HABITAT USAGE OF BATS IN LAND BETWEEN THE LAKES NATIONAL RECREATION AREA AND A COMPARISON OF ACOUSTIC RECORDING TECHNIQUES

-

Joshua Jay Schulte

HABITAT USAGE OF BATS IN LAND BETWEEN THE LAKES NATIONAL RECREATION AREA AND A COMPARISON OF ACOUSTIC RECORDING TECHNIQUES

A Master's Thesis

Presented to

The College of Graduate Studies

Austin Peay State University

In Partial Fulfillment

of the requirements for a

Master of Science in Biology

Joshua Jay Schulte

May 2012

May, 2012

To the College of Graduate Studies:

We are submitting a thesis written by Joshua J. Schulte entitled "Habitat usage of bats in Land Between the Lakes National Recreation Area and a comparison of acoustic recording techniques." We have examined the final copy of this thesis for form and content. We recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science in Biology.

Research/Committee Advisor/Chair

Committee Member

Committee Member

Accepted for the Council

Dean, College of Graduate Studies

Statement of Permission to Use

In presenting this thesis in partial fulfillment of the requirements for the Master of Science in Biology at Austin Peay State University, I agree that the library shall make it available to borrowers under the rules of the library. Brief quotations from this field study are allowable without special permission, provided that accurate acknowledgement of the source is made.

Permissions for extensive quotation or reproduction of this field study may be granted by my major professor, or in his/her absence, by the Head of the Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature

4/30/12 AWB

Date

ACKNOWLEDGEMENTS

I would like to thank Dr. Andrew Barrass for his guidance and support during this research project. I would also like to thank Drs. Don Dailey and Rebecca Johansen for their advice and support. This project required late hours and I have the following to thank for their help in the field: Riley McCormick, Veronica Mullen, Michael Fulbright, Matthew Wagner, Mark Hoger, Lindsay Brotherton, Clea Klagstad, and Joshua Hall. Without the support of the staff from Land Between the Lakes, this project would not have been possible, particularly Steve Bloemer, Curtis Fowler, Travis McDonald and Elizabeth Raikes. Lastly, I would like to thank Jennifer Rhodes for being my eye in the sky and making sure the weather did not get the best of me.

ABSTRACT

Habitat usage of bats was examined in Land Between the Lakes National Recreation Area (LBL) using the AnaBat system. Eighteen sites were selected that represented several different habitat types within LBL. The habitat types selected were edge, open field, forest, riparian, lentic, corridor and logging. Recordings were made for 4.5 hours after sunset on 45 nights with sites selected randomly each night. The number of bat call files was used as an indicator of activity and bat calls were identified to species where possible. The effectiveness of the AnaBat unit was compared with another recorder called the Avisoft Ultrasound Gate. The devices were deployed side-by-side at random sites and programmed as similarly as possible. They were deployed on 24 nights and allowed to record for at least 2.5 hours. Results indicate few significant differences in bat activity between sites with water and those without water, even when examining at the species level. Edges and open fields may be equally important to riparian corridors and lentic areas but for different reasons. High amounts of insect noise within the forests of LBL confounded data analysis and conclusions as to their importance to bat habitat usage could not be drawn. Results indicate that the AnaBat unit recorded more bat calls overall and more little brown bat calls, but also recorded more noise and calls that could not be identified to species. Differences were likely due to the specifics of the devices, particularly the microphones they use. These devices should not be used interchangeably due to the different number of calls recorded and the nature of the file recorded.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Assessing foraging habitat preferences of any bat species can provide vital information on its management and conservation (Miller et al. 2003). North American bats, despite being the only flying mammal, still require much needed habitat research, particularly pertaining to foraging habitat (Miller et al. 2003). The identification of habitat use in bats can provide important information for policy makers regarding landscape management and long term conservation practices (Arnett 2003). With the discovery of White-Nose Syndrome, a deadly bat-killing fungus, in 2006, information and assessments of bat populations in the eastern United States has become critically important (Frick et al. 2009). Several species of bats exist within Tennessee, but state specific studies on the habitat preferences of these species are limited. Land Between the Lakes National Recreation Area (LBL) provides a good opportunity for studying habitat preferences of bats as the area has a variety of habitat types, a previous history of bat research, and can provide more state specific information regarding bat activity.

Land Between the Lakes has been a site of past mist netting efforts to determine which species of bat are present. To date, the following species have been detected in LBL by mist-netting: *Lasiurus borealis* (eastern red bat), *Lasiurus cinereus* (hoary bat), *Eptesicus fuscus* (big brown bat), *Myotis lucifugus* (little brown bat), *Myotis septentrionalis* (northern long-eared bat), *Myotis grisescens* (gray bat), *Lasionycteris noctivagans* (silver-haired bat), and *Perimyotis subflavus* (tricolored bat; Moyer 1997, USFS pers comm 2011). The area of interest in this study is LBL located in northwestern Tennessee and southwestern Kentucky. While extensive knowledge on the foraging habitats of bats has been recorded, relatively few of these studies pertain to the mostly deciduous forests of this area.

Foraging Preferences of Bat Species found at LBL

Eastern red bats (*Lasiurus borealis*) have a wide range across the United States (except for the Rocky Mountains), south Alberta, Canada and extensively in Mexico (Fenton 1999) and has been recorded across several habitats. In mixed coniferous-deciduous forest, they have been found to prefer forest edges as opposed to the forest interior but tend to stay near sources of water (Hein et al. 2009; Winhold & Kurta 2008). Several studies have shown that red bats prefer to forage in riparian corridors and lentic water sources such as ponds (Stringer & Loftis 1999; Owen et al. 2004; Johnson & Gates 2008). Others have found that red bats prefer open and structurally uncluttered habitats for foraging in a variety of habitats (Jung et al. 1999; Brooks & Ford 2005). Walters et al. found that red bats foraged in woodlands, newly planted tree fields, open water and pasturelands while avoiding developed areas, but no clear preferences within the non-developed areas was established (2007). As for the effect of forest canopy on foraging preferences, red bats have shown no difference in foraging above, within, or below the forest canopy (Elmore et al. 2005; Menzel et al. 2005). They have been found to avoid upland areas in general (Carter et al. 2004; Owen et al. 2004). Based on these studies, red bats appear to be habitat generalists. Given that several of these studies have found red bats over water sources, it is probably they will forage in riparian corridors, streams, and ponds as compared to secondary preferences such as open woodlands and forest edges.

Big brown bats (*Eptesicus fuscus*) have a very wide range, found across southern Canada, throughout the United States and Central America, and extending into northwestern South America (Kurta & Baker 1990). Data on the foraging habitats of big brown bats is conflicting.

Some researchers propose that big brown bats are a foraging habitat generalist stating that big brown bats show no preference between over-water and over-land foraging sites, edge and non-edge habitats and areas with and without canopy enclosures (Geggie & Fenton 1985; Furlonger et al. 1987). In contrast, researchers have found that big brown bats do prefer to forage in riparian forests (Everette et al. 2002; Owen et al. 2004; Brack et al. 2007). Duchamp (2004) suggests that big brown bats prefer agricultural areas and edges over water. Other studies suggest that they exclusively prefer forest edges (Carrol et al. 2002; Hein et al. 2009). Several studies have suggested that given the relatively large size of the species (10-13 cm in length, 28-33 cm wingspan), big brown bats prefer open and structurally uncluttered areas and forage above the canopy rather than within or below (Brooks & Ford 2005, Menzel et al. 2005; Winhold & Kurta 2008). The highest occurrence of this species is likely to be in riparian zones and forest edges.

Hoary bats (*Lasiurus cinereus*) have a wide range. Found in all areas of the United States, they are also found in most of Canada (except western Canada), extensively in Mexico and even in parts of South America (Shump & Shump 1982). Like the red bat, the hoary bat is found across numerous types of habitat. Being a larger bat species (13-14.5 cm in length, up to 40 cm wingspan), they have been found to prefer open forest as opposed to more cluttered forests regardless of stand makeup (Shump & Shump 1982; Jung et al. 1999; Owen et al. 2004; Brooks & Ford 2005; Veilleux et al. 2009). In the Lake Manitoba area of Canada, hoary bats were more often found along the lake shore and marsh areas, which were relatively open and not cluttered (Barclay 1985) They have been found foraging more so at forest edges rather than forest interiors (Hein et al. 2009). Similar to red bats, Owen et al. (2004) found that hoary bats have no preference between forests with gaps and intact canopy, though its presence was low in both. In terms of canopy use previous studies show that hoary bats have a preference for foraging above the forest canopy (Kalcounis et al. 1999; Menzel et al. 2005). Given the information gathered on the hoary bat, it is likely they prefer still water areas such as bays and especially along forest edges.

The silver-haired bat (*Lasionycteris noctivagans*) has been found throughout the United States and into Canada, extending along the western coast up toward Alaska (Kunz 1982). Its wide distribution also shows that the species is adapted for a variety of habitats. In both deciduous and mixed coniferous-deciduous forests, silver-haired bats prefer riparian areas to lentic bodies found in upland areas (Owen et al. 2004; Duff & Morel 2007). Silver-haired bats have been found to forage near areas with open and still water, as well (Barclay 1985; Duff & Morrel 2007). Similar to the hoary and red bats, silver-haired bats prefer open forest areas as opposed to dense forests (Patriquin & Barclay 2003; Owen et al. 2004) and have no preference between forests with gaps and continuous canopy, though activity was low in both in comparison to riparian areas (Owen 2004). Jung (1999) had contradictory data implying silver-haired bats may be adapted to forest gaps and foraging in the presence of high vegetative clutter. No reportable literature exists on canopy height foraging preferences. Based on the review of available literature, the silver-haired bats share the same foraging characteristics as those of red bats.

Evening bats (*Nycticeius humeralis*) are smaller in size compared to hoary and big brown bats. A study conducted by Duchamps et al. (2004) found that in a more urban setting, evening bats were more prevalent in wooded areas and agricultural fields over transportation corridors, low urban development, and open water areas. In South Carolina, evening bats prefer not to forage within or below the canopy of pine forests and have been found foraging in areas of low clutter, suggesting that they prefer foraging in areas of intermediate clutter (Menzel et al. 2005).

In a study making use of radio telemetry, evening bats were found foraging in pine forests and bottomlands but rarely in upland hardwoods (Carter et al. 2004). Hein et al. (2009) found that evening bats were likely to be found foraging along forest edges. The amount of data available for evening bats is limited due to small sample sizes of collections or detections in previous studies. Based on available data, evening bats prefer to use forest edges overall.

Little brown bats (scientific name) have an extensive range across the United States (absent from Texas and parts of Oklahoma, Louisiana, New Mexico and Arizona) as well as the southern half of Canada (Fenton & Barclay 1980). The relatively small size of this bat species (6-10 cm in length, 22-27 cm wingspan), suggests that they are highly adapted for dense forest and canopy (Fenton & Barclay 1980; Jung et al. 1999; Menzel et al. 2003; Menzel et al. 2005). However, they have been found to forage low in forested and open riparian corridors (Lunde & Harestad 1986; Patriquin & Barclay 2003; Broders et al. 2003; Owen et al. 2004). Barclay (1991) also found that little brown bats prefer to forage over ponds and streams in addition to forest edges or corridors. A similar study found that little brown bats prefer to forage at forest edges as opposed to forest interiors (Hogberg et al. 2002; Hein et al. 2009), but have been found to be equally able to forage in intact canopies (Kalcounis et al. 1999; Owen et al. 2004). Additionally, little brown bats have been detected rarely in wetland areas (Zimmerman & Glanz 2000; Rogers et al. 2006). The main explanation provided for these foraging preferences likely lies more in prey availability and ease of foraging rather than their small body size serving as an adaptation to foraging in cluttered habitats (Broders et al. 2003, Patriquin & Barclay, 2003). In LBL, it is likely little brown bats will prefer to forage over riparian areas and ponds with secondary foraging habitats being forest edges and corridors.

Gray bats (*Myotis grisescens*) are very similar in size and appearance to little brown bats and are distinguished by their monochromatic gray fur (Decher & Choate 1995). Unlike the little brown bat, however, the range of the gray bat is limited predominately to the southeastern United States (Decher & Choate 1995). Gray bats are one of two federally endangered species and were listed as in 1976 (United States Department of the Interior 1976). The availability of data on foraging habitat preferences for gray bats is very limited. Gray bats have been found foraging over forest streams and along the edge of lentic water impoundments (Tuttle 1976, LaVal et al. 1977, LaVal and LaVal 1980). However studies of gray bats have focused on riparian areas and none have examined non-riparian areas (Lacki et al. 1995; Virgil & LaVal 2006; Johnson et al. 2010). Based on what little data reviewed, it is likely the majority of gray bat detections over bay and riparian zones and few over non-riparian zones.

Tricolored bats (*Perimyotis subflavus*; also known as eastern pipistrelles) are found primarily in the eastern half of the United States and along the western third of Mexico into Honduras (Arroyo-Cabrales et al. 2011). Similar to little brown bats, tricolored bats are small in size (Arroyo-Cabrales et al. 2011). Furthermore, they have been found to have similar habitat preferences to those of little brown bats. Even though they are morphologically capable of foraging in high clutter situations, they have been found to prefer open water areas such as ponds and riparian zones (Broders et al. 2003, Patriquin & Barclay 2003). They have been observed foraging in open fields such as pasture lands adjacent to forests (Davis & Mumford 1962). Furthermore, they appear to show no preference to forests with or without gap areas and will forage equally above, inside, and below the canopy (Owen et al. 2004; Menzel et al. 2005). Due to the similarities between the little brown and tricolored bats, tricolored bats prefer to forage low over riparian areas and ponds with secondary sites at forest edges and corridors.

Background on Bat Echolocation

More than 750 species of bats are capable of some form of echolocation, but which may vary among species in style and form (Schnitzler et al. 2008). The echolocation calls of bats range from 14 kHz to over 150,000 kHz, which is beyond the range of human hearing. Navigation and foraging are the two primary purposes of echolocation but it is unclear as to which purpose drove its evolutionary development (Schnitzler et al. 2008). Bats face many challenges foraging for insects at night such as weather conditions, presence and type of clutter (trees, structures, etc.), ambient noises (human generated, insect generated, etc.), availability of prey, and detectability of prey (Schnitzler et al. 2008). In general, bat calls fall under two categories: constant-frequency (CF) and frequency modulating (FM). Constant-frequencies calls, also known as narrowband calls, are those calls that fall under a narrow range of frequencies, such as 40 to 44 kHz (Schnitzler et al. 2008). Frequency modulating calls, also known as broadband calls, are those that fall under a wide range of frequencies (Schnitzler et al. 2008). For example, those bats that produce a call that ranges from 100 kHz to 20 kHz would be considered FM bats. Some species of bats are only capable of CF or FM calls while others are capable of shifting between the two types depending on their environment (Fenton 1990; Schnitzler et al. 2008). When bats are foraging in open or low clutter environments, the calls tend to be more CF in nature or have CF elements to them (Schnitzler et al. 2008). These calls tend to have a longer range and are better suited for general detection purposes such as detecting flying insects. When bats are flying in environments with obstacles such as trees, their calls tend to be FM in nature (Schnitzler et al. 2008). While these calls provide greater detail of the bat's surroundings, they have a reduced range compared to CF calls. However, range becomes less necessary in more cluttered environments.

Bats of genus *Myotis* tend to be strictly FM bats and have thus are better suited for high clutter environments (Corben et al. 2011). Bats of genus *Lasiurus* tend to be FM bats with CF elements in their calls (Corben et al. 2011). This group of bats can rapidly change the nature of their calls when they switch environments. When lasiurids are in high clutter environments the calls will be FM in nature and when in low clutter situations the calls tend to be more CF in nature. The same call structure is used by evening and silver-haired bats. Tricolored bats have mostly FM call structure with CF elements but not to the extent of the previously mentioned species (Corben et al. 2011). A commonality all aforementioned insectivorous bats share is that as they are approaching prey items, the calls become more broadband and the call rate increases. This increase in rate is so great that it is typically called a 'feeding buzz' (Corben et al. 2011). Once the prey item is seized (or missed), the calls return back to their search mode.

Acoustic Recording Instruments

Since bat echolocation calls are beyond the range of human hearing and it is difficult to observe these animals visually during the night, scientists often rely on acoustic observations using one of several recording devices designed to detect the ultrasonic calls of bats. Two such devices were used for this study. One device frequently used is called the AnaBat (Titley Electronics, Perth, Australia). The AnaBat unit detects sounds that range from 12 kHz to 250 kHz; however, the sensitivity of the device decreases as frequencies drop below 20 kHz. When a sound enters the microphone, the data are sent to what is called a Zero-Crossings Analysis Interface Module (ZCAIM) within the AnaBat unit. The ZCAIM analyzes the incoming sound wave to determine its frequency and then records that information on a compact flash card with a timestamp. The AnaBat unit also does not record every sound; it only records the loudest sound the microphone picks up in that instant. Thus, if two bats are calling at the same time, the AnaBat unit will only record the bat which is the loudest. Thus use of this device in bat surveys is limited by this aspect of the AnaBat recording device. For example, if an insect is producing a sound louder than the bat, then the bat will not be recorded and thus not detected.

Another device used for recording bat vocalizations is the Avisoft Ultrasonic Soundgate 116 (Avisoft Bioacoustics, Berlin, Germany). The Avisoft unit is a computer assisted full-spectrum recorder that can record any and all frequencies that it has been programmed to record. A full-spectrum recorder collects all sound data, including frequency, amplitude, and duration. The options available to the user range from specific frequency ranges, amplitude ranges, and other variables such as call duration and rate. Unlike the AnaBat unit, the Avisoft unit must be connected to a computer to function. When the Avisoft unit detects a sound that falls within the programmed parameters, it records and saves the sound as a .wav file with a timestamp that can be used for further analysis.

A large number of other ultrasonic acoustic recording equipment exists, but relatively few studies have been conducted to compare them. A study comparing the AnaBat unit to two full spectrum recorders, the AR-125 (Binary Acoustic Technology) and SM2 (Wildlife Acoustics) found that the three devices are not interchangeable since each device detected different species at different rates. Given this finding, caution is needed when designing experiments that use multiple detectors (Allen et al. 2011).

Purpose of Study

Land between Lakes provides a good opportunity to study bat feeding habitats in a managed natural park area. The area possesses a wide variety of habitat types, and thus, provides the opportunity to compare and contrast the foraging habitats of various bat species. The objectives of this study were to:

1) collect acoustic data from edge, field, forest, riparian, lentic, corridor and logging sites in LBL,

2) evaluate and analyze collected data to determine habitat preferences of bat species in LBL, and

3) compare the AnaBat recording device to the Avisoft recording device to test the ability of each to detect acoustic vocalizations of bat species.

CHAPTER II

MATERIALS AND METHODS

Study Area

The Land Between the Lakes National Recreation Area is a 68,800 ha peninsula about 65 km long and 12-16 km wide. It is bounded by Kentucky Lake (the impounded Tennessee River) on the west, Lake Barkley (the impounded Cumberland River) to the east, and a man-made canal connecting the two impoundments to the north. The peninsula extends southward through Lyon and Trigg counties, Kentucky, and Stewart County, Tennessee. The southern boundary is located at US Highway 79 near Dover, Tennessee (Figure 1). The region was managed from 1964 to 1999 by the Tennessee Valley Authority. Since 1999, it has been under the management of the United States Department of Agriculture Forest Service (USFS).

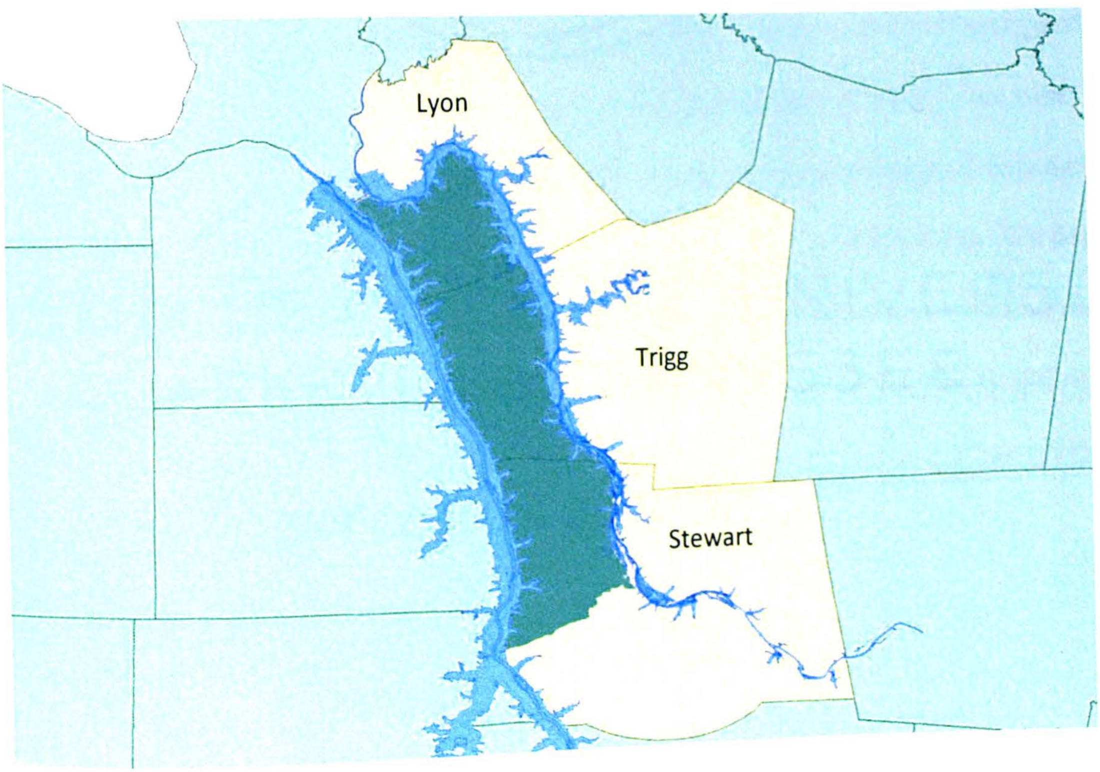


Figure 1. General geographic location of LBL (dark green shaded area) and associated counties.

The landscape of LBL consists of highly dissected uplands (USFS 2004). Around 92% percent of LBL is forested with hardwood oak species (Franklin 1994). The remaining 8% of the forests in LBL are comprised of mesophytic species (such as sugar maple, American beech, etc.) or planted pine forest (Franklin 1994). The rest of LBL consists of managed grasslands, agricultural fields and ponds. Agricultural lands are highly dissected and rotated between feed corn and soybeans (USFS 2004). A variety of grassland types are present such as maintained prairie land (such as the bison preserve), maintained wildflower plantings that are disked (or otherwise treated) every two years, straw grass plantings that are mowed yearly or unmaintained grasslands (USFS 2004).

Habitat Study Sites

A total of 18 sites were selected *a priori* to establish a good representation of habitat types within LBL (Figure 2, Appendix A). Two fields maintained grassland and two agriculture fields used to grow feed corn were selected. The agricultural and grassland field sites were divided into three sub-sites each. Each of the fields were abutted against forests. Within each field, a forest edge and a site 50 m within the forest were selected. The third site in each field included an open field site 50 m away from the forest edge. All distances were measured roughly perpendicular to the forest edge line. The purpose of doing such was to compare bat activity within a forest, at the forest edge, and in open, adjacent field sites to determine if bats exhibit a preference for one of these habitat types.

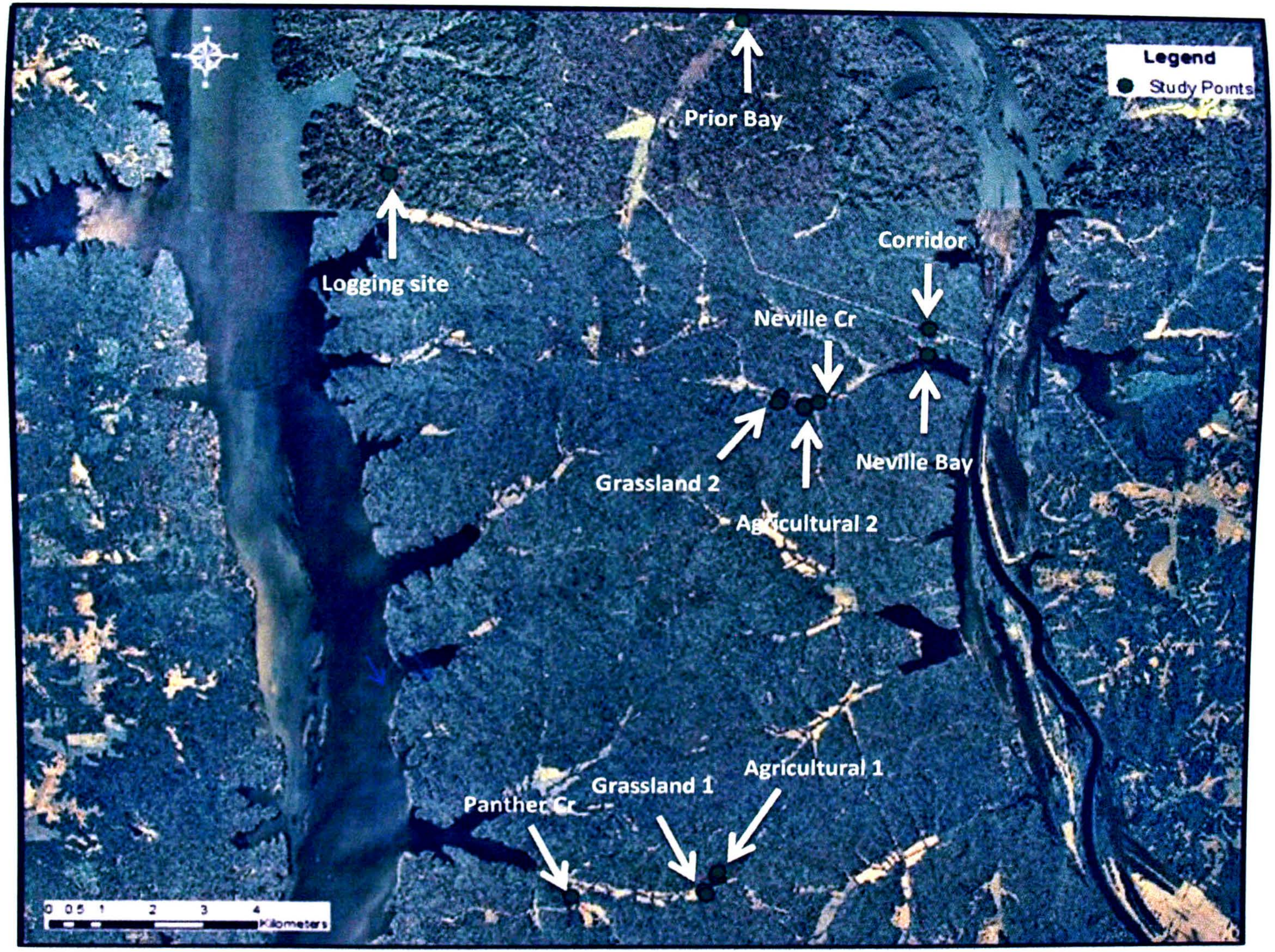


Figure 2. Map of study points with LBL. All sites are within Tennessee with the exception of the site at Prior Bay.

Two additional study sites along Panther and Neville Creeks, in which detectors were placed on banks immediately adjacent to each stream, were also examined. Panther Creek is a continuous stream with 50% canopy coverage with consistent flow from Piney Bay of Kentucky Lake. Neville Creek is an intermittent stream that periodically dries depending on rainfall levels. During the study, water was consistently present within the stream though its flow varied with rainfall amounts. Like Panther Creek, the canopy cover was approximately 50%.

A 10 m wide power line corridor that went through a forest was also selected as a study site. The detectors were placed approximately in the middle of the corridor to record bat activity. The final selected site was a logging site that had been logged more than five years prior to the study. The latter was chosen to represent open woodland with open canopy relative to the aforementioned forest sites.

The study sites selected are only a small portion of the total variety of habitat and landscape types that bats likely encounter and use as foraging sites. However, the selected study sites were purposefully chosen to encompass some of the variety of habitats to further explore whether bats in general or specific bat species show preferences for a given habitat type when foraging for food. However, it is important to note that those represented herein do not represent all habitat types used by bats or even all types within the LBL region.

Acoustic Recording Instruments

The acoustic recording instrument used to determine habitat preference was the AnaBat (Titley Electronics of Perth, Australia). Five AnaBat units including two models, the SD1 and SD2 were used for the course of the project. Furthermore, two microphone types were available:

AnaBat standard microphone and AnaBat high mount extension cable microphone. Because no studies have been conducted to determine if one model or one microphone is more effective than the other, the different models and microphones were assigned randomly to study sites (Figure 2) during each sampling night with three to five units deployed at a time. All AnaBat units were calibrated to a sensitivity level of six with the audio and data division levels set at eight (Corben et al. 2011, Appendix B). Using either SanDisk 2GB Compact Flash or SanDisk 4GB Compact Flash cards, the AnaBat units were programmed to start recording at or up to 15 minutes prior to sunset and were allowed to record for 4.5 hours after sunset. The reasons for the shorter recording period as opposed to recording all night are primarily logistical. Those who sampled with AnaBat units to record all night often weather proofed their equipment and a study found that such weather proofing could affect the detectability of bats (Britzke et al. 2011). Furthermore, the weather during the summer months in Tennessee is highly variable with severe weather developing rapidly. Research has found that the bulk of bat activity occurs during the first half of the night (Kunz 1973; Thomas et al. 1987; Hayes 1997; Rogers 2006). Because of the shorter recording period, however, some bat species may have been missed. Thus, all inferences made from collected data were limited to the first 4.5 hours of the night following sunset.

The AnaBat units were mounted on either Red Head or Brucus tripods and secured using canopy ties. All detectors were set at a height of approximately 1.8 meters (the maximum height allowed by the Red Head tripod). The angle for the detectors was 90 degrees perpendicular to the ground (Britzke et al. 2011). In certain cases, to protect against condensation, the AnaBat units were wrapped in a hand towel but the microphone was left uncovered.

In order to compare the effectiveness of the AnaBat to the Avisoft devices, the Avisoft UltraSoundGate 116 (Avisoft Bioacoustics, Berlin, Germany) with a CM16/CMPA microphone was also used. The two different devices were set up side-by-side at each study location and for each recording event. On certain nights, the AnaBat and Avisoft units were deployed side by side at random habitats for twenty minutes at a time (Johnson 2002). This was done during the course of the 4.5 hour recording period of the habitat study. GPS coordinates were taken at each site and a description of the site was recorded. On August 4th, 2011, an AnaBat SD2 ceased operating. Because a total of four AnaBat units were needed to complete the study within the allotted timeframe, the random 20 minute comparative trials were no longer logistically possible. Thus for the duration of the study, the AnaBat and Avisoft units were deployed side by side on tripods at one of the 18 previously mentioned habitat study sites. To eliminate potential site-based bias, the sites were selected randomly each recording night. The Avisoft unit recorded for up to 2 hours since that is the battery life of the Dell Laptop. The units were deployed at the same height and angle (1.8 m and 90°).

The Avisoft units were used in conjunction with a Dell Latitude laptop and acoustic recording software, Recorder USG (Avisoft Bioacoustics 2010). Calls within the range of 14 kHz to 250 kHz were recorded to duplicate the settings of those used for the AnaBat unit. Each triggered recording occurred for a maximum of 15 seconds, which is the maximum recording length for the AnaBat unit. Recorded calls were saved as .wav files The Recorder USG program has several filters designed to eliminate abiotic and biotic noise. Since the AnaBat unit has no such filters built into it, they were not used for the Avisoft unit. The gain or sensitivity level was set to five, which is the approximate middle level and the level most comparable to that used for the AnaBat unit.

Mist-netting and Harp Trapping

Due to logistical concerns and federal permit issues related to contaminating bats with White Nose Syndrome (WNS), mist-netting and harp trapping were not conducted as part of this study. However, previous mist-netting studies have been conducted within LBL. That data was accessible and used to as an indication of the species of bats have been established as present in LBL. Having this information lends greater credence to species identification when using acoustic identification (Ford et al. 2010).

Data Analysis

AnaBat files were analyzed with BCID East 2012 (Bat Call Identification, Inc.). BCID East 2012 evaluates the parameters of bat calls such as mean frequency, slope of the call, duration, and others and compares them to a reference library of call parameters of known bat species. The program also filters out extraneous noise files (such as those files only containing insect noise) and produces a spreadsheet that details what bat species was identified in each file and its confidence level. The resulting files were visually inspected to find any possible errors and compared with bat call examples provided in Corben et al. (2011). All files with fewer than five pulses or those sequences that were of poor quality were designated as unknown (Britzke et al. 2011). Greater conservation was used with files designated as belonging to *Myotis grisescens* and *M. sodalis.* Both species are federally endangered and their presence in LBL would have serious implications for management policies. It would be inappropriate to presume their presence based solely on the recording of a call alone since the calls of the *Myotis* genus are quite similar to each other. It is better to confirm species presence visually through mist-netting or harp trapping to make better informed policy decisions.

Table 1.
List of species names and abbreviations used for the purposes of this study.

Species	Common Name	Abbr.
Eptesicus fuscus	Big brown bat	EPFU
Lasiurus borealis	Eastern red bat	LABO
Lasiurus cinereus	Hoary bat	LACI
Lasionycteris noctivagans	Silver-haired bat	LANO
Myotis grisescens	Gray bat	MYGR
Myotis lucifugus	Little brown bat	MYLU
Myotis species	Myotis species	MYsp
Nycticeius humeralis	Evening bat	NYHU
Perimyotis subflavus	Tricolored bat	PESU

Avisoft files were analyzed using SonoBat 3.05 Ozark Suite (SonoBat 2012). Like BCID, SonoBat analyzes the parameters of bat calls such as mean frequency, slope of the call, duration, and others and compares them against files known to belong to specific species, particularly those of the southeastern United States. SonoBat 3.05 builds a spreadsheet detailing what species were determined and the confidence in the identification. A visual assessment of each file was conducted also to identify any potential call errors. As with the AnaBat unit data, greater conservatism was used with calls designated as belonging to *M. grisescens* and *M. sodalis.* Any files which had fewer than five calls or were too low in quality were designated as unknown (Britzke 2011).

The use of two different programs to analyze the data from the two different devices was necessary because AnaBat files do not have amplitude data and are a different format than the .wav file produced by the Avisoft unit and the files cannot be converted to the other format Thus, this study will not only compare the two detectors, but also the overall methodology for analyzing and identifying bat calls.

Statistical Analyses

Site to Site Comparisons

The JMP 9.0.2 (SAS Inc. 2010) software was used for all statistical analyses. A majority of the data collected (both total bat calls and species-specific calls) was not normally distributed. Transforming the data to normality only worked for two categories: total bat calls recorded and those belonging to the evening bat. The transformation that yielded the most normal distribution for these two categories was the Box-Cox power transformation.

To test if site had an effect on overall bat and bat species activity, either one-way analyses of variance (ANOVAs) or Kruskal-Wallis tests were conducted depending on the normality of the data analyzed. The data were pooled across dates for these tests (Ford et al. 2005). The *post hoc* test for significant ANOVAs was the Tukey-Kramer HSD and the *post hoc* test for significant results from a Kruskal-Wallis was the Steel-Dwass All Pairs test (Neuhauser & Bretz 2001). In the *post hoc* tests, the following comparisons were made: activity within the agricultural and grasslands, activity between the edges, fields, and forests of the agricultural and grasslands, activity between the bays, activity between the creeks, activity between creeks and bays combined, and any differences between those sites with water and the agricultural/grassland sites. Additionally, the corridor site was compared to the other edge sites to get a preliminary estimation of whether the presence of power lines affects bat presence. The logging site was compared to the field sub-sites to preliminarily evaluate the effects of logging on bat presence.

No tests for interaction between habitat sites and month were conducted because each habitat site was recorded only twice per month. Due to this small sampling effort by month, it was not appropriate to test for any interaction.

Comparison of Species

Species-specific acoustic data were not normally distributed even after transformation attempts. Kruskal-Wallis tests were conducted to determine if there was a significant difference in number of bat calls between species. No tests for interactions were tested between species detected and site or species detected and month as there is no consensus on the best nonparametric equivalent of a two-way ANOVA (Baskauf, personal comm.).

Comparing Avisoft and AnaBat Analyses of Bat Calls

The Avisoft unit could only record from two to three hours each night due to the battery life of the Dell laptop. Only the first two hours of data from both the Avisoft and the AnaBat units for each recording night were used for the purposes of comparison. The data were divided into two sets: those data from the 20 minute recording sessions and those data from the two hour recording sessions. The data were not normally distributed and the nonparametric Wilcoxon Rank Sums test was used to compare the total calls recorded and the number of calls by species between the two detectors. The number of species each device recorded at each site was also compared. This data was normally distributed and so a t-test was used for that comparison.

CHAPTER III

RESULTS

Acoustic devices were set out at most sites two nights a month from June to October for a total of 45 nights with a total of 175 4.5 hour successful recording sessions. Due to a failure of an AnaBat device, the forest in Grassland 2 was only recorded once in August and once in October. Neville bay was only recorded once in September and was not recorded in October due to the presence of campers. The potential for human presence confounding the data were cited as concerns. Due to the robust nature of the ANOVA and Kruskal-Wallis, Neville Bay was included in the analysis but significant results were evaluated conservatively as suggested by Sokal & Rohlf (1995).

A total of 184,520 sound files were recorded using the AnaBat detector. Of those, 32,659 files contained bat calls and 18,037 files could be successfully identified to species or genus (Figure 3). The other 151,861 files were either random abiotic noise or insect sounds recorded during the night. The means and standard errors of calls by site and by species are presented in Table 2 and Table 3 provides the he means and standard deviations of calls by month and by species.

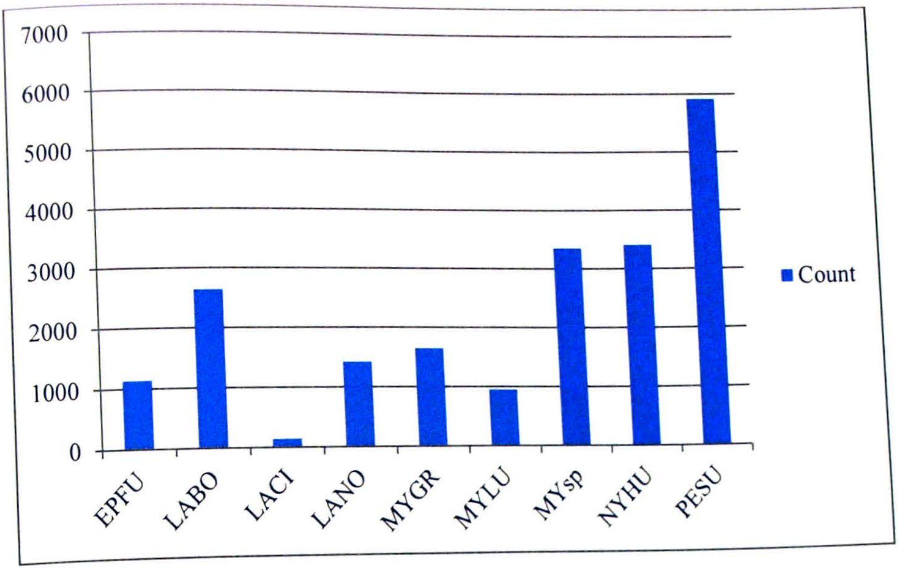


Figure 3. Total counts of bat call files by species or genus. Files designated UNKN were left out to preserve scale (N=14622). All files were identified by BCID 2012 and visually confirmed with reference files.

Table 2.
Means and standard errors of bat files by species and site. All files were identified by BCID 2012 and visually confirmed with reference files.

Site	EPFU	LABO	LACI	LANO	MYGR	MYLU	MYsp	NYHU	PESU	UNKN	Overall Mear
Agri 1 - Edge	16.5±7.8	65.6±24.8	1.7±0.7	13.1±4.7	13.1±3.4	45±22.6	10.8±20.2	59.4±20.2	51.3±14.4	133.5±25.5	410±97.1
Agri 1 - Field	13.9±3.9	13.9±5.1	0.9±0.3	22±9.7	3.6±2.2	2.0±1.0	0.5±0.3	47±17.4	33.0±11.0	108.7±29.6	245.5±51.3
Agri 1 - Forest	1.5±0.8	0.1±0.1	1.0±0.89	4.1±3.4	0.2±0.2	0.0±0.0	0.0±0.0	1.3±0.4	0.1±0.1	42.1±16.5	50.4±19.8
Agri 2 - Edge	2.0±0.7	8.5±3.8	0.9±0.3	1.3±0.5	7.5±3.9	3.5±2.2	2.6±0.9	5.7±1.7	20.8±5.0	70.2±12.9	123.0±23.2
Agri 2 - Field	3.6±2.1	10.1±51	0.2±0.1	3.7±1.2	0.9±0.3	0.4±0.3	0.2±0.2	15.8±4.9	36.6±11.8	51.3±7.4	122.8±23.5
Agri 2 - Forest	1.7±1.3	1.0±1.0	0.0±0.0	0.9±0.5	0.0±0.0	0.0±0.0	0.2±0.1	1.9±1.7	0.3±0.2	21.8±4.3	27.8±5.2
Corridor	3.5±1.5	6.6±2.4	0.0±0.0	2.6±0.9	5.2±1.6	2.2±0.6	1.7±0.6	12.8±4.7	31.7±8.1	56.1±15.1	122.5±31.3
Grassland 1 - Edge	13.2±6.0	36.7±10.9	1.7±1.2	9.6±5.5	8.6±2.0	13.1±6.9	9.2±3.4	38.2±8.2	54.9±10.7	85.8±21.4	271.0±40.5
Grassland 1 - Field	17.0±13.8	6.1±2.5	0.6±.04	16.3±12.6	0.7±0.4	0.2±0.1	0.1±0.1	12.7±3.8	12.1±4.6	39.8±13.0	105.6±30.1
Grassland 1 - Forest	0.1±0.1	0.1±0.1	0.8±0.7	0.5±0.5	0.0±0.0	0.2±0.2	0.0±0.0	0.4±0.3	0.5±0.2	15.4±3.4	18.0±4.1
Grassland 2 - Edge	5.4±1.5	15.3±4.5	0.1±0.1	4.0±1.3	22.4±14.3	9.4±4.0	7.0±4.1	16.6±4.1	26.2±5.5	166.0±41.4	272.4±55.4
Grassland 2 - Field	6.9±2.7	5.6±1.4	1.4±0.7	39.3±24.7	2.3±1.0	0.7±0.3	0.0±0.0	17.4±5.1	26.5±9.1	66.9±11.5	167.0±40.2
Grassland 2 - Forest	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.3±0.3	0.0±0.0	17.1±3.4	17.4±3.5
Logging	0.3±0.2	9.6±1.9	0.0±0.0	1.0±0.5	3.2±1.0	2.5±0.6	1.2±0.4	7.6±1.1	24.8±6.8	58.4±20.0	108.6±23.1
Neville Bay	13.3±11.1	8.3±2.3	1.0±0.7	3.3±1.0	7.0±1.3	1.6±0.8	1.4±0.8	15.7±6.3	57.4±20.5	89.9±22.7	198.9±38.9
Neville Creek	11.2±6.3	36.9±16.9	0.6±0.3	3.5±1.0	7.3±1.5	5.6±2.0	6.4±2.1	33.7±15.9	58.4±21.9	154.8±50.1	318.4±102.0
Panther Creek	5.7±4.3	17.0±4.5	0.2±0.2	12.4±7.6	6.2±1.7	6.3±2.5	6.3±1.5	17.4±3.4	50.6±10.7	155.7±30.0	277.8±42.3
Prior Bay	3.5±1.4	25.2±4.8	3.6±1.3	7.2±3.3	78.5±39.8	3.0±.1.0	27.6±9.4	42.4±6.5	121.9±31.4	157.5±30.3	470.4±96.3

Table 3.
Means and standard deviations of bat call files by species and month. All files were identified by BCID 2012 and visually confirmed with reference files.

Month	EPFU	LABO	LACI	LANO	MYGR	MYLU	MYsp	NYHU	PESU	UNKN	Overall Mean
June	5.4±1.2	19±5.8	1.0±0.4	2.9±0.5	3.9±1.4	7.8±4.4	4.2±1.7	23.1±5.6	37.6±6.7	37.6±6.6	162.9±31.4
July	3.2±0.8	28.9±8.0	0.8±0.3	1.9±0.4	21.8±12.0	13.6±5.8	8.0±2.9	25.9±6.4	57.3±12.4	106.2±19.8	267.8±50.9
August	9.9±4.0	12.1±3.5	1.1±0.4	18.9±7.9	7.7±2.0	3.6±1.0	4.7±1.6	18.4±4.0	30.6±7.1	85.3±15.7	192.4±30.5
September	8.9±3.3	7.3±1.8	0.6±0.2	4.5±1.7	5.2±1.3	1.5±0.4	0.9±0.3	18.8±5.9	25.2±4.6	90.4±13.7	163.3±22.1
October	5.2±2.4	7.4±1.4	0.5±0.3	12.6±3.6	8.2±4.5	0.3±0.1	3.5±1.4	10.7±2.3	16.8±4.0	76.6±9.7	141.7±19.7

Comparison of Bat Calls Recorded Across Months

Although July had the most calls on average, a one-way ANOVA testing total bat calls across months revealed no significant difference ($F_{4,174}$=0.6225, p=0.6225). A one-way ANOVA revealed no significant difference in the amount of evening bat calls across months ($F_{4,174}$=0.5221, p=0.7196). Kruskal-Wallis tests revealed no significant difference in the amount of calls across months for big brown, hoary, eastern red, gray, and tricolored bats as well as those bats of the *Myotis* genus (Table 4). The Kruskal-Wallis test did reveal a significant difference in the number of silver-haired bat calls across months (χ^2_4=23.6500, DF=4, p<0.0001). Steel Dwass All Pairs tests revealed that October had significantly more silver-haired bat calls than the months of June, July and August (all *p*-values<0.0035). All other month to month comparisons revealed no significant differences (all *p*-values>0.0556). The Kruskal-Wallis test revealed a significant difference in the number of little brown bat calls across months (χ^2_4=21.7680, p=0.0002). Steel-Dwass All Pairs tests indicated that the month of October had significantly more little brown bat calls than the months of June, July and August (Steel-Dwass All Pairs, all *p*-values<0.0082). All other month to month comparisons revealed no significant differences (Steel-Dwass All Pairs, all *p*-values>0.0921).

Table 4.
Chi-squared, degrees of freedom and *p*-values for Kruskal-Wallis tests comparing species specific call amounts between sites.

Species	χ^2	DF	*p*-value
Eptesicus fuscus	4.0197	4	0.4033
Lasiurus borealis	6.8154	4	0.1460
Lasiurus cinereus	3.2739	4	0.5131
Myotis grisescens	5.3420	4	0.2540
Perimyotis subflavus	7.7434	4	0.1014
Myotis genus	5.0118	4	0.2861

Comparison of Bat Calls Recorded between Field and Water Sites

Total bat calls

An one-way ANOVA revealed a significant difference in the number of bat calls between sites in LBL ($F_{17,174}$ = 19.0656, p <0.0001). Within Agricultural Field 1 (Agri 1), there was no significant difference between the field and edge (p=0.9869). Both field and edge did have a significantly higher number of calls compared to the forest (p<0.0001 for both edge and field against forest). The same trend was found for Agricultural Field 2 (Agri 2, p=0.0021 for edge against forest, p=0.0014 for field against forest), Grassland 1 (p<0.0001 for edge against forest, p =0.0003 for field against forest) and Grassland 2 (p<0.0001 for both edge and field against forest).

When comparing across the different edge locations, there were more total bat calls at the edge of Agri 1 than Agri 2 (p=0.0037). The test detected no other significant differences between the different edge sub-sites (all p-values>0.0571) or between the fields and forest sub-sites for the agricultural and grassland fields (all p-values>0.3171).

No significant differences were detected among Prior Bay, Neville Bay, Neville Creek and Panther Creek (all p-values>0.7553). Prior Bay had significantly more bat calls on average compared to all sub-sites of Agri 2, the field of Grassland 1, and all forest sub-sites (all p-values<0.0121). Neville Bay had significantly more calls overall than all forest sub-sites (all p-values<0.0001). The test detected no significant differences between Neville bay and all other agricultural and grassland sub-sites (all p-values>0.4478). Panther Creek had significantly more calls than the field of Grassland 1 and all forest sub-sites (all p>0.0446). No other differences between Panther Creek and the other sub-sites were detected (all p-values>0.2829). Neville Creek had significantly more bat calls than all the forest sub-sites (all p-values<0.0001). The test revealed no other significant differences comparing Neville creek to other sub-sites (all p-values>0.4478).

Eptesicus fuscus

Kruskal-Wallis Test revealed a significant difference in big brown bat calls by site (χ^2_{17}= 66.318, p<0.0001). When comparing the edge, field, and forests of the agricultural areas, no significant differences were detected (all p-values>0.2128). The field and edge sites of the two grasslands also did not have any significant differences (all p-values>0.4554). The edges of both, however, did have higher numbers than their respective forest sites (p=0.0123 for Grassland 1 edge to forest, p=0.0260 for Grassland 2 edge to forest). No significant differences were detected when comparing across edges, across fields and across forests (all p-values>0.5167). No significant differences were detected across Prior Bay, Neville Bay, Neville Creek and Panther

Creek (all p-values>0.9996). Finally, no significant differences were detected when comparing the water sites with the agricultural and grassland areas (all p-values>0.7577).

Lasiurus borealis

Kruskal-Wallis test revealed a difference in the number of eastern red bat calls by site (χ^2_{17} = 105.3795, p<0.0001). In Agri 1, there was no significant difference between the field and edge portion (p=0.7581). Both edge and field had a significantly higher number of calls than the forest (p= 0.0107 for both.) There was no significant difference detected between edge, field and forest sites of Agri 2 (p=1.0000). The edge and field of Grassland 1 had significantly more calls than the forest (p=0.0107 and p=0.0190 respectively). The field of Grassland 1 showed no significant difference from its respective edge (p=0.3202). The amount of red bat calls recorded at the edge, however, was higher than those recorded in the forest (p= 0.0269). The amount of eastern red bat calls at the edge and field of Grassland 2 were not significantly different from each other (p=0.9826). The field and forest of Grassland 2 did not show any significant difference (p=0.0713). The edge of Grassland 2 had significantly more calls recorded than in the forest (p=0.0269). Finally, no significant differences were detected among the different edges, fields and forests (all p-values>0.5007).

No significant differences were detected among Prior Bay, Neville Bay, Neville Creek and Panther Creek (all p-values>0.6104) or between the water sites and the edge and fields of the agricultural and grassland sites (all p-values>0.1683 and higher). All water sites had significantly more activity than the forest sites (all p-values<0.493).

Lasiurus cinereus

Kruskal-Wallis test revealed a significant difference comparing the number of hoary bat calls between sites (χ^2_{17}=45.3557, p=0.0002). However, the Steel-Dwass All Pairs test revealed no significant difference across all pairs (all p-values>0.1219). The Kruskal-Wallis may have detected a significant difference that is not substantial enough to be detected by the more conservative Steel-Dwass All Pairs Test.

Lasionycteris noctivagans

Kruskal-Wallis test revealed a significant difference comparing the number of hoary bat calls to sites (χ^2_{17}= 59.1341, p<.0001). Significant differences between sites did exist, but none that apply to comparing the sub-sites within and between the agricultural and grassland sites (all p-values>0.1049). There were no significant differences detected between Prior Bay, Neville Bay, Panther Creek and Neville Creek (all p-values=1.0000) or between any agricultural, grassland, and water sites (all p-values>0.0537).

Myotis grisescens

Kruskal-Wallis test revealed a significant difference comparing the number of gray bat calls to sites (χ^2_{17} = 96.1401, p<.0001). In Agri 1, there was no difference detected between field and edge or field and forest (p=0.5069 and p=0.8894 respectively). The edge had significantly more calls than the forest (p=0.0404). In Agri 2, there were no significant differences detected across all sub-sites (all p-values>0.0704). The edge of Grassland 1 had more gray bat calls than the field and forest (p=0.0438 and 0.0080 respectively). The field of Grassland 1 was not significantly different than the respective forest (p=0.9251). Grassland 2's edge had significantly more calls than its field and forest (p=0.0438 and p=0.008 respectively). No significant difference was detected between forest and field. Finally, Grassland 2's field showed no significant difference compared to the forest or to the edge (p=0.952). The edge had significantly more calls than the forest (p=0.0269).

No significant differences were detected when comparing between all edges, all fields, all forests, and the water sites (all p-values>0.0512). In comparing the grasslands and agricultural fields to the water sites, the forests had significantly fewer calls than the water sites (all p-values<0.0438).

Myotis lucifugus

Kruskal-Wallis test revealed a significant difference comparing the number of little brown bat calls to sites ($\chi^2_{17} = 82.2960$, $p<0.0001$). Significant differences between sites did exist, but none were among the sub-sites within and between the agricultural and grassland sites (all p-values>0.0669).

There were no significant differences detected between Prior Bay, Neville Bay, Panther Creek, and Neville Creek (all p-values>0.9776). Neville and Panther Creeks had significantly more calls detected than the forests of Agri 1 and 2. (all p-values<0.0251). All other water site to grassland/agricultural comparisons were not significant (all p-values>0.0843).

Myotis species

For the purposes of the analyses, all files classified as being in the genus *Myotis* were pooled together, including those files identified as *Myotis lucifugus* and *Myotis grisescens.* A Kruskal-Wallis test revealed there was a significant difference in the activity of *Myotis* species between sites ($\chi^2_{17} = 113.9501$, $p<0.0001$). The edge sub-sites at Agri 1 and Grasslands 1 and 2 had more activity than their respective forest sub-sites (all p-values <0.0404). The edge of

Grassland 1 had more activity than its respective field sub-site (*p*=0.0313). No other significant differences, when comparing different or similar (i.e. edge to edge) sub-sites to each other, were detected (all *p*-values>0.0714).

The Steel-Dwass Test revealed no difference in *Myotis* species activity between the field sites and Prior Bay (all *p*-values>0.0568). Neville Bay, Panther Creek, and Neville Creek all had more *Myotis* activity than all the forest sub-sites (all *p*-values>0.0459). More *Myotis* calls were recorded at Neville Creek than the field sub-sites of Grassland 1, Grassland 2 and Agri 2 (all *p*-values>0.0294). All other sites with water to sites without water comparisons were not significant (all *p*-values >0.0568).

Perimyotis subflavus

Kruskal-Wallis test revealed a significant difference in the number of tricolored bat calls by sites ($\chi^2_{17} = 105.0419$, $p<0.0001$). The test revealed no significant difference in tricolored bat calls between the field and edge of Agri 1 (*p*=0.2260). Both field and edge, however, had significantly more calls than in the forest (*p*<0.0001 for both). No significant difference was detected between the field and edge of Agri 2 (*p*=0.5700). Both field and edge had significantly more calls than in the forest (*p*<0.0001 for both). The edge of Grassland 1 had significantly more calls than both the field and the forest of the same site (*p*=.0014 and *p*<0.0001 respectively). The field of Grassland 1 had significantly more calls than the forest (*p*=0.0005). Both the field and edge of Grassland 2 had significantly more calls than the forest (*p*=0.0002). Grassland 2 edge and field did not significantly differ from each other (*p*=0.4960).

Grassland 1 edge had significantly more tricolored bat calls than Agri 2 and Grassland 1 edges (*p*=0.0257 and 0.0407 respectively). All other comparisons of edges to edges, fields to fields and forests to forests were not significant (all p-values>0.0599). The test revealed no significant differences between the water sites (all p-values>0.1041).

Prior Bay did not have more calls than either edges of Agri 1 and Grassland 1 (p=0.1212 and p=0.1620 respectively). When compared to all other agricultural and grassland sub-sites, there was significantly higher activity at Prior Bay (all p-values<0.0172). Neville Bay only had more tricolored bat calls than all the forest sites (all p-values<0.0006). Panther Creek did not have significantly more calls than the fields and edges of Grassland 2 and Agri 1 (all p-values>0.0694). Nor did it have more calls than the edge of Grassland 1 (p-values>0.8205). It did have more calls than other agricultural and grassland sub-sites (all p-values<0.0376). Neville Creek did not have more calls than the edges and fields of Grassland 2, Agri 1, and Agri 2 (all p-values>0.3840). Like Panther Creek, it did not have more calls than the edge of Grassland 1 (p=0.4270). Neville Creek had more calls recorded than all other agricultural and grassland sites (all p-values<0.0159).

Nycticeius humeralis

An one-way ANOVA revealed a significant difference in evening bat calls between sites ($F_{17,174}$=20.5397, p<0.0001). The edge and field of Agri 1 were not significantly different from each other (p=1.0000). The edge had significantly more calls than the forest (p=0.0053). This was not the case for the field compared to the forest (p=0.1041). The sub-sites of Agri 2 had no significant differences (all p-values>0.3023). Grassland 1's edge and field were not significantly different from each other (p=0.7268). The field was not significantly higher than the forest, but the edge was higher than the forest (p=0.9702 and p=0.0111 respectively). The edge and field of Grassland 2 were not significantly different from each other (p=0.7268). The field was not significantly higher than the forest, but the edge was higher than the forest (p=0.9702 and

$p=0.0111$ respectively).

Across the edges, there were no significant differences between Agri 1, Grassland 1 and Grassland 2 (all p-values>.8440). The edges of Agri 1 and Grassland 1 had significantly more evening bat calls than the edge of Agri 2 (both p-values<0.0084). The edges of Grassland 2 and Agri 2 were not significantly different from each other ($p=0.6025$). No significant differences were detected across fields, forests or water sites (all p-values>0.1204). When comparing water sites to field sites, Prior Bay had significantly more calls on average than the edge of Agri 2 ($p=0.0002$). No other differences between water and the agricultural and grassland sub sites detected (all p-values>0.1204).

Logging Site

Total Bat Calls

The logging site had significantly more bat calls than the forests of Agri 2, Grassland 1 and Grassland 2 (all p-values<0.0043). Prior Bay and the edge of Agri 1 had significantly more calls than the logging site ($p=0.0042$ and $p=0.0203$ respectively). The test detected no other significant differences between the logging site and all other sites (all p-values 0.0505 and higher).

Eptesicus fuscus

The logging site had significantly higher activity than Grassland 1 and 2 edges ($p=0.0263$ and $p=0.0494$ respectively). All other comparisons were not significant (all p-values>0.0640).

Lasiurus borealis

The logging site had significantly higher activity than all the forest sub-sites (all *p*-values<0.0496). The test did not reveal a significant difference when compared to all other sites (all *p*-values>.5588).

Lasionycteris noctivagans

No significant differences were detected when comparing the logging site against all other sites (all *p*-values>0.0630).

Myotis grisescens

No significant differences were detected when comparing the logging site against all other sites (all *p*-values>0.0707).

Myotis lucifugus

Significantly more little brown bat calls were recorded at the logging site compared to the forests of Agri 1 and 2 (*p*=0.0248 for both). The test detected no significant differences between the logging site and any other site (all *p*-values>0.0691).

Myotis species

Myotis species were more frequently recorded at the logging site when compared to all forest sub-sites (all *p*-values<0.0266). No significant differences were detected when comparing the logging site to all other sites (all *p*-values>0.1151).

Perimyotis subflavus

Significantly more tricolored bat calls were recorded at the logging site compared to the forests forest sub-sites (all p-values<0.0266). The test detected no significant differences between the logging site and any other site (all p-values>0.6295).

Nycticeius humeralis

Evening bats were more frequently recorded at the logging site when compared to all forest sub-sites (all p-values<0.0021). No significant differences were detected when comparing the logging site to all other sites (all p-values>0.1151). Prior bay had more evening bat calls than the logging site (p=0.0433).

Corridor Site

Total Bat Calls

The Steel-Dwass All Pairs test revealed that the corridor site had significantly more calls recorded than all the forest sub-sites (all p-values<0.0303). Prior Bay and the edge of Agri 1 had significantly more calls than the corridor site (p=0.0034 and p=0.0198 respectively). The test detected no other significant differences between the corridor site and all other sites (all p-values 0.1756 and higher).

Eptesicus fuscus

No significant differences were detected when comparing the corridor site to the edge sub-sites (or any of the other 17 sites, all p-values>0.7078).

Lasiurus borealis

No significant differences were detected when comparing the corridor site to the edge sub-sites (or any of the other 17 sites, all p-values>0.1274).

Lasionycteris noctivagans

There was no significant difference in the number of silver-haired bat calls when comparing the corridor site to any other study site (all p-values>0.3163).

Myotis grisescens

No significant differences were detected when comparing the corridor site against all other sites (all p-values>0.0707).

Myotis lucifugus

Significantly more little brown bat calls were recorded at the corridor site compared to the forests of Agri 1 and 2 (p=0.0173 for both). The test detected no significant differences between the corridor site and any other site (all p-values>0.1581).

Myotis species

More *Myotis species* calls were recorded at the corridor site than all of the forest sub-sites, the fields of Grassland 1 and Agri 2 (all p-values<0.0491). No significant difference was detected when compared against all other sites (all p-values>0.2764).

Perimyotis subflavus

Significantly more tricolored bat calls were recorded at the corridor site compared to the forest sub-sites (all p-values<0.0218). The Steel-Dwass All Pairs test detected no significant differences between the corridor site and any other site (all p-values>0.6919).

Nycticeius humeralis

Evening bats were more frequently recorded at the corridor site when compared to all forest sub-sites (all *p*-values<0.0006). No significant differences were detected when comparing the corridor site to all other sites (all *p*-values>0.0590).

Comparison of Recordings from AnaBat and Avisoft Units

The AnaBat units recorded a total of 4,297 sound files and the Avisoft unit recorded 3,720 sound files (Figure 4). Means and standard errors are presented in Tables 5 and 6. Wilcoxon test results for the 20 minute recording sessions revealed that the AnaBat unit recorded significantly more noise files (files with no bat calls in them) and files identified as little brown bats (Table 7). No significant differences were detected when comparing the detectors' recordings of all other species, total bat calls, or those files in which the calls could not be identified to a specific species (Table 7). There also was no difference between the number of species each session recorded (Z_{50}=-1.01935, p=0.3080).

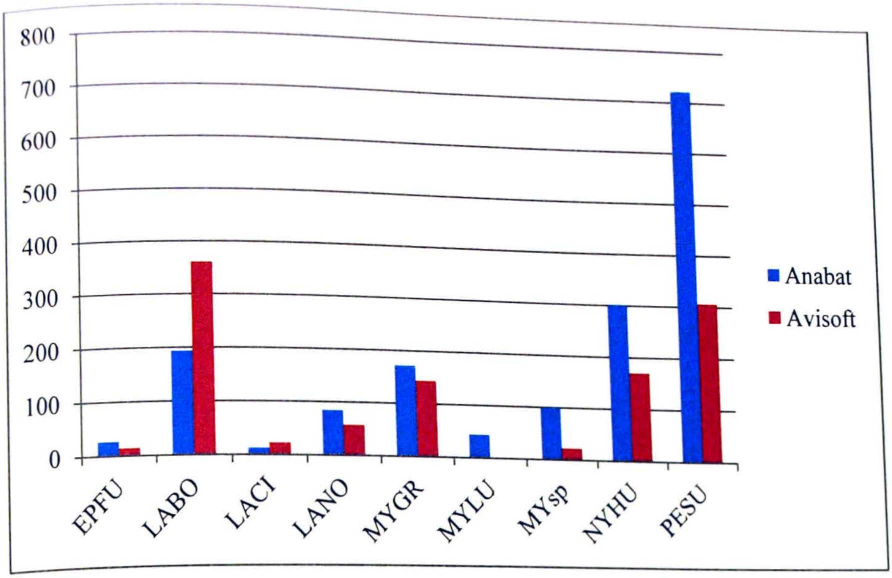


Figure 4. Total bat call files collected by species. Files designated as UNKN (N=1294 for AnaBat, N=443 Avisoft) removed to maintain scale. All AnaBat files were identified by BCID 2012 and visually confirmed with reference files. All Avisoft files were identified by SonoBat 3.05 and visually confirmed with reference files.

Table 5.
Means and standard errors for the number of bat call files by species per detector after two hours of recording. All AnaBat files were identified by BCID 2012 and visually confirmed with reference files. All Avisoft files were identified by SonoBat 3.05 and visually confirmed with reference files.

Detector	EPFU	LABO	LACI	LANO	MYGR	MYLU	MYsp	NYHU	PESU	UNKN	Total	Noise	# of Species
AnaBat	1.6±0.4	5.8±2.0	0.3±0.1	5.1±2.3	7.1±3.6	0.8±0.3	4.4±2.3	12.6±4.6	20.7±8.8	70.7±14.8	129.1±32.0	358.3±140.6	4.7±0.7
Avisoft	0.7±0.4	16.7±8.9	0.5±0.3	3.1±1.3	6.7±3.3	0.06±0.06	0.8±0.3	8.0±3.6	9.1±2.7	22.6±9.4	68.2±25.0	134.4±68.5	3.6±0.6

Table 6.
Means and standard errors for the number of bat call files by species per detector after 20 minutes of recording. All AnaBat files were identified by BCID 2012 and visually confirmed with reference files. All Avisoft files were identified by SonoBat 3.05 and visually confirmed with reference files.

Detector	EPFU	LABO	LACI	LANO	MYGR	MYLU	MYsp	NYHU	PESU	UNKN	Total	Noise	# of Species
AnaBat	0.1±0.05	4.0±1.4	0.4±0.2	0.2±0.1	2.3±0.9	1.2±0.4	1.1±.4	4.0±1.2	15.7±4.5	6.7±1.6	35.58.2	66.2±21.4	3.8±0.4
Avisoft	0.2±0.1	3.8±1.9	0.6±0.2	0.4±0.2	1.5±0.5	0.0±0.0	0.4±0.3	1.7±0.6	6.5±2.2	3.2±1.1	18.2±4.5	0.0±0.0	3.1±0.4

Table 7. Results of Wilcoxon tests comparing species, files with unidentifiable calls, total bat calls and noise files recorded by the AnaBat and Avisoft during 20 minute intervals.

Type	Z	DF	*p*-value
EPFU	0.84441	50	0.3889
LABO	-1.0042	50	0.3153
LACI	1.95083	50	0.0511
LANO	0.16740	50	0.8671
MYGR	0.11784	50	0.8977
MYLU	-3.67040	50	0.0002
MYsp	-1.67340	50	0.0942
NYHU	-1.20040	50	0.2300
PESU	-1.35780	50	0.1745
UNKN	-2.53290	50	0.0110
Total	1.884290	50	0.0595
Noise	-5.86890	50	<0.0001

The results for the two hour recording sessions were similar to those of the 20 minute sessions. The AnaBat unit recorded more calls belonging to the big brown bat, the little brown bat, and more noise files (Table 8). All other comparisons revealed no significant differences (Table 8). There was also no significant difference detected when comparing the number of species each detector recorded (Z_{30}=-1.08200, p=0.2793).

Table 8.
Results of Wilcoxon tests comparing species, files with unidentifiable calls, total bat calls and noise files recorded by the AnaBat and Avisoft during two hour intervals.

Type	Z	DF	*p*-value
EPFU	-2.13026	30	0.0332
LABO	0.34698	30	0.7286
LACI	0.49583	30	0.6200
LANO	-0.36842	30	0.7126
MYGR	0.44985	30	0.6528
MYLU	-2.76423	30	0.0057
MYsp	-0.91244	30	0.3615
NYHU	-1.08493	30	0.2780
PESU	-0.51702	30	0.6051
UNKN	-2.78189	30	0.0054
Total	-1.81256	30	0.0699
Noise	-0.77411	30	0.4389

CHAPTER IV

DISCUSSION

Bat Habitat Usage

Although many of the sites in LBL had more bat activity than all of the forest sub-sites, caution is needed in the interpretation of this result (Figures 5 and 6). Insect sounds occurred more frequently in the forest sub-sites, mostly in the form of katydid stridulations (personal observation). The sound frequencies of these stridulations range from 10 kHz to 30 kHz, which is within the range of detection for the AnaBat and Avisoft units. Since the AnaBat units only record the loudest sound in the immediate vicinity and in sequence, it is possible that several bat calls were not recorded during times of katydid stridulation. At the present time, there is no known way to compensate for this issue with the AnaBat unit. Thus, all conclusions made from these data are based on activity compared between all sites except for the forest sub-sites.

No other significant differences in the number of bat calls detected were found when comparing the edge and field sub-sites within the agricultural and grassland sites. When comparing variation across sub-sites, only the edges of agricultural fields 1 and 2 had a significant difference between habitats. This finding is contrary to those of previous published studies. In studies comparing habitats similar to those in this study, forest edges consistently had greater activity and diversity of bat species than open areas (Everette et al. 2001; Menzel 2004; Owen et al. 2004).

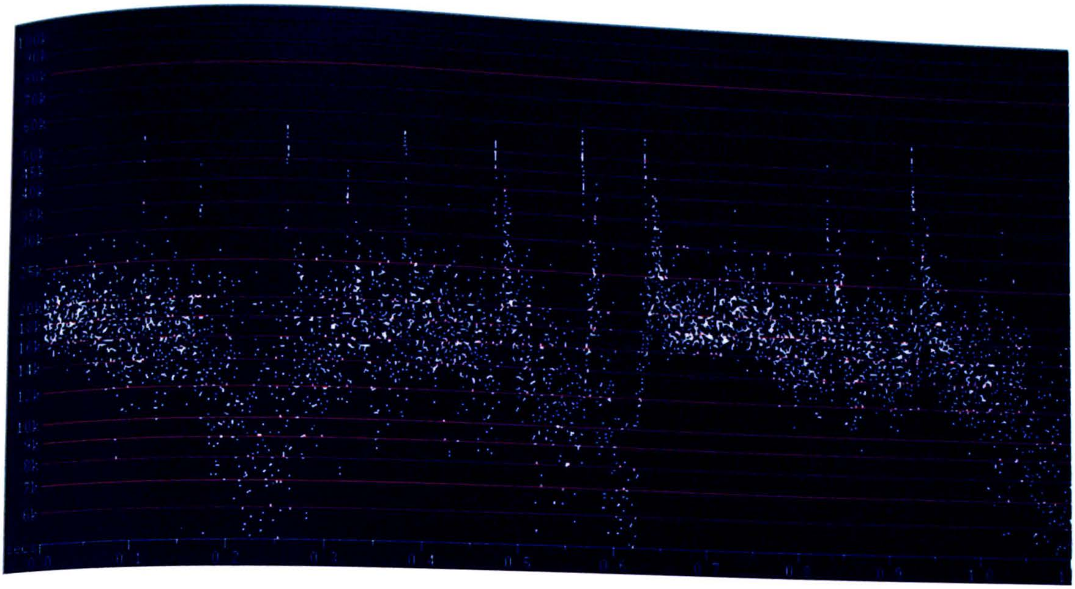


Figure 5. Analook sonograph of an unidentified bat call acoustically masked by katydid stridulation.

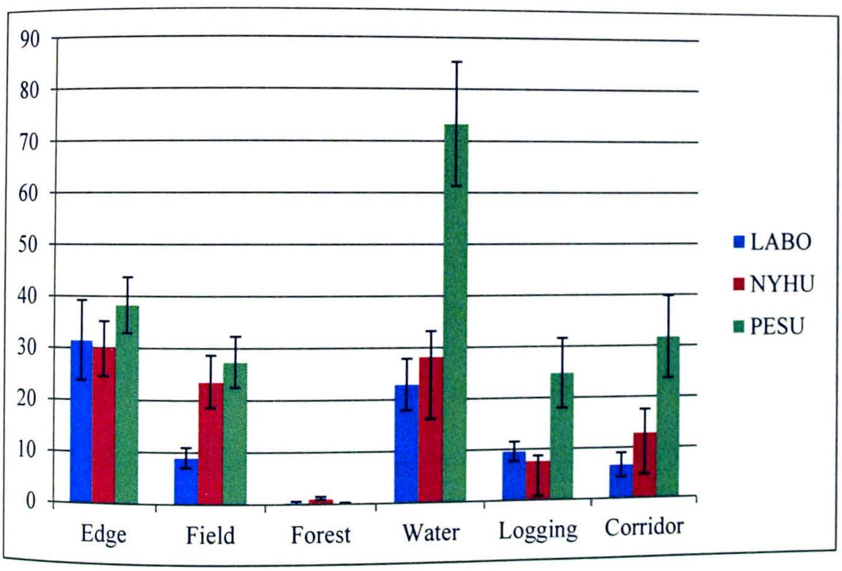


Figure 6. Means and standard errors of the three most commonly recorded and identified bat species in LBL by habitat type.

In general, the consensus among several studies is that riparian corridors or those areas with standing water tend to have greater activity than those areas located away from water

(Everette et al. 2001; Agosta 2002; Carrol et al. 2002; Walters 2007; Duff & Morrel 2007; Hein et al. 2009). This study consistent with these previous findings in several cases. For example, Prior Bay had more overall activity compared to edge and field sub-sites of Agri 2 and the field sub-site of Grassland 1. Panther Creek had more bat activity on average when compared to the field sub-site of Grassland 1. While the collective study information is useful and can provide general overviews of bat activity, it is considered inappropriate to draw conclusions on the bat community foraging habitat preferences as different bat species can exhibit different habitat preferences (Barclay 1991; Miller et al. 2003; Ford et al. 2005).

Average big brown, silver-haired, and eastern red bat vocalization activity was consistent across all the sites of LBL. A variety of habitat preferences for the three species have been established by previous studies. Some studies suggest the species prefer riparian corridors, standing water, and forest edges (Carrol et al. 2002; Walters 2007; Duff & Morrel 2007; Hein et al. 2009). Duchamp (2004) found that red and big brown bats prefer agricultural lands and forests edges over sites with flowing or standing water. Studies have also shown that the species prefer open habitats for foraging (Patriquin & Barclay 2000; Brooks & Ford 2005; Winhold & Kurta 2008). There is a consensus among researchers that big brown, silver-haired and eastern red bats have no clear habitat preferences and should be considered habitat generalists (Stringer & Loftis 1999; Agora 2002). The results of this study are in agreement with this assessment.

Evening bat vocalization activity was similar to that of the big brown, eastern red and silver-haired bats with a few exceptions. On average, evening bat activity was higher at Prior Bay and the edges of Agri 1 and Grassland 1 when compared to the edge of Agri 2. Evening bats have been shown to have preferences for agricultural areas and edges as opposed to those with areas with water (Duchamp 2004; Hein et al. 2009). The findings of this study suggest that the evening bat is a habitat generalist in the hours just after sunset given that few differences in habitat use were found.

Little brown, gray and general *Myotis spp.* bat vocalization activity was similar to each other in most regards. Gray bat activity was higher at the edges of Grasslands 1 and 2 than their respective field sub-sites. These results were somewhat surprising as it was expected that gray bat activity would be significantly higher at Prior Bay due to its proximity to Tobacco Port Cave, a known gray bat roost (Moyer 1997). Previous studies show that little brown bats prefer riparian areas and edges over open areas (Kurta 1982; Barclay 1991; Brigham et al. 1992). Adams reported that little brown bats prefer to forage in open areas when species diversity in a given area is low (1997). Very few habitat usage comparisons for gray bats have been conducted and but indicate that gray bats prefer foraging over forest streams and standing water (Tuttle 1976; LaVal et al. 1977; LaVal & LaVal 1980). Because there were few significant differences in average bat call recordings by site, the results of this study indicate that little brown and gray bats tend to be more generalists when it comes to habitat selection. At least 750 bat calls were classified as *Myotis spp.*, but the present software technology cannot distinguish between the similar calls of the different species of *Myotis*. Due to this software limitation, it is entirely possible little brown, gray, and northern long-eared bats calls were recorded, but they could not be identified.

Tricolored bat activity was more varied than other species of bats in LBL. The edge of Grassland 1 had consistently more tricolored bat activity than its respective field, and the edges of Agri 2 and Grassland 2. This was most likely due to prey availability being higher at that particular edge, thus leading to a greater amount of activity. More tricolored bats were observed flying at the edge of Grassland 1 than the other edges (personal observation). It is possible there may have been a higher concentration of tricolored bats roosting near the edge of Grassland 1 but more research should be done to confirm this. Activity for tricolored bats was higher at Prior Bay when compared to all field sub-sites and the edges of Agri 2 and Grassland 2. Activity at Panther Creek was greater than field sub-sites of Agri 2 and Grassland 1 and the edge of Agri 2. This suggests that tricolored bats have preferences for those habitats with water. Tricolored bats have shown similar preferences for sites with standing or moving water in other studies (Broders et al. 2003; Patriquin & Barclay 2003; Brack et al. 2004; Owen et al. 2004; Ford et al. 2005).

Three explanations for specific habitat use in bats have arisen during the recent decades of research on the topic: 1) size of bats, 2) species-specific characteristics of bat echolocation and 3) prey availability.

In general, smaller bats are more maneuverable and are better adapted to flying through dense forests or areas with many obstacles while larger bats are better adapted to fly in more open environments (Broders et al. 2003; Patriquin & Barclay 2003; Menzel et al. 2003; Menzel et al. 2005). Others have noted however that larger bats, such as the medium-sized red bat, are highly maneuverable and well adapted to dense forest habitats (Stringer & Loftis 1999). Unfortunately, because of the katydid interference in the data from the forest sub-sites, the effect of bat size on forest habitat preference could not be evaluated in this study.

Another explanation for specific habitat use involves bat echolocation characteristics. Bats which consistently emit frequency modulating (FM) calls are better adapted for environments with many obstacles (e.g. forest clutter) while those that consistently emit constant frequency (CF) calls are better adapted to more open environments (Moss et al. 2004; Schnitzler et al. 2008; Corben et al. 2011). The explanation, however, does not apply to all species since many bats can shift their calls from FM to CF with ease depending on their environment (Moss et al. 2004; Schnitzler et al. 2008; Corben et al. 2011). As with the previous explanation of the effect of body size on habitat selection, it is difficult to support or reject the hypothesis of bat echolocation characteristics as an explanation for habitat preferences observed.

The third explanation involves prey availability. Larger bats can typically consume larger, hardier prey (such as Lepidopterans and Coleopterans) while smaller bats prefer softer, smaller prey (Moyer 1997; Agosta 2002; Feldhamer et al. 2009). There is evidence that due to species-specific prey preferences, prey resources are partitioned between different species which may reduce interspecific competition (Moyer 1997). When examining habitat types, riparian corridors and forest edges have the greatest diversity and abundance of flying insects (Furlonger et al. 1987, Barclay 1991). However, other studies have found that agricultural lands and maintained grasslands can support a diverse population of arthropods (Moyer 1997). While prey availability is a likely explanation for the trends in bat activity seen in this study more research will need to be conducted. A previous study, however, in LBL by Moyer suggested that prey availability may be a determining factor in bat activity (1997).

The importance of field and edge sites may be equally important as water sites. Riparian corridors may have consistently high insect diversity and abundance but bats may also be using these areas for drinking water in addition to site specific foraging (Stringer & Loftis, 1999). Areas without water may have insects that bat species prefer, which may explain the general lack of significant difference in activity between those sites with water and those without. It may be that the bats in LBL are generally opportunistic foragers in the hours after dusk.

Future research on bat foraging and habitat usage at LBL should examine the insect prey available at the different sites. Moyer (1997) examined prey availability but only deployed insect traps at riparian corridors. Deployment of insect traps at various habitat sites without water could reveal more information on foraging and provide explanations on bat habitat activity as it relates to prey availability. Furthermore, an acoustic sampling method which can compensate for the insect noise within the forests of LBL is highly encouraged for use in multiple habitats. This will allow a researcher to better examine habitat usage by bats within LBL.

Evaluation of Logging and Corridor Sites

Evidence from previous studies shows that bat activity can be negatively or positively affected by logging activities, depending on the species. For example, the activity of larger species (big brown bats, hoary bats, silver-haired bats) tends to be positively affected by thinning while activity by smaller species (*Myotis* spp., tricolored bats) is negatively affected (Morris et al. 2010, Ethier et al. 2011). The explanation cited for this behavior may be related to the size of the bats as mentioned previously (Morris et al. 2010, Ethier et al. 2011). Because only one logging and corridor site was selected herein, results with respect to the effects of logging on bat habitat use should be viewed as largely preliminary. Only the big brown bat, a larger species, had significantly more activity at the logging site compared to the edges of Grasslands 1 and 2 and thus is consistent with previous studies. Morris et al. (2010) had a similar finding when examining hard edges and clear cut/thinned pine forests. Further studies examining the logging areas in LBL should be conducted to determine if the effects of forest removal on bat activity is similar to published data.

The corridor site exhibited no distinguishable patterns in bat activity, especially when compared to the edge sub-sites. Hein et al. (2009) examined the characteristics of forest corridors and how they can affect bat activity. They found that bat activity was higher at the edges of corridors rather than the interior of the corridors. This further supports the importance of edge habitats for bat feeding activity and that corridors may be useful transportation pathways for bats (Hein et al. 2009). LBL has a series of utility and road corridors throughout the park area. These can be used to further examine the importance of corridors to bat feeding in a forested area.

Comparison of Avisoft and AnaBat Acoustic Monitoring

In general, there were no significant differences in the performances of the two recording devices. More specifically, the AnaBat units recorded more big brown, little brown, and more noise files than the Avisoft system. This finding is in contrast to a study that found the Avisoft unit actually recorded more bat calls than the AnaBat unit and did so over longer distances (Adams et al. 2011).

