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The Relationship of Bat Activity to Habitat Type and Structure Retention in Managed, Boreal Forests of West-Central Alberta

by

Heidi D. Lippert ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements for the degree of Master of Science

in

Conservation Biology

Department of Renewable Resources

Edmonton, Alberta
Spring 2001

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For Amy,

who never had a chance.

ABSTRACT

During the summers of 1998-99, I examined bat activity in west-central Alberta in three forest types, and in areas where standing structure was retained following harvest. All seven forest bat species expected to occur in west-central Alberta were verified by ultrasonic and capture techniques.

Results from this study show that narrow seismic lines running through mature aspen-, pine- and spruce-dominated forest provide commuting habitat equally well for all bat species or species aggregates. In addition, the amount of structure retention in a cut block did not affect bat activity at pond sites.

This study revealed a low abundance of ideal roost structures across forest types in mature boreal forest stands. The recruitment of these structures, which are essential to the reproductive success of many forest bat species, is also limited. As a result, standing dead material and live recruitment trees should be retained to conserve bat populations.

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CHAPTER 1: GENERAL INTRODUCTION

Introduction

Concerns about the long-term sustainability of managed, forested ecosystems have resulted in a demand for forest companies to develop management plans that incorporate maintenance of non-timber values. This transition requires an understanding of the complexities of ecosystems on all trophic levels. Conservation of biodiversity has become a major focus of industry, government and biologists, as a mean of maintaining ecosystem sustainability. Many efforts are now directed at identifying forest practices that conserve biological diversity across the landscape. In order to conserve a species or a population, certain habitat and resource requirements must be met, yet in many cases information on species distributions, basic ecological requirements and relationