IMPACTS OF DIFFERENT FOREST TREE-HARVEST METHODS
ON DIETS AND POPULATIONS OF INSECTIVOROUS FOREST BATS

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Megan K. Caylor

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COMMITTEE MEMBERS

Committee Chair: John O. Whitaker, Jr., PhD
Professor of Biology
Indiana State University

Committee Member: Peter Scott, PhD
Associate Professor of Biology
Indiana State University

Committee Member: Steven L. Lima, PhD
Professor of Biology
Indiana State University
ABSTRACT

The Hardwood Ecosystem Experiment (HEE) in central Indiana presents an excellent opportunity to study species reactions to different forestry practices: clearcutting, shelterwood cutting, and single tree selections. This project focuses on the differences in the populations and diets of the various insectivorous bat species in the HEE management units. Bats studied were *Myotis septentrionalis*, *Lasiurus borealis*, *Eptesicus fuscus*, *Perimyotis subflavus*, *Myotis sodalis*, *Myotis lucifugus*, and *Lasionycteris noctivagans*. Since insectivorous bats do not simply eat whatever is available, and I hypothesize that the diets of these bats will not change despite their changing environment and changing populations. To test these ideas, guano was collected between years 2006-2010 and ANABAT calls were recorded between years 2007-2010. I analyzed 440 guano samples, and the invertebrate parts were identified visually to the lowest taxonomic level within a reasonable amount of time; this is most often to family, but always order for the Lepidopterans. The data were compared within each species: before and after treatment, across treatment types, between males and females, and across different months.

There was no significant change between bat diets before and after treatments, and each species maintained a specific diet across the years. These results reinforce previous conclusions that bats select among available foods and do not simply eat whatever is available. I also analyzed 5346 call minutes using ANABAT bat detectors. There were significant changes in *Myotis sodalis*, *Lasiurus borealis*, and *Perimyotis subflavus* call minutes. This supports the hypothesis that the diets still remain constant despite the changes in the species populations.
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CHAPTER 1

IMPACTS OF DIFFERENT FOREST TREE-HARVEST METHODS ON DIETS OF INSECTIVOROUS FOREST BATS

Introduction

Bats are one of a small group of predators on night-flying insects, including crop pests. It is important to understand how and if this role changes with habitat loss and the clearing of trees. It is also important to understand if there are beneficial changes in bat diets when forest management practices are implemented. There have been relatively few experiments in the United States relating change in environment with change in bat foraging habits. Menzel et. al in 2005 studied foraging activity in various habitats including clearcuts, but did not include diet in their study. While the Missouri Ozark Forest Ecosystem Project (MOFEP) included similar forest treatments in the Missouri Ozarks, not a single resulting study included bats. There have been no studies on bats where the environment has been altered so rigorously over one year as in the Hardwood Ecosystem Experiment in Morgan-Monroe and Yellowwood State Forests in Indiana.

Contrary to earlier suggestions in the literature that bats eat whatever is available, insectivorous bats select from the available foods (Belwood and Fenton 1976, Fenton and Morris 1976). Only when foods are scarce, such as at the beginning or end of the active season or in high latitudes, do bats approach feeding on whatever is available (Belwood and Fenton 1976,
In addition, certain sporadically available foods such as ants, termites and trichopterans appear highly desirable and are consumed by many species of bats when available (Whitaker 2004).

Little is known about the direct effects of forest cutting management practices on bat populations or food. This study brings to light more information on the diet of the species in Indiana forests as well as on the impact on the diet, if any, of forest disturbance. This will later be useful in determining diet impact of forest bat populations (and perhaps manipulation of habitat to account for diet). Bats often eat pest species such as the spotted cucumber beetle, numerous scarabaeid beetles and the Asiatic oak weevil (Whitaker 2004), and manipulation of a landscape to promote destruction of certain invasive pest species would be beneficial to agricultural practices.

*The Hardwood Ecosystem Experiment (HEE)*

Data for this project were collected from Morgan-Monroe and Yellowwood State Forests during the implementation of Hardwood Ecosystem Experiment (HEE). This project was created by Purdue University (PU) and the Indiana Department of Natural Resources (IDNR) in 2006 with the intention of continuing 100 years. Every 20 years a cutting will be performed. Nine total management units of 900 acres each are involved. Three management units are control units in which no cutting takes place, three are uneven age cut units, and three are even age cut units. Within each 900 acre management unit is a 200 acre sample unit, and within the sample unit are four 10 acre treatment areas. The treatment area sizes are necessary for oak regeneration and are
an attempt to mimic early successional habitats that are adjacent to large blocks of forest cover (Proposed Action Plan 2005). The treatments are different forest management techniques.

Within each even age sample unit there are two 10 acre clearcuts and two 10 acre shelterwood cuts. The shelterwood cuts remove the trees from an area in three cuttings. The preparatory cut was in 2008 and did not remove overstory tress from the area, but removed non-oak stems of 25.4cm dbh and below (Kalb 2011). In 5-10 years after successful oak regeneration in the shelterwoods, an establishment cut will remove poorly-formed canopy and subcanopy trees (Kalb 2011). The final cut 5-10 years after that will remove remaining overstory (non-oak) trees, leaving a forest of the same age (even age) oak saplings. A clearcut removes all trees and underbrush (logging companies remove desired trees, and the rest are cut down once the logging companies are finished). Despite plans to implement prescribed burns when the project began, because the budget would now allow it, burns are no longer planned for any of the treatment areas. Half of the treatment areas will be on north slopes and half on south slopes. Half of the treatment areas will include deer exclosures and half will not.

Within each uneven age sample unit there will be group and single tree selection harvesting. This will produce a forest composed of trees with different ages. In half of the sample unit, non-oak species with a diameter at breast height (dbh) less or equal to 15 cm were girdled in order to promote oak growth, and harvest was delayed until after this treatment. The overstory may be thinned later in order to increase light penetration and encourage seedling growth. Each of the uneven age treatment areas was placed in different physiographic locations in the sample unit. Harvests within the units will occur on a 20 year schedule (Kalb 2011).
Indiana State University (ISU) is monitoring bat population changes during this study. The protocol calls for four total net nights per management unit for in-hand species confirmation. Recordings of echolocation calls are made using ANABATs, with two nights for each of four treatment areas within each management unit (with the same number for the control management units). These calls are later analyzed to determine what species of bats and how many are passing through the various areas. PU has teams studying birds, vegetation, small mammals, long-horned beetles, saturniid lepidopterans, box turtles, timber rattlesnakes, and deer impact. This information is accessible to help provide context for my diet study.

Also, timber stand improvements (TSI) were still in progress during the summer of 2009. TSI was performed in order to remove or girdle trees that logging companies left standing after the cuts that should have been removed during the cuts.

The general landscape of Morgan-Monroe and Yellowwood State forest management units is upland with some riparian habitats. It is mostly a beech-maple forest with some oak-hickory and an observed understory of spicebush (*Lindera benzoin*), common pawpaw (*Asimina triloba*), and greenbrier (*Smilax spp*). There are few rivers or streams in the selected management units for treatment and therefore the forest canopy cover (instead of the location of water) should be what is driving any changes in the behavior and selectivity of prey by bats. Morgan-Monroe State forest is over 9,712 hectares in Morgan and Monroe counties and was established in 1929 (Kalb 2011). Yellowwood State Forest is over 9,439 hectares in Brown county and was established in 1940 (Kalb 2011).
Bat Foraging Ecology

In general, predators search in a single area known to have prey before broadening their search (Kareiva and Odell 1987). This suggests that an insectivorous bat will return to areas they know to have prey before looking for and choosing new sites, perhaps even if prey composition and habitat structure changes.

Morphology often predicts how bats use forest successional stage or clutter (Broders et al. 2004). The changes implemented in the HEE study affect the successional stage and the density of the vegetation. Brooks and Ford (2005) and Broders et al. (2004) found that the smaller, shorter-winged northern myotis were interior foragers in Massachusetts, whereas the slightly larger little brown and Indiana myotis foraged in edge and open canopy. In a different region, the amount of foraging activity in open canopy (and with no canopy) was higher for silver-haired, big brown and hoary bats compared to those of species apparently adapted for vegetative clutter such as eastern pipistrelles and red bats (Menzel et al. 2005). A change in foraging behavior is expected in the HEE experiment, but will this affect the overall use of the site and the types of insects selected by each species of bat?

It has been hypothesized that random feeding on insects by adult bats is higher in the early spring because insect populations are low and variable, but it may also be because the bats must learn where the highest populations of selected insects are (Edyth and Kunz 1977). Adult females are most selective in July and juveniles randomly select insects (Edyth and Kunz 1977). This suggests that the ability to discriminate between certain insect populations increases with experience and is also hypothesized to put juveniles into a different niche than adults to reduce conspecific competition (Adams 1997). In hoary bats, foraging time increases between early
lactation and fledging and then declines as the young become independent (Barclay 1988). If bats must first learn to find the highest populations of selected insects in newly disturbed sites, this may mean that initial foraging will include insects in proportion to their availability (as it does in the spring), and that during the increasing foraging time of adult female bats between early lactation and fledging the selected insect populations will become known and the consumption of insects will no longer be determined by availability.

The size of the bat may be an important part of the reaction to the specific type of forest disturbance and diet. Large bats such as hoary bats foraging within open habitats use lower frequency calls (that produce less detailed echoes), possibly because they can use visual cues when they are in the open. When they are in closed canopy habitats they use higher frequency sounds because they have less light and are unable to see as well (Barclay et al 1999). This may affect the type of prey they pursue and the location they select. Smaller bats have a smaller gape, higher frequency echolocation (and therefore less ability to detect larger prey), and this may prevent them from capturing larger prey (Ober and Hayes 2008).

Bat Diets

Eastern pipistrelles generally eat Homoptera, Diptera, and Lepidoptera in Indiana (Brack and Whitaker 2004, Whitaker 2004). Silver-haired bats have been known to eat Lepidoptera and Hemerobiidae in Indiana (Whitaker 2004). These bats are migratory and do not occur in Indiana during summer, only spring and fall (and a few in winter). Eastern red bats have a diet of primarily Lepidoptera and Coleoptera. Hoary bats consume primarily Lepidoptera but have been shown to eat Pentatomidae and other foods as well (Carter et al 2003, Brack and Whitaker 2004).

Little brown bats feed heavily on Diptera (especially Chironomidae) and Trichoptera (Edyth and Kunz 1977, Brigham et al. 1990, Hamilton 1998, Whitaker 2004, Ober and Hayes 2008) but also feed on snout beetles (Curculionidae) and other small beetles (Brack and Whitaker 2004). Northern Myotis have a diverse diet of Diptera, Lepidoptera and Coleoptera (Carter et al 2003, Whitaker 2004, Brack and Whitaker 2004). Northern myotis especially, but also little brown myotis, aerial-hawk and glean from surfaces (Ratcliffe and Dawson 2003) and therefore spiders are often seen in their diets. Indiana myotis often consume Lepidoptera and Diptera (Tuttle 2006) but also eat Curculionidae and other beetles in Indiana (Brack and Whitaker 2004). Indiana bats are federally endangered.

*Call Characteristics and Diet*

The frequency of bat feeding calls influences what their optimal prey size is and whether or not the eared insects can detect them. The allotonic frequency hypothesis suggests that the frequency of an insectivorous bat’s echolocation calls determines what species they are able to select and eat (Jones and Rydell 2003). This is because a bat’s echolocation call reflects optimally from an insect body that is the same size as the wavelength of the call (Jones and
Rydell 2003). The bat’s call frequency is also important because of the evolution of “ears” in certain moths and other insects (Bogdanowicz et al 1999, Jacobs 2000, Schoeman and Jacobs 2003). Moths with ears are most sensitive to frequencies between 20 and 60 kHz (Fenton et al 1998). Generally studies have split groups of bats into high duty cycle echolocating bats and low duty cycle echolocating bats. High duty cycle bats signal greater than 50% of the time. Low duty cycle bats signal less than 20% of the time, and include the family Vespertilionidae (the only family represented in this study). Bogdanowicz (1999) asserted that low duty cycle echolocating bats’ diets were not dependent on the evolution of ears in moths, suggesting that morphological characteristics rather than echolocation call frequency limits the range of potential prey items. However, Jacobs (2000) and Schoeman (2003) showed that the low duty cycle echolocating bats’ diets are indeed affected by the ability of an insect to hear them. This suggests that morphological characteristics and call frequency will affect the selected species of insect prey and the overall diets of the bats. If bats cannot perceive or catch certain insects because of defensive mechanisms, this eliminates insects from their diet, but does not represent active selection against eating these insects. This fact is important when making final conclusions about presence or absence of certain insect families in bat diets.

Insect Community Changes with Forest Management

Some insects have been studied with regard to their response to forest management techniques. Many studies have focused on pest insects (Forkner et al. 2006, Veteli et al. 2006, Watt et al. 1997), or lepidopterans (Summerville and Crist 2002). Lepidopterans are often studied because they are good indicator taxa of quality of the environment (Kitching et al. 2000,
In Russian and Finnish pine forests, pest herbivore insect density (Lepidopteran and sawfly larvae) was much higher in unthinned versus thinned forests (Veteli et al. 2006). The group selection treatments (uneven age treatments) used in the HEE management units can possibly be considered thinned forest because the clutter is reduced.

Compared to the treatment area sizes in the HEE project, many plot sizes that have been studied have been small, but they may still give an indication of possible insect guild responses to the different treatments. Damage caused by many insect pests was not influenced 1-2 years after treatments such as complete clearing, line planting (widely spaced lines of vegetation cleared), taungya (crops grown for 2-4 years after clearing) and manual clearance single hectare plot treatments in Cameroon (Watt et al. 1997), but leaf-chewing insects had highly reduced richness and insect density, and leaf-mining insects were less affected (Watt et al. 1997). The separate treatments did not have individual effects (Watt et al. 1997).

Insect change in response to forestry treatments has been studied within the Missouri Ozark Forest Ecosystem Project (MOFEP). Species richness of herbivore insects was reduced in even-aged and uneven-aged treatments (Forkner et al. 2006). Spring-feeding species were more affected than late-season species. Uneven-aged management reduced species richness more than even-aged management because the microclimates within the uneven-aged treatments were more directly altered than those within the even-aged treatments (Forkner et al. 2006). Insect communities in uncut areas were not impacted by the cut areas (Forkner et al. 2006).

Moth species richness is reduced significantly with clearcut management techniques, and community composition changes greatly (Summerville and Crist 2008). Selective logging only causes moderate changes in community structure (Summerville and Crist 2008). Moths that are
dietary specialists as larvae and dispersal-limited as adults are most sensitive to timber management (Summerville and Crist 2008). Selective logging has also been shown to preserve species richness of lepidopterans (Summerville and Crist 2002).

Lepidopterans have also been studied within the HEE project in Morgan-Monroe State Forest during years 2007 and 2009. Lepidopterans in the HEE project management units 1-5 appear to be highly sensitive to the timber harvest disturbances, except for shelterwood cuts (Summerville 2011). Specifically, there was a 30-40% loss of species richness (Summerville 2011) as well as a 42% drop in abundance and this effect extends beyond the timber harvests at least 200 meters (Summerville 2011). These two years were years that bat guano was taken from the same areas, indicating a change in the lepidopteran community and therefore available foods to those bats eating lepidopterans.

Overall, the conclusion is that even-age and uneven-age management techniques negatively affect species diversity and richness in insect communities. Uneven-age treatments seem to affect insect density and richness less than even-age treatments. Since insects are the prey item of the bats, if the bats were eating whatever is available, the species diversity and richness of insects in their diet should change with treatments.

Objectives

The purpose of this thesis is to determine whether there are changes in foods consumed by insectivorous bats in a situation where the habitat is drastically altered through management over a five year period. Baseline data were recorded prior to the changes as well as after the changes.
After treatments, I hypothesize that while the bat activity will change due to the treatments, the bats will still continue to forage on foods similar to what was previously consumed. This study shed light on bat activity in disturbed forests as related to feeding activity, and may aide in manipulation of forests in such a way as to accommodate feeding needs of bats.

Methods

Study Site

Maps containing management units 1-9 as well as each mist net site (where guano was collected) are included as Figures 1-4. These maps depict the immensity of the project as well as the layout of the treatment areas within the management units. The maps also depict changes in years 2006 through 2010 of mist net sites due to unexpected inaccessibility.

Mist Netting

Bats were sampled using mist nets. I sampled at 2 sites in each of the 9 Hardwood Ecosystem Experiment’s management units between May 15th and August 15th of each year. At each site 4 multi-tiered mist-net sets (Avinet, Inc. Dryden, New York) were arranged to maximize bat captures, often across travel corridors such as logging roads. These sites were netted twice per year on non-consecutive nights, producing 36 net nights of sampling per year. Mist nets were set up by nightfall and kept in place for 5 hours. Netting was delayed during rain and resumed when it stopped or cancelled if the rain or temperatures below 10°C persisted. Because bats forage less during cool nights in order to save energy (Anthony and Rautenbach 1981), temperatures were measured hourly. Data collected on captured bats included species,
sex, reproductive condition, right forearm length, weight, an estimate of age (juvenile or adult), and guano. Guano samples were obtained by placing the bat in a plastic Ziploc (or similar) bag for up to 5 minutes. The bag was labeled with date, sex, band number, site number, and species. Numbered metal bands (Prozana Ltd, Icklesham, East Sussex, United Kingdom) were fitted to the right (males) or left (females) forearm to allow identification of individual bats. All bats were released.

From 2006-2008 Jeremy Sheets headed the ISU part of the project. He put out recording ANABATs, netted, and also collected guano samples. These guano samples were used to determine the ‘before’ aspect for this thesis. Data were collected between sunset and 2am each sampling night.

Guano Analysis

Guano was placed in watch glasses with a 70% ethanol solution. The guano was teased apart and the remaining invertebrate parts after bat digestion were inspected. Invertebrates were identified to as low a taxonomic level as possible. The guano from one bat at one capture was treated as one sample despite differences in the number of pellets (pellets within one sample are very similar in content to one another- much more so than between different bats- and counting them as separate bats would bias the results towards larger samples). The volume percentage of each food type was recorded.
Statistics

Whitaker et al. (2009) outlined statistical procedures for bat guano analysis. Percent volume (the proportion out of 100% volume of a single sample that is one type of insect) of each insect group is obtained through guano analysis. ANOVAs test for differences between foods in different groups of bats, i.e., species, sex, or age. In this method, the original percentage volume data are converted into Arcsine proportions to allow the data to approach normality and then examined with a one-way ANOVA. If the null hypothesis is rejected (at least one group differs from the other), Student-Newman-Keuls multiple range tests will be used to determine which of the groups differ significantly.

In order to accommodate multiple dependent variables, a MANOVA was used. Only the insect groups with values larger than 10% were analyzed in order to allow for adequate statistical power. The independent variables were species year, treatment, month, and sex. The dependent variables were still converted into Arcsine proportions before performing the statistical procedure. All statistics were performed in SPSS.

An ANOVA was also used to determine significant differences between bat captures in mist nets over years 2006-2010.
Figure 1. Hardwood Ecosystem Experiment full extent.
Figure 2. Management Units (MU) 1, 2, 3, and 4 are in Morgan-Monroe State Forest.
Figure 3. Management Unit 5 is in both Morgan-Monroe and Yellowwood State Forest.
Figure 4. MU6, 7, 8, and 9. MU7 and MU8 are uneven-aged cut treatments with group selection cuts.
Results

Bat Captures

The bats captured were northern myotis, little brown myotis, Indiana myotis, eastern pipistrelles, eastern red bats, hoary bats, silver-haired bats, and big brown bats. No guano was obtained from the hoary bats captured. This species diversity includes all that occur in the region except for the evening bat (Nycticeius humeralis) and grey bat (Myotis grisescens). These species are typical for a central Indiana forest.

A total of 576 bats was captured between years 2006-2010 (Figure 5). A total of 225 Northern myotis was captured, 173 red bats, 103 big brown bats, 33 Eastern pipistrelles, 23 Indiana myotis, 14 little brown myotis, 5 silver-haired bats, and 3 hoary bats.

Bat Diets

Guano from 407 bats was analyzed, or 70.7% of total bats collected. This number represents how often a guano sample was collected from a captured bat. All guano samples collected were analyzed. Each bat species maintained specific diets separate from one another (see below). Results differed between each group of invertebrates that were found in the diet. Groups of invertebrates that were found include: Lepidoptera, Coleoptera (Scarabaeidae, Carabidae, Chrysomelidae [Diabrotica undecimpunctata], Curculionidae and unknown Coleoptera), Hymenoptera (Ichneumonidae and Formicidae), Diptera (Chironomidae, Culicidae, unknown Diptera), Neuroptera (Hemerobiidae), Hemiptera (Pentatomidae, Lygaeidae, unknown Hemiptera), Trichoptera, Homoptera (Cicadellidae and unknown Homoptera), Araneae and
Acari. Not all species of bats consumed all of these groups of invertebrates, but all species of bats consumed at least one of these groups.

**Northern myotis (Myotis septentrionalis)**

Guano from 203 Northern myotis (MYSE) was analyzed (n = 43 in 2006, n = 35 in 2007, n = 36 in 2008, n = 65 in 2009, n = 24 in 2010, 90.2% of total MYSE collected). The coleopterans Scarabaeidae and Carabidae, Lepidoptera, and unknown Diptera were the four insect groups that were represented most in the diet (>10%). There were no significant effects of treatment on year of MYSE captured (p = 0.959, df = 20, partial η² = 0.018, Figure 6). There was a difference between guano of males and females (p = 0.020, df = 4, partial η² = 0.080). Specifically, females ate more Carabidae than males (p = 0.006, df = 1 partial η² = 0.052, Figure 7). These differences were not caused by treatment or year.

**Big brown bat (Eptesicus fuscus)**

Guano from 97 big brown bats (EPFU) was analyzed (n = 21 in 2006, n = 16 in 2007, n = 22 in 2008, n = 14 in 2009, n = 24 in 2010, 94.2% of total EPFU collected). The main foods of this species (>10%) were Scarabaeidae, Carabidae, Curculionidae, Hemiptera (Pentatomidae), and Hymenoptera (Ichneumonidae) (Figure 8). There were no significant effects of treatment on year of EPFU captured (p = 0.184, df = 15, partial η² = 0.114). There was a significant difference between the diets of males and females (p = 0.038, df = 5, partial η² = 0.205), specifically that females ate more Cuculionidae than males over the years (p = 0.008, df = 1, partial η² = 0.125, Figure 9). This difference was separate from the treatments.
**Eastern red bat (Lasiurus borealis)**

A total of 75 Eastern red bat (LABO) guano samples were analyzed (n = 19 in 2006, n = 13 in 2007, n = 16 in 2008, n = 15 in 2009, n = 12 in 2010, 43.4% of total LABO collected). The five main groups consumed by this species (>10%) (Figure 10) were Lepidoptera, unknown Diptera and the coleopterans Scarabaeidae, Carabidae, and Curculionidae. There was a significant difference between months (p = 0.005, df = 15, partial $\eta^2 = 0.297$). Particularly, this difference was with unknown Diptera (p = 0.003, df = 3, partial $\eta^2 = 0.360$, Figure 11). Much more Diptera was consumed in August 2006 and 2007 than in other months and June in 2009 than in other months. There was not an interaction between month and year (p = 0.785, df = 1, partial $\eta^2 = 0.002$). The diets did not change over the years because of any specific treatment (p = 0.828, df = 20, partial $\eta^2 = 0.103$). There was also no significant difference between the diets of males and females (p = 0.579, df = 5, partial $\eta^2 = 0.125$).

**Eastern pipistrelle (Perimyotis subflavus)**

Guano from 17 Eastern pipistrelle (PESU) was analyzed (n = 1 in 2006, n = 3 in 2007, n = 5 in 2008, n = 4 in 2009, n = 4 in 2010, 51.5% of total PESU collected). The main groups of insects consumed (>10%) are unknown Diptera, unknown Hemiptera, unknown Coleoptera, and Lepidoptera (Figure 12). There were not enough samples of PESU to analyze statistically.
Indiana myotis (*Myotis sodalis*)

Guano from 22 Indiana myotis (MYSO) was analyzed (n = 4 in 2006, n = 3 in 2007, n = 8 in 2008, n = 2 in 2009, n = 5 in 2010, 95.7% of total MYSO collected). The two main foods of this species (>10%) were Lepidoptera and Diptera (Figure 13). There were not enough samples of MYSO to support conclusions statistically.

Little brown myotis (*Myotis lucifugus*)

Guano from 13 little brown myotis (MYLU) was analyzed (n = 5 in 2006, n = 3 in 2007, n = 2 in 2008, n = 1 in 2009, n = 2 in 2010, 92.9% of total MYLU collected). The main foods of this bat (>10%) are unknown Diptera, Scarabaeidae, Carabidae, Lepidoptera, unknown Hemiptera, and Araneae (Figure 14). There were not enough samples of MYLU to support conclusions statistically.

Silver-haired bat (*Lasionycteris noctivagans*)

Guano from two Silver-haired bat (LANO) diets was analyzed (n = 1 in 2008 and n = 1 in 2009, 40% of total LANO collected). These bats were only sampled two of the total years, though they did span before and after the treatments. Their diets were high in unknown Diptera.
Figure 5. Total bat counts for years 2006-2010.
Figure 6. Northern bat (MYSE) analyzed guano samples.

**MYSE Before Treatment (n = 114)**

- Lepidoptera: 25.3%
- Carabidae: 26.1%
- Curculionidae: 6.5%
- Diptera: 30.7%
- Scarabaeidae: 4.6%
- Unknown Coleoptera: 2.6%
- Chrysomelidae: 0.3%
- Hymenoptera: 1.3%
- Other: 2.6%

**MYSE After Treatment (n = 89)**

- Lepidoptera: 25.4%
- Carabidae: 13.2%
- Curculionidae: 7.1%
- Diptera: 31.0%
- Scarabaeidae: 11.7%
- Unknown Coleoptera: 4.6%
- Hymenoptera: 0.8%
- Other: 1.2%
- Chrysomelidae: 3.6%
Figure 7. Northern myotis females consumed more Carabidae than males.

Male and female *Myotis septentrionalis* percent Carabidae consumed 2006-2010.
Figure 8. Big brown bat (EPFU) analyzed guano samples.

EPFU Before Treatment (n = 59)

EPFU After Treatment (n = 38)
Figure 9. Female big brown bats ate more Curculionidae than males over the years 2006-2010.

**Male and female *Eptesicus fuscus* percent Curculionidae consumed 2006-2010.**
Figure 10. Eastern red bat (LABO) analyzed guano samples.
Figure 11. Eastern red bats consumed more unknown Diptera in August 2006 and 2007 than in other months in those years and consumed more in June 2009 than other months in that year.

*Lasiurus borealis* percent Diptera consumed May-August, 2006-2010.
Figure 12. Eastern Pipistrelle (PESU) guano samples.
Figure 13. Indiana myotis (MYSO) guano samples.
Figure 14. Little brown myotis (MYLU) guano samples.
Discussion

*Individual Bat Species’ Diets*

**Northern myotis (Myotis septentrionalis)**

The literature indicates that this bat consumes Diptera, Lepidoptera, Coleoptera, and Araneae (Carter et al 2003, Whitaker 2004, Brack and Whitaker 2004), which is what the bats in this study consumed. This was completely typical of this species and entirely expected. It is interesting to note that the only differences detected after diet analysis in this species is between males and females. This could be due to the different diet needs of pregnant and lactating individuals relative to those that are simply providing for themselves. Pregnant and lactating Mexican free-tailed bats (Tadarida brasiliensis) have different diets because of different nutritional content of insects (Kunz et al. 1995). Since the treatments had no effect on diet, it is fair to conclude that Northern myotis do not vary their diets based on differences in forest structure, openings, different insects available or increased exposure. Since the month had no effect on diet, it is fair to conclude that Northern myotis diets are resistant to prey abundance and diversity changes over the course of the summer (May-August).

**Big brown bat (Eptesicus fuscus)**

study, the bats consumed the coleopterans Scarabaeidae and Carabidae as well as the hemipteran Pentatomidae. However, altering the forest structure, increasing openings, changing the insects available and increasing the possibility of exposure to predators does not alter the diets. The difference between the males and females may be attributed to the same reasons as in the Northern myotis: pregnant and lactating females may have different diet needs than the males (Kunz et al. 1995). Curculionidae may have a nutrient not present in the other food items, although this has not been studied.

**Eastern red bat (Lasiurus borealis)**

The literature indicates that this bat consumes mainly Coleoptera and Lepidoptera (Carter et al 2003, Brack and Whitaker 2004). In this study, this bat species consumed mostly Lepidoptera, Scarabaeidae and Curculionidae, which is typical of this species. The treatments did not affect diet, meaning that there was also no effect through forest structure, increasing openings, changing insects available or increasing the possibility of exposure to predators. There were also no differences detected between males and females, though there may have been too much variation between the samples to detect a difference with the sample size. There was a discernable difference between months over the summer, and this suggests that Eastern red bats are more affected by differing prey abundance between May and August than other species.

**Eastern pipistrelle (Perimyotis subflavus)**

The literature indicates this bat consumes Homoptera, Diptera, and Lepidoptera (Brack and Whitaker 2004, Whitaker 2004). In this study, this species consumed unknown Diptera, unknown Coleoptera, Lepidoptera, and unknown Hemiptera. It is unusual that they consumed as
much Coleoptera as they did. This could possibly reflect a lack of Homoptera in the environment
and a prevalence of Coleoptera. This bat’s main food was still typical of the species. Again, there
were unfortunately too few samples to detect any effects of treatment statistically because of
high variation between samples or a small sample size.

**Indiana myotis** (*Myotis sodalis*)

The literature indicates that this bat consumes Lepidoptera, Diptera, and Coleoptera,
particularly Curculionidae (Brack and Whitaker 2004, Tuttle 2006). The bats in this study
consumed primarily Lepidoptera, Diptera, unknown Hemiptera, and the coleopteran Carabidae.
The coleopteran Curculionidae was consumed, but at lower levels than other families of Coleoptera. There were unfortunately too few samples to detect any effect of treatments.

**Little brown myotis** (*Myotis lucifugus*)

The literature indicates that this bat consumes Diptera (such as Chironomidae) and
coleopterans, specifically Curculionidae (Edyth and Kunz 1977, Brigham et al. 1990, Hamilton
1998, Brack and Whitaker 2004, Whitaker 2004, Ober and Hayes 2008). In this study, this bat
species consumed unknown Diptera (except in 2007), Carabidae, Scarabaeidae, and unknown
Hemiptera. There were unfortunately too few samples to detect any effect of treatments.

**Silver-haired bat** (*Lasionycteris noctivagans*)

The literature indicates that this bat consumes Lepidoptera and Hemerobiidae (Whitaker
2004). In this study, this bat species consumed mostly unknown Diptera, but only two samples
were examined. The capture sites were near water, so this could be a product of the location.
This species also migrates through the state, and they are here only early and late in the season. They may also need different nutritional needs while migrating than they do while raising young.

**Overall Conclusions**

Overall, bat diets remained similar to their previously published diets in all years. This means that despite not only the treatments but the differences in the locations of these bats relative to the other studies, there is little change in the established diets of the various species of bat. This would be consistent with the conclusion that bats choose their diets and do not simply consume from available foods.

Available insects should be changing in the treated forests, as presented in the introduction, although few data were accumulated on foods available, as the only insects studied were moths (Summerville 2011) and long-horned beetles. Species compositions do change due to forestry management in several different orders of insects (Summerville 2011, Summerville and Crist 2002, Forkner et al. 2006, Veteli et al. 2006, Watt et al. 1997). The results presented indicate that despite a likely change in available foods, the bats did not greatly change their diets. The forestry treatments also changed the composition of the trees and the undergrowth, presenting each species with either a more often or less often frequented type of opening depending on wing shape and size of bat. Despite this, the bats also generally maintained the same diet over the years of treatment that they did before the treatment. Again, this demonstrates resilience in types of foods consumed. Some of the populations of bats species were affected both positively and negatively by the treatments (Indiana myotis, Eastern pipistrelles and Eastern red bat as presented in Chapter Two) and yet the diets of those individuals were generally the same as in previous studies. This is more evidence of resilience of the diets of bats against...
change. Lastly, in two species (Northern myotis and big brown bat), a significant difference was seen between the two sexes that did not change because of treatment. This is evidence that not only does the species as a whole maintain specific diet, each gender maintains its own specific diet despite changing environments.

When each of these species of bats is found in an area, despite forest composition, openings, and exposure to predators, we can still infer the type of diet they have and the type of insects they are eating in that area. While there is no evidence that invertebrate species consumed remains steady, the orders of insects seen in the diets in this study most likely will. This could become useful when anticipating prey consumption by new communities of bats or anticipating prey type increase when bat communities decrease.

*Future Studies*

Future studies should include information on available foods in the various habitats. No specific information is currently available on the identification of foods available to bats in the study areas. At the time the diet study was taking place, insect studies were ongoing and it was thought that insect light traps put out in addition to the passive traps used by the entomology team might have negatively affected their results. However, the insects studied by this entomology team were long-horned beetles. This is an order of insects that is not consumed by bats (Cerambycidae). It seems imperative that the insect community be much more fully studied and made available to the bat team in order to determine whether the insect communities from which the bats choose their food items are actually changing in this study.

It is still early in the study and bat diets and insect communities should continue to be studied in the future in order to see if there are longer term effects on either group.
References


CHAPTER 2
HABITAT USE OF INSECTIVOROUS FOREST BATS

Introduction

Bat foraging occurrence can be determined through acoustic study (Russo and Jones 2003, Wickramasinghe et al. 2003, Scott et al., 2010). The number of bat passes recorded in each site can be used as an indication of bat activity (Krusic et al. 1996, Vaughan 1996) and that is often converted into minutes in order to estimate intensity of bat activity (Wickramasinghe et al. 2003). Acoustic detection can be more effective than capture methods for determining presence of certain species (O’Farrell and Gannon 1999). It also provides a number of benefits including a less-invasive method of collecting species occurrence data, ability to record passively throughout entire nights, and ability to sample multiple locations simultaneously with minimal effort (Williams et al. 2006).

The negatives to ANABAT detection include the inability of echolocation readings to distinguish individual animals (Duchamp et al. 2006). This means that a specific count of numbers of bats cannot be determined using ANABAT calls. Unknown detection probabilities may also be a source of bias in results and conclusions (Krusic et al. 1996, Menzel et al. 2002).

Objectives

The objective of this portion of the study is to determine whether the bat communities are changing with regards to the treatments. If the bat communities are changing, but their diets are
not (Chapter One) then this represents more evidence that while there may be pressure on a bat community in one way or another, the diets of the bats are resilient enough to withstand this. This portion of the study is mainly to examine the claim that the forest treatments do affect the bats.

Methods

Acoustic Sampling

Starting in 2007, management units were sampled with 12 Anabat II bat detectors (ANABATs, Titley Electronics, Ballina, New South Wales, Australia) and Zero Crossing Analysis Interface Modules (ZCAIMs, Ttitley Electronics, Ballina, New South Wales, Australia) placed in treatment areas (TA’s). ANABATs were set out one night early in the season (May 15-July 8) and one night late in the season (July 9-August 15) for each TA. In even-aged and control management units (MU), 4 TA’s were sampled in one night, but in the uneven-aged MU’s only 4 of 8 TA’s were sampled (randomly chosen). Each ANABAT was set approximately one meter from the ground on a polyvinyl chloride (PVC) pipe and housed within a plastic storage container with a 45° PVC elbow at one end. Similar setups have been used in previous studies (Yates and Muzika 2006). Microphones on ANABATs were placed 1 cm from the PVC elbow. Detectors were aligned on a random azimuth selected from a random numbers table. Each detector was placed either inside, adjacent to, or outside the TA (also on one night per MU). There were 216 samples taken each year. ANABAT calls were identified to species using a discriminate function model ANALOOK (version 1.6, Titley Electronics), an ANABAT call library and a statistical program in R (GNU Project, University of Auckland, New Zealand) provided by Eric Britzky and Joe Duchamp (manuscript in review).
The information mentioned previously that was collected using the ANABATs was considered when making final conclusions about the overall behavior of the bats in regards to the treatments. If the ANABAT study showed a significant change in the population, then it could be concluded that the different treatment areas had a significant effect on the behavior and habitat choice of the bats.

**Hardwood Ecosystem Experiment**

The methods of the Hardwood Ecosystem Experiment (HEE) are explained in detail in chapter one of this thesis. Years 2006-2008 were before the treatments and 2009-2010 were after the treatments.

**Statistics**

ANOVA's were performed on natural log transformed data in order to satisfy the normality assumption of the statistical test. Because of uneven sample sizes, the Bonferonni post-hoc test was performed.

**Results**

**ANABAT Call Sequence Recordings**

ANABAT data was analyzed by Joe Duchamp. There was a total of 864 sample nights and 7601 identified calls (Table 1). These call sequences were translated into minutes of activity. A species is considered present during a 1-min block of time regardless of the number of sequences within a file, or the number files for that species within the 1-min interval (Miller 2001).
**Indiana Myotis (Myotis sodalis)**

There were significantly fewer Indiana myotis calls detected after the specific treatments than before the treatments (df = 6, p = 0.009, $r^2 = 0.191$). There were more bat minutes recorded in the uneven aged treatments than the even aged treatments and the controls (Figure 15). The recorded minutes decreased between 2007 and 2008 (prior to treatment). Between 2008 (before treatment) and 2009 (after treatment) there was no significant change, but there was a decrease of bat calls between 2008 (before treatment) and 2010 (after treatment). This indicates a gradual instead of immediate decrease.

**Eastern Red Bat (Lasiurus borealis)**

There is no evidence that either of the specific treatments after they were implemented have had any effect on the minutes of bat calls recorded (Figure 16). There was a significant increase in the number of bats over the years (df = 3, p = 0.007, $r^2 = 0.151$). The number of bats was significantly larger in 2009 and 2010 (after treatment) from 2007 and 2008 (before treatment).

**Eastern pipistrelle (Perimyotis subflavus)**

Despite a trend that appears to indicate that eastern pipistrelles are affected by the treatments (Figure 15), statistical differences were not found (p = 0.205, df = 2). Statistical differences were found between the years (p < 0.000, df = 3, $r^2 = 0.157$). There were significantly more bat minutes recorded in 2009 and 2010 than 2007 and 2008 indicating an increase occurred outside of the treatments.
Other Bats

There were no significant differences found in *Myotis septentrionalis*, *M. lucifugus* or *Eptesicus fuscus* that would lead to the conclusion that these species were affected after the treatments were conducted. There were also no differences between years for these species. Not enough calls of *Lasiurus cinereus* were recorded to determine statistical effects of treatments.
Table 1. Call minutes for each species for each year that acoustic sampling was done for the HEE project.

<table>
<thead>
<tr>
<th></th>
<th>EPFU</th>
<th>LABO</th>
<th>LACI</th>
<th>MYLU</th>
<th>MYSE</th>
<th>MYSO</th>
<th>PESU</th>
<th>Total</th>
</tr>
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<tr>
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<td>19</td>
<td>14</td>
<td>0</td>
<td>8</td>
<td>156</td>
<td>93</td>
<td>118</td>
<td>408</td>
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<tr>
<td>2008</td>
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<td>24</td>
<td>0</td>
<td>34</td>
<td>283</td>
<td>203</td>
<td>176</td>
<td>730</td>
</tr>
<tr>
<td>2009</td>
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<td>372</td>
<td>6</td>
<td>104</td>
<td>318</td>
<td>155</td>
<td>516</td>
<td>1655</td>
</tr>
<tr>
<td>2010</td>
<td>366</td>
<td>569</td>
<td>3</td>
<td>173</td>
<td>213</td>
<td>166</td>
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<td>9</td>
<td>319</td>
<td>970</td>
<td>617</td>
<td>1873</td>
<td>5346</td>
</tr>
</tbody>
</table>
Figure 15. Indiana myotis (MYSO) call minutes between years 2007-2010.

**Mean *Myotis sodalis* (MYSO) Call Minutes 2007-2010.**
Figure 16. Eastern red bat (LABO) call minutes between years 2007-2010.

**Mean Lasiurus borealis (LABO) Call Minutes 2007-2010.**

![Graph showing mean Lasiurus borealis call minutes for different treatments and years between 2007 and 2010.](image)

- **Treatment:** Control, Uneven Aged, Even Aged
- Error Bars: ± 2 SE
Figure 17. Eastern pipistrelle (PESU) call minutes between years 2007-2010.

Mean *Perimyotis subflavus* (PESU) Call Minutes 2007-2010.
Discussion

The only bat that appears to be affected by the specific forestry treatments after they were implemented is *Myotis sodalis*. This is particularly interesting because this species is endangered. The uneven aged treatments (shelterwood cuts and single tree selection cuts) appeared to most negatively affect the bats, as their presence decreased in this type of cut after the treatments were in place. However, 2009 did not show as big of an effect as 2010, and so the conclusion may be that the bats took a period of time to quit using the uneven aged treatments. This also indicates that *Myotis sodalis* decreases in thinned forest stands, and that they may prefer the clutter from unthinned stands in either travel or foraging.

Two species of bats (*Lasiurus borealis* and *Perimyotis subflavus*) appeared to have increased numbers after the treatments were implemented, although the increase in numbers was not specifically caused by any of the treatments. There are two main possible explanations for this: either the differences in the years are completely independent of the treatments and are caused by other factors such as weather, or that the differences are independent of the treatments because the bats have such large home ranges that the effects of each treatment are overlapping with the effects of other treatments or the controls. This is a possibility because bat home ranges widely vary, and have been seen to cover areas larger than the treatments areas. If this is happening, then both *Lasiurus borealis* and *Perimyotis subflavus* increased activity due to the treatments.

This population study (chapter two) applies to the diet study (chapter one) because it describes the changing bat species populations over the years 2007-2010, and allows conclusions
to be made regarding the behavior of the bat populations separate from the diets. Conclusions can also be made combining the change in the populations and the change in the diets. Of the three species whose diets were statistically analyzed in chapter one, only one of them (*Lasiurus borealis*) had statistically more calls after the treatments. This may be because the treatments may have had no effect whatsoever on *Eptesicus fuscus* and *Myotis septentrionalis*. Instead of evidence of steadiness in diet regardless of environmental changes, the lack of change in diet from chapter one coupled with the lack of change in populations in this chapter simply may be evidence that neither diet nor bat calls are good indicators of what pressure that forestry management puts on bat populations.

Specific studies in the future need to focus with ANABATs on where precisely the bats are foraging in order to make conclusions regarding where the bats are eating their foods. This study assumes that the bats would be affected if they did eat available foods, but there is no evidence yet that their available foods are located within or around the treatments (despite the forest treatments they may be commuting to different parts of the forest to forage).

References


