/2006**	**7/24/2006**	**7/31/2006**	**8/10/2006**	**8/26/2006**
plot 1	1	6	3	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	2	0
plot 4	0	0	0	0	0	0
plot 5	0	10	0	0	0	0
plot 6	0	0	4	0	0	0
plot 7	3	0	60	0	51	0
plot 8	18	0	7	0	0	1

RF502	**6/12/2006**	**6/15/2006**	**7/24/2006**	**7/27/2006**	**8/10/2006**	**8/16/2006**
plot 1	0	3	0	0	0	0
plot 2	0	16	0	1	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	0	1	0	0
plot 5	0	1	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	0	0	0	0	0	0

RF703	6/6/2006	6/26/2006	7/17/2006	7/27/2006	8/8/2006	8/18/2006	
plot 1	0	0	1	0	0	0	
plot 2	0	0	0	0	0	0	
plot 3	0	0	0	1	0	0	
plot 4	0	0	0	0	0	0	
plot 5	0	0	0	0	0	0	
plot 6	0	0	0	0	0	0	
plot 7	0	0	0	0	0	0	
plot 8	0	0	0	0	0	0	

RF704	6/15/2006	6/28/2006	7/9/2006	7/19/2006	8/2/2006	8/18/2006	8/24/2006
plot 1	0	0	0	0	0	0	0
plot 2	4	7	0	1	0	0	0
plot 3	0	0	0	1	0	0	0
plot 4	10	0	6	5	32	2	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	7	0	0
plot 7	0	0	5	0	0	0	0
plot 8	0	0	1	0	0	0	0

RFCON	6/12/2006	6/21/2006	7/9/2006	7/25/2006	7/31/2006	8/16/2006	8/24/2006
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	0	0	0	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	0
plot 8	0	0	0	0	0	0	0

RFCON2	7/17/2006	7/25/2006	8/2/2006	8/8/2006	8/26/2006
plot 1	0	0	0	0	0
plot 2	0	0	0	0	0
plot 3	0	0	0	0	0
plot 4	0	0	0	0	0
plot 5	0	0	0	0	0
plot 6	0	0	0	0	0
plot 7	0	0	0	0	0
plot 8	0	0	0	0	0

[a] **RF** = Richland Furnace, **ZA** = Zaleski

[b] **50, 70, CON** = 50 and 70% retention harvests, control sites

[c] **1,2** = replicated of each treatments or control site

APPENDIX C

Eptesicus fuscus/Lasionycteris noctivagans ACTIVITY BY PLOT

ZA [a]70[b]1[c]	6/14/07	6/27/06	6/30/06	7/8/06	7/20/06	8/1/06	8/22/06
plot 1	2	0	1	0	62	0	1
plot 2	0	0	0	4	0	1	8
plot 3	0	0	0	1	6	2	4
plot 4	27	0	1	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	8
plot 7	0	0	0	0	0	0	0
plot 8	0	0	0	0	3	0	0

ZA702	6/8/06	6/20/06	7/26/06	7/28/06	8/9/06	8/15/06	8/23/06
plot 1	0	0	2	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	1	0	0	0	0	0	0
plot 4	0	0	0	6	0	0	0
plot 5	0	0	0	0	2	0	0
plot 6	0	0	0	0	2	0	0
plot 7	0	0	0	0	1	0	0
plot 8	0	0	0	0	30	4	10

ZA503	6/5/2006	6/20/2006	7/6/2006	7/10/2006	8/1/2006	8/25/2006
plot 1	0	0	0	0	0	0
plot 2	0	0	0	2	0	0
plot 3	0	0	0	20	15	2
plot 4	8	0	0	0	0	0
plot 5	0	0	0	0	1	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	1	0	0	0	0	0

ZA504	6/14/2006	6/30/2006	7/8/2006	7/28/2006	8/9/2006	8/21/2006	8/22/2006
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0

plot 3	0	0	0	0	0	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	4	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	1
plot 8	3	0	0	0	0	0	0

ZACON	**6/13/2006**	**6/27/2006**	**7/10/2006**	**7/26/2006**	**8/11/2006**	**8/21/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	0	0	0	0
plot 5	0	0	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	0	0	0	0	0	0

ZACON2	**7/18/2006**	**7/20/2006**	**8/11/06**	**8/15/06**	**8/23/06**	**8/25/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	0	0	0	0
plot 5	0	0	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	0	0	0	0	0	0

RF501	**6/21/2006**	**7/19/2006**	**7/24/2006**	**7/31/2006**	**8/10/2006**	**8/26/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	2
plot 3	0	0	0	1	0	1
plot 4	0	1	0	0	0	0
plot 5	0	3	0	0	0	0
plot 6	0	0	0	2	1	1
plot 7	1	0	0	0	5	0
plot 8	0	0	0	0	0	2

RF502	**6/12/2006**	**6/15/2006**	**7/24/2006**	**7/27/2006**	**8/10/2006**	**8/16/2006**
plot 1	0	1	0	0	0	1
plot 2	0	0	2	0	0	6
plot 3	0	0	0	0	0	0
plot 4	1	0	0	0	0	0
plot 5	0	0	2	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	7	0	0	2
plot 8	0	0	5	1	0	0

RF703	6/6/2006	6/26/2006	7/17/2006	7/27/2006	8/8/2006	8/18/2006	
plot 1	0	0	1	0	0	0	
plot 2	0	0	0	0	0	1	
plot 3	0	0	1	2	0	3	
plot 4	0	0	2	0	0	0	
plot 5	0	0	0	0	0	0	
plot 6	0	0	0	0	9	0	
plot 7	0	0	0	0	0	0	
plot 8	0	0	0	0	0	0	

RF704	6/15/2006	6/28/2006	7/9/2006	7/19/2006	8/2/2006	8/18/2006	8/24/2006
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	1	0	0	0	0
plot 4	0	0	0	6	0	2	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	1	0	0	0	8
plot 7	0	0	0	0	0	0	0
plot 8	0	0	5	0	0	0	0

RFCON	6/12/2006	6/21/2006	7/9/2006	7/25/2006	7/31/2006	8/16/2006	8/24/2006
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	0	0	0	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	0
plot 8	0	0	0	0	0	0	0

RFCON2	7/17/2006	7/25/2006	8/2/2006	8/8/2006	8/26/2006
plot 1	0	0	0	0	0
plot 2	0	0	0	0	0
plot 3	0	0	0	0	0
plot 4	0	0	0	0	0
plot 5	0	0	0	0	0
plot 6	0	0	0	0	0
plot 7	0	0	0	0	0
plot 8	0	0	0	0	0

[a] **RF** = Richland Furnace, **ZA** = Zaleski

[b] **50, 70, CON** = 50 and 70% retention harvests, control sites

[c] **1,2** = replicated of each treatments or control site

APPENDIX D

Myotis spp./Pipistrellus subflavus ACTIVITY BY PLOT

ZA[a]70[b]1[c]	**6/14/2007**	**6/27/2006**	**6/30/2006**	**7/8/2006**	**7/20/2006**	**8/1/2006**	**8/22/2006**
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	0	0	0	0	0
plot 4	0	0	1	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	0
plot 8	0	3	0	0	0	1	0

ZA702	**6/8/2006**	**6/20/2006**	**7/26/2006**	**7/28/2006**	**8/9/2006**	**8/15/2006**	**8/23/2006**
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	0	0	0	0	0
plot 4	0	0	1	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	1
plot 8	0	0	0	0	0	0	0

ZA503	**6/5/2006**	**6/20/2006**	**7/6/2006**	**7/10/2006**	**8/1/2006**	**8/25/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	1	0
plot 4	0	0	0	0	0	0
plot 5	0	0	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	1	1	0	0	0	0