Several explanations for the AnaBat units recording more little and big brown bats exist. It is possible that the zone of reception for the AnaBat unit is larger than that of the Avisoft unit, which may account for the AnaBat's ability to record more little and big brown bats. Relatively few studies tested the detection range of AnaBat or Avisoft equipment. A study showed that AnaBat units have a maximum detection range of 50 meters (Corben et al. 2011). This is in contrast, however, to another study which determined a detection range of 20 m (Adams et al. 2011). That same study showed that the Avisoft unit has a detection range of up to 40 m. Unfortunately, detection ranges and zones of reception (three-dimensional shape of the microphone detection area) can be confounded by such variables as terrain, weather, position and angle of the equipment, and the intensity of individual bat calls (Corben et al. 2011, Britzke et al. 2011).

Another explanation involves the electronics inherent in the devices. Since the devices produce entirely different file types, there may be elements of the electronics that make the AnaBat unit more favorable for detecting those species. There may be variables which affect sound recording that simply cannot be controlled such as weather or abiotic and biotic noise. A limitation of the AnaBat unit is that it can only record that sound in the appropriate range with the loudest amplitude. The Avisoft unit can record all sounds within its range of detection, but noise can still mask bat calls. When viewing these sounds with the software, identification of the sound file to specific species can be difficult. Neither BCID East 2012, SonoBat 3.05 software nor other lab analyses can analyze bat calls effectively when a large amount of extraneous noise occurs in a field sample.

An additional explanation for differences is the software being used to analyze the data. Since the AnaBat unit produces ZCAIM file and the Avisoft unit produces .wav files, the two file types are different. Although both software packages examine the same parameters of bat calls, the quality of recordings and the type of files produce may be affecting the identification of calls. For example, both the AnaBat and the Avisoft units may have recorded a bat of genus *Myotis*, but the AnaBat unit may have recorded enough call components to identify the bat as *Myotis grisescens* while the Avisoft unit did not. This would then affect the analysis by the software packages and subsequent visual confirmation.

Thus, it is important to be consistent with the device in use when designing experiments with acoustic detectors and to realize that data from different types of recorders should not be used concurrently in analyses (Allen et al. 2011; Britzke 2011). The few significant differences in the comparison of data between Avisoft and AnaBat units observed herein? support this assertion. Experiments that control species recorded, habitat, and electronic variables are encouraged to determine the efficacy of different recorders. Furthermore, neither detector seemed to fare particularly well when biotic noises such as insects are present during sampling periods. Perhaps with time, more sophisticated equipment and accompanying software can filter out insect noise while retaining bat calls within the same frequency range.

Conclusions

The results indicate that edge and field habitats, without water sources, may be equally important to habitats with water. The most likely explanation for habitat usage of the different bat species of LBL was prey availability; although these species have not been reported to be in competition with each other with respect to prey selection (Moyer 1997). This will need to be examined with future studies examining insect prey availability at the studied habitat sites. Insect noise was abundant in the forests of LBL which made effective acoustic sampling comparisons of bat activity with other sites difficult. As such, technological development which can effectively filter out biotic noise while retaining bat vocalizations is needed to truly assess habitat usage. Further examination of the effects of forest removal and the use of corridors should also be considered.

The Avisoft and AnaBat systems should not be used interchangeably when conducting surveys for bats. The AnaBat unit recorded more little brown and big brown bat calls. Both systems have their merits as well as their flaws and both can adequately complete the task of acoustic sampling for bat calls. Both devices can have sound recording or analysis confounded by biotic noises which can make identification of bat vocalizations difficult. Further research with stronger controls for equipment and habitat variables are strongly encouraged.

REFERENCES

Adams, A.M., Jantzen, M.K. & Hamilton, R.K. 2011. Bat detector comparison with synthetic playback and free-flying bats. 41st Annual Meeting of the North American Society for Bat Research, Toronto, Ontario, Canada.

Adams, R.A. 1997. Onset of volancy and foraging patterns of juvenile little brown bats, *Myotis lucifugus*. *Journal of Mammalogy*, **78**, 239-246.

Agosta, S.J. 2002. Habitat use, diet and roost selection by the Big Brown Bat (*Eptesicus fuscus*) in North America: a case for conserving an abundant species. *Mammal Review*, **32**, 179-198.

Aldridge, H. D. J. N. & Rautenbach, I.L. 1987. Morphology, echolocation and resource partitioning in insectivorous bats. *The Journal of Animal Ecology*, **56**,763-778.

Allen, C.R., Romeling, S.E. & Robbins, L.W. 2011. A comparison of acoustic monitoring and sampling technology. In: *Bats: Protecting Threatened Bats at Coal Mines.*

Arnett, E.B. 2003. Advancing science and partnerships for the conservation of bats and their habitats. *Wildlife Society Bulletin*, **31**, 2–5.

Arroyo-Cabrales, J., Miller, B., Reid, F., Cuarón, A.D. & de Grammont, P.C. 2008.*Pipistrellus subflavus*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2.

Avisoft Bioacoustics. 2011. *Avisoft Bioacoustics RECORDER, Version 4.2.3*. Berlin, Germany: Avisoft Bioacoustics.

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

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

Bat Call Identification, Inc. 2012. *BCID East 2012, Version 2.4.1.* Kansas City, Missouri: Bat Call Identification, Inc.

Brack, V. & LaVal, R.K. 2006. Diet of the gray myotis (*Myotis grisescens*): Variability and consistency, opportunism and selectivity. *Journal of Mammalogy*, **87**, 7-18.

Brack, V., Robbins, L.W. & Davis, C.R. 2007. Bats of Fort Leavenworth Military Reservation and nearby areas of eastern Kansas and western Missouri. *Transactions of the Kansas Academy of Science*, **110**, 73-82.

Broders, H.G. Quinn, G.M. & Forbes, Graham, G.J. 2003. Species status, and the spatial and temporal patterns of activity of bats in southwest Nova Scotia, Canada. *Northeastern Naturalist*, **10**, 383-398.

Brooks, R.T. & Ford, M.W. 2005. Bat activity in forest landscape of central Massachusetts. *Northeastern Naturalist,* **12**, 447-462.

Britzke, E.R., Duchamp, J.E., Murray, K.L., Swihart, R.K. & Robbins, L.W. 2011. Acoustic identification of bats in the eastern United States: a comparison of parametric and nonparametric methods. *The Journal of Wildlife Management,* **75**, 660-667.

Carroll, S.K., Carter, T.C. & Feldhamer, G.A. 2002. Placement of nets for bats: effects on perceived fauna. *Southeastern Naturalist,* **1**, 193-198.

Carter, T.C., Menzel, M.A., Chapman, B.R. Miller, K.V. 2004. Partitioning of food resources by syntopic eastern red (*Lasiurus borealis*), Seminole (*L. seminolus*), and evening (*Nycticeius humeralis*) bats. *American Midland Naturalist,* **151**, 186-191.

Corben, C., Lausen, C. & Livengood, K. 2011. AnaBat Techniques Course; 2011 April 18-21, Pikeville, TN.

Davis, W.H. & Mumford, R.E. 1962. Ecological notes on the bat *Pipistrellus subflavus*. *American Midland Naturalist*, **68**, 394-398.

Decher, J. & Choate, J.R. 1995. *Myotis grisescens*. *Mammalian Species*, **510**, 1-7.

Duchamp, J.E., Sparks, D.W., & Whitaker, J.O. 2004. Foraging-habitat selection by bats an urban-rural interface: comparison between a successful and a less successful species. *Canadian Journal of Zoology,* **82**, 1157-1164.

Duff, A.A. & Morrell, T.E. 2007. Predictive occurrence models for bat species in California. *Journal of Wildlife Management*, **71**, 693-700.

Elmore, L.W., Miller, D.A. & Vilella, F.J. 2005. Foraging area size and habitat use by red bats (*Lasiurus borealis*) in an intensively managed pine landscape in Mississippi. *American Midland Naturalist*, **2**, 405-417.

Ethier, K. & Fahrig, L. 2011. Positive effects of forest fragmentation, independent of forest amount, on bat abundance in eastern Ontario, Canada. *Landscape Ecology*, **26**, 865-876.

Everette, A.L., O'Shea, T.J., Ellison, L.E., Stone, L.A., & McCance, J.L. 2001. Bat use of a high-plains urban wildlife refuge. *Wildlife Society Bulletin,* **29**, 967-973.

Fenton, M.B. & Barclay, R.M. 1980. *Myotis lucifugus*. *Mammalian Species*, **142**, 1-8.

Feldhamer, G.A., Carter, T.C. & Whitaker, J.O. 2009. Prey consumed by eight species of insectivorous bats from southern Illinois. *American Midland Naturalist*, **162**, 43-51.

Fenton, M.B. 1990. The foraging behavior and ecology of animal-eating bats. *Canadian Journal of Zoology*, **68**, 411–422.

Ford, W.M., Menzel, M.A., Rodrigue, J.L, Menzel, J.M. & Johnson, J.B. 2005.Relating bat species presence to simple habitat measures in a central Appalachian forest. *Biological Conservation,* **126**, 528-539.

Franklin, S.B. 1994. Late Pleistoscene and Holocene vegetation history of Land Between the Lakes, Kentucky and Tennessee. *Transactions Kentucky Academy of Science,* **55**, 6-19.

Frick, W.F., Pollock, J.F., Hicks, A.C., Reynolds, K.E., Reynolds, S.D., Butchkoski, C.M., & Kunz, T.H. 2009. An emerging disease causes regional population collapse of a common North American bat species. *Science*, **329**, 679-682.

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

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

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

Hein, C.D., Castleberry, S.B., & Miller, K.V. 2009. Site-occupancy of bats in relation to forested corridors. *Forest Ecology and Management*, **257**, 1200-1207.

Hogberg, L.K., Patriquin, K.J. & Barclay, R.M. 2002. Use by bats of patches of residual trees in logged areas of the boreal forest. *American Midland Naturalist*, **148**, 282-288.

Johnson, J.B., Menzel, M.A., Edwards, J.W. & Ford, W.M. 2002. A comparison of two acoustical bat survey techniques. *Wildlife Society Bulletin*, **30**, 931-936.

Johnson, J.B. & Gates, J.E. 2008. Bats of Assateague Island National Seashore, Maryland. *American Midland Naturalist*, **160**, 160-170.

Johnson, J.B., Ford, W.M., Edwards, J.W. & Menzel, M.A. 2010. Bat community structure within riparian areas of northwestern Georgia, USA. *Folia Zoologica*, **59**, 192-202.

Jung, T.S., Thompson, I.D., Titman, R.D. & Applejohn, A.P. 1999. Habitat selection by forest bats in relation to mixed-wood stand types and structure in central Ontario. *Journal of Wildlife Management*, **63**, 1306-1319.

Kalcounis, M.C., Hobson, K.A., Brigham, R.M. & Hecker, K.R. 1999. Bat activity in the boreal forest: importance of stand type and vertical strata. *Journal of Mammalogy*, **80**, 673-682.

Kalcounis-Rüppel, M.C., Psyllakis, J.M. & R.M. Brigham. 2005. Tree roost selection by bats: an empirical synthesis using meta-analysis. *Wildlife Society Bulletin*, **33**, 1132-1132.

Lacki, M.J., Burford, L.S. & Whitaker, J.O. 1995. Food habits of gray bats in Kentucky. *Journal of Mammalogy*, **76**, 1256-1259.

Lunde, R.E. & Harestad, A.S. 1986. Activity of little brown bats in coastal forests. *Northwest Science*, **60**, 206-209.

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

Kunz, T.H. 1982. *Lasionycteris noctivagans*. *Mammalian Species*, **172**, 1-5.

Kunz, T.H. & Kurta, A. 1988. Capture methods and holding devices. In: *Ecological and Behavioral Methods for the Study of Bats* (Ed. By T.H. Kunz), pp. 1-30. Washington, D.C.: Smithsonian Institution Press.

Kurta, A. & Baker, R.H. 1990. *Eptesicus fuscus*. *Mammalian Species*, **356**, 1-10.

Kurta, A, Kunz, T.H. & Kagy, K.A. 1990. Energetics and water flux of free-ranging big brown bats (*Eptesicus fuscus*) during pregnancy and lactation. *Journal of Mammalogy,* **71**, 59-65.

Lacki, M.J., Burford, L.S. & Whitaker, J.O. 1995. Food habits of gray bats in Kentucky. *Journal of Mammalogy*, **76**, 1256-1259.

LaVal, R.K., Clawson, R.L., LaVal, M.L. & Caire, W. 1977. Foraging behavior and nocturnal activity patterns of Missouri bats, with emphasis on the endangered species *Myotis grisescens* and *Myotis sodalist*. *Journal of Mammalogy*, **58**, 592-599.

LaVal, R.K. & LaVal, M.L. 1980. Ecological studies and management of Missouri bats, with emphasis on cave-dwelling species. *Missouri Department of Conservation Terrestrial Series*, **8**, 1-53.

Menzel, J.M., Menzel, M.A., Kilgo, J.C., Ford, W.M., Edwards, J.W. & McCracken, G.F. 2005. Effect of habitat and foraging height on bat activity in the coastal plain of South Carolina. *The Journal of Wildlife Management*, **69**, 235-245.

Miller, D.A., Arnett, E.B., & Lacki, J.L. 2003. Habitat management for forest-roosting bats of North America: a critical review of habitat studies. *Wildlife Society Bulletin,* **31**, 30-44.

Morris, A.D., Miller, D.A. & Kalcounis-Ruepell, M.C. 2010. Use of forest edges by bats in a managed pine forest landscape. *Journal of Wildlife Management,* **74**, 26-34.

Moss, C.F., Thomas, J.A. & Vater, M. 2005. *Echolocation in Bats and Dolphins*. Chicago, IL: University of Chicago Press.

Moyer, B.D. 1997. Diversity and spatial, temporal and diet characteristics of bat species in a southern deciduous forest: TVA's Land Between the Lakes [thesis]. Miller State University, Murray, KY.

Murray, K.L., Britzke, E.R., Hadley, B.M. & Robbins, L.W. 1999. Surveying bat communities: a comparison between mist nets and the AnaBat II detector system, *Acta Chiropterologica*, **1**, 105–112.

Neuhauser, M. & Bretz, F. 2001. Nonparametric all-pairs multiple comparisons. *Biometric Journal*, **43**, 571-580.

Norberg, U.M. & Rayner, J.M.V. 1987. Ecological, morphology and flight in bats (Mammalia: Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London*, **316**, 335-427.

Patriquin, K.J. & Barclay, R.M.R. 2003. Foraging by bats in cleared, thinned and unharvested boreal forest. *Journal of Applied Ecology,* **40**, 646-657.

Owen, S.F., Menzel, M.A., Edwards, J.W., Ford, W.M., Menzel, J.M., Chapman, B.R., Wood, P.B., & Miller, K.V. 2004. Bat activity in harvested and intact forest stands in the Allegheny Mountains. *Northern Journal of Applied Forestry,* **21**, 154-159.

Rogers, D.S., Belk, M.C., Gonzalez, M.W. & Coleman, B.L. 2006. Habitat use by bats along a riparian corridor in northern Utah. *The Southwestern Naturalist*, **51**, 52-58.

Schnitzler, H., Moss, C.F. & Denzinger, A. 2008. From spatial orientation to food acquisition in echolocating bats. *Trends in Ecology and Evolution*, **118**, 386-394.

SAS Inc. 2010. *JMP Pro, Version 9.02.* Cary, North Carolina: SAS Institute, Inc.

Shump, K.A. & Shump, A.U. 1982. Lasiurus borealis. *Mammalian Species*, **183**, 1-6.

Sokal, R.R. & Rohlf, F.J. 1995. *Biometry: Third Edition.* W.H. Freeman and Company, New York, NY.

SonoBat. 2012. *SonoBat Ozark, Version 3.05*. Arcata, California: SonoBat.

Stringer, J.W. & Loftis, D.L. 1999. Foraging and habitat use of red bats in mixed mesophytic forests of the Cumberland Plateau, Kentucky. Proceedings, 12th Central Hardwood Forest Conference; 1999 February 28-March 2; Lexington, KY. General Technical Report SRS-

24. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Thomas, D. W. 1988. The distribution of bats in different ages of douglas-fir forests. *Journal of Wildlife Management*, **52**, 619-626.

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

Thompson, R.L. & Poindexter, D.B. 2006. Vascular flora of the Elk and Bison Prairie, Land Between the Lakes National Recreation Area, Trigg County, Kentucky. *Castanea*, **71**, 105-123.

Tuttle, M.D. 1976. Population ecology of the gray bat (*Myotis grisescens*): factors influencing grown and survival of newly volant young. *Ecology*, **57**, 587-595.

United States Department of Agriculture Forest Service. 2004. *Biological Assessment for the Land and Resources Management Plan*. Land Between the Lakes, Golden Pond, KY.

United States Department of Agriculture Forest Service. 2007. *Revised Environmental Assessment: Continued Maintenance of Open Lands*. Land Between the Lakes, Golden Pond, KY.

Veilleux, J.P., Moosman, P.R., Reynolds, D.S., LaGory, K.E. & Walston, L.J. 2009. Observations of summer roosting and foraging behavior of a hoary bat (*Lasiurus cinereus*) in southern New Hampshire. *Northeastern Naturalist*, **16**, 148-152.

Virgil, B. & LaVal, R.K. 2006. Diet of the gray myotis (*Myotis grisescens*): Variability and consistency, opportunism and selectivity. *Journal of Mammalogy,* **87**, 7-18.

Walters, B.L., Ritzi, C.M., Sparks, D.W., & Whitaker, J.O. 2007. Foraging behavior of eastern red bats (*Lasiurus borealis*) at an urban-rural interface. *American Midland Naturalist,* **157**, 365-373.

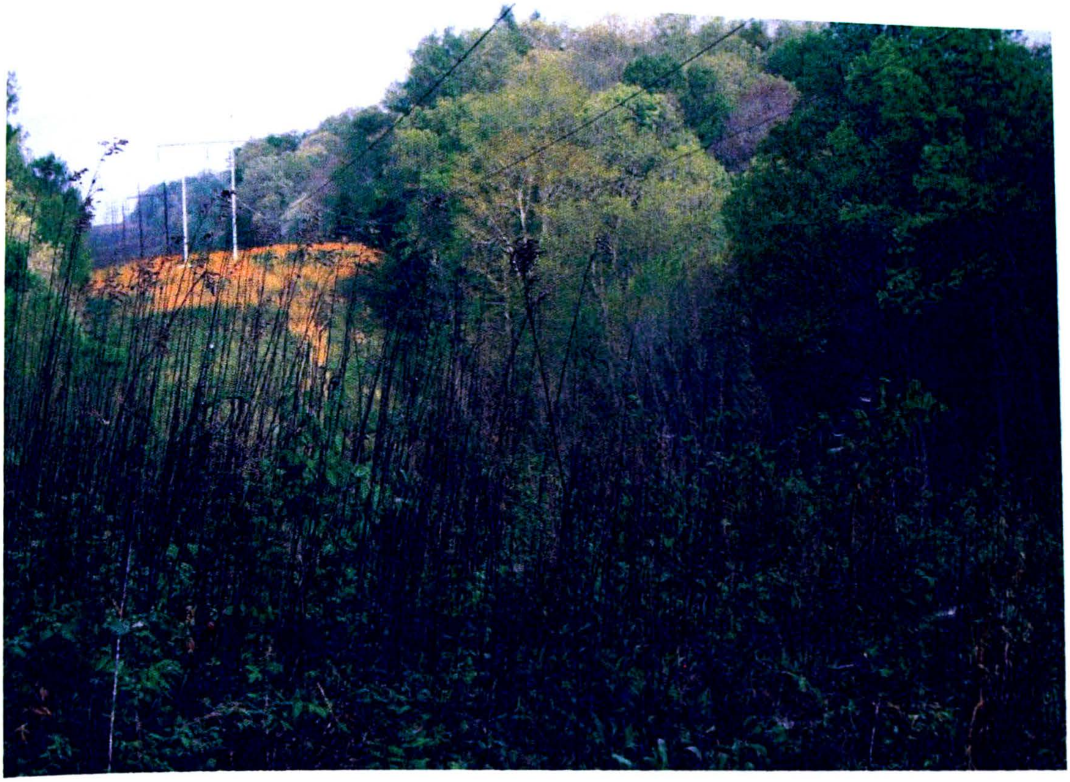
Winhold, L. & Kurta, A. 2008. Netting surveys for bats in the Northeast: differences associated with habitat, duration of netting and use of consecutive nights. *Northeastern Naturalist,* **15**, 263-374.

Zimmerman, G.S. & Glanz, W.E. 2000. Habitat use by bats in eastern Maine. *Journal of Wildlife Management*, **64**, 1032-1040.

APPENDIX A

Names, coordinates, habitat types, and photographs of study sites.

Site	Latitude	Longitude	Habitat Type
Agricultural Field 1 - Edge	36.51282000	-87.96059000	Edge
Agricultural Field 1 - Field	36.51310000	-87.96087000	Field
Agricultural Field 1 - Forest	36.51235000	-87.96033000	Forest
Agricultural Field 2 - Edge	36.60405000	-87.94217000	Edge
Agricultural Field 2 - Field	36.60426000	-87.94217000	Field
Agricultural Field 2 - Forest	36.60365000	-87.94217000	Forest
Corridor	36.61846000	-87.91581000	Corridor
Grassland 1 - Edge	36.51611000	-87.95816000	Edge
Grassland 1 - Field	36.51559000	-87.95806000	Field
Grassland 1 - Forest	36.51660000	-87.95807000	Forest
Grassland 2 - Edge	36.60509000	-87.94724000	Edge
Grassland 2 - Field	36.60558000	-87.94704000	Field
Grassland 2 - Forest	36.60475000	-87.94772000	Forest
Logging Site	36.64461100	-88.03027800	Logging
Neville Bay	36.61368600	-87.91602800	Lentic
Neville Creek	36.60475000	-87.93909000	Riparian
Panther Creek	36.51176000	-87.98949000	Riparian
Prior Bay	36.67475000	-87.95665000	Lentic



Corridor

Neville Bay

Neville Creek

Grassland 1

Grassland 2

Agricultural Field 1

Agricultural Field 2

Panther Creek

Logging Site

Prior Bay

APPENDIX B

Settings for AnaBat SD1/SD2 with Green Microphone or Standard Black Microphone (randomized).

All settings on the AnaBat unit are completed utilizing labeled buttons on the front of the unit. Recording time length is established by programing the compact flash card with CFCRead (Corben 2011). In this study, sunset was the start time and 4.5 hours after sunset was the end time.

Parameter	Setting
Data Division Ratio	8
Audio Division Ratio	8
Sensitivity	6
Recording Time Length	4.5 hours after sunset

Settings for BCID 2012 East Software

All settings for BCID 2012 are found in the main program window. All default settings were maintained with the exception of one: the call library. Under the species tab, Tennessee was selected for the species call library. All other settings are designed to filter out sounds below 14 kHz and above 250 kHz and calls of a duration less than one ms or greater than 20 ms. These settings filter out those files that contain extraneous abiotic or biotic noise while keeping those files with bat calls within them.

Settings for Avisoft Bioacoustics USG 116 with CMPA/CM16 Microphone

The actual device itself only has one button and two control knobs. The only knob manipulated was the gain setting which was set to five.

Settings for Recorder USG Program

Once the following parameters were established, the record button was pressed and the program was allowed to run until the battery of the Dell Laptop died. All settings other than the ones listed below were set to inactive or 0.

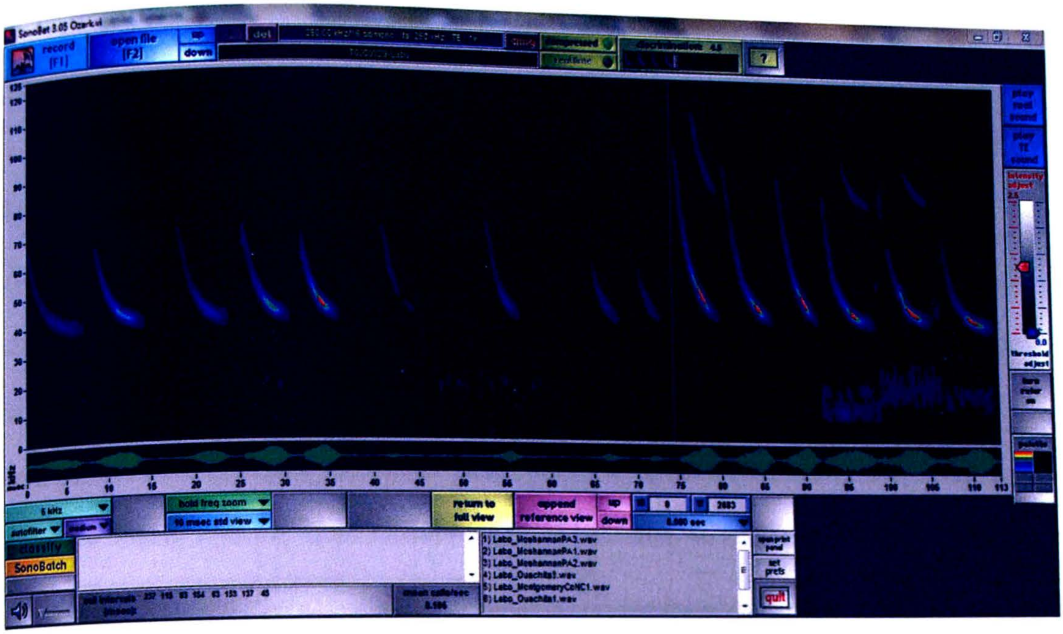
Parameter	Setting
Filter	None selected
Sampling Frequency Range	14kHz to 250 kHz
Sampling Rate	16 bit
Recording Time per File	15 seconds
Decibel threshold for Recording	10 dB

Settings for SonoBat 3.05

The settings in SonoBat 3.05 were maintained as they came with the program. When one opens SonoBatch, the .wav files from recording sessions are loaded into the program. Within the batch processor, there are filters that operate in a similar manner to the filter found in BCID 2012 East. . These filters are designed to filter out sounds below 14 kHz and above 250 kHz and calls of a duration less than one ms or greater than 20 ms The other settings are listed as follows.

Parameter	Setting
Max # of calls to consider per file	20
Acceptable call quality	0.6
Discriminant probability threshold	0.9
Filter setting	Auto

It is important to note that all sound files were visually examined and compared to a reference sonograph file regardless of whether they met the 60% call quality or 90% discriminant probability threshold.



Time-expanded SonoBat 3.05 software analysis of a red bat call sequence and a reference file for comparison on right.

VITA

Joshua Jay Schulte was born in St. Paul, Minnesota on 19 December 1981, the son of Linda Ruth Peachey and James Allen Schulte. After completing his work at Mounds Park Academy, he went on to Denison University where he studied biology and educational studies and received his Bachelor of Science in May 2005. During the summer of 2005, he participated in a brief herpetological project. He then taught middle school science in the Clarksville-Montgomery County School System for three years. During the course of teaching, he earned a Master of Arts in Teaching from Austin Peay State University in December 2008. In 2010, he left the middle school teaching position to complete his Master of Science in Biology degree at Austin Peay State University. He plans to continue his teaching career at either the high school or community college level.