ZA504	**6/14/2006**	**6/30/2006**	**7/8/2006**	**7/28/2006**	**8/9/2006**	**8/21/2006**	**8/22/2006**
plot 1	0	0	0	0	0	0	0
plot 2	3	0	0	0	0	0	0

plot 3	0	1	0	0	0	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	3
plot 7	0	0	0	0	0	0	8
plot 8	2	0	0	0	0	0	0

ZACON	**6/13/2006**	**6/27/2006**	**7/10/2006**	**7/26/2006**	**8/11/2006**	**8/21/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	0	0	0	0
plot 5	0	0	0	0	0	0
plot 6	0	0	1	0	0	0
plot 7	0	0	0	0	0	0
plot 8	0	0	0	0	0	0

ZACON2	**7/18/2006**	**7/20/2006**	**8/11/2006**	**8/15/2006**	**8/23/2006**	**8/25/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	4	0	0	0	0	0
plot 4	0	1	0	0	0	0
plot 5	1	0	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	1	0	0	0	0	0
plot 8	0	0	0	0	0	0

RF501	**6/21/2006**	**7/19/2006**	**7/24/2006**	**7/31/2006**	**8/10/2006**	**8/26/2006**
plot 1	0	1	2	0	0	0
plot 2	1	0	0	0	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	1	0	0	0
plot 5	0	0	0	0	0	0
plot 6	13	0	5	0	0	0
plot 7	0	0	1	0	15	0
plot 8	0	0	1	0	0	0

RF502	**6/12/2006**	**6/15/2006**	**7/24/2006**	**7/27/2006**	**8/10/2006**	**8/16/2006**
plot 1	0	0	0	0	0	0
plot 2	0	0	2	0	0	0
plot 3	0	0	0	0	0	0
plot 4	0	0	0	0	1	0
plot 5	0	0	0	0	0	0
plot 6	1	0	0	0	0	0
plot 7	0	0	1	0	0	0
plot 8	0	0	0	0	0	0

RF703	6/6/2006	6/26/2006	7/17/2006	7/27/2006	8/8/2006	8/18/2006
plot 1	0	0	0	0	0	0
plot 2	0	0	0	0	0	0
plot 3	0	0	0	0	0	3
plot 4	0	0	1	0	0	0
plot 5	0	0	0	0	0	0
plot 6	0	0	0	0	0	0
plot 7	0	0	0	0	0	0
plot 8	0	0	0	0	0	0

RF704	6/15/2006	6/28/2006	7/9/2006	7/19/2006	8/2/2006	8/18/2006	8/24/2006
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	0	0	0	0	0
plot 4	0	0	0	5	4	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	8	0	11
plot 7	0	0	0	0	0	1	0
plot 8	0	0	0	0	0	0	0

RFCON	6/12/2006	6/21/2006	7/9/2006	7/25/2006	7/31/2006	8/16/2006	8/24/2006
plot 1	0	0	0	0	0	0	0
plot 2	0	0	0	0	0	0	0
plot 3	0	0	0	0	0	0	0
plot 4	0	0	0	0	0	0	0
plot 5	0	0	0	0	0	0	0
plot 6	0	0	0	0	0	0	0
plot 7	0	0	0	0	0	0	0
plot 8	0	0	0	0	0	0	0

RFCON2	7/17/2006	7/25/2006	8/2/2006	8/8/2006	8/26/2006
plot 1	0	0	0	0	0
plot 2	0	0	0	0	0
plot 3	0	0	0	0	0
plot 4	0	0	0	0	0
plot 5	0	0	0	0	0
plot 6	0	0	0	0	0
plot 7	2	3	0	0	0
plot 8	0	0	0	0	0

[a] **RF** = Richland Furnace, **ZA** = Zaleski

[b] **50, 70, CON** = 50 and 70% retention harvests, control sites

[c] **1,2** = replicated of each treatments or control site

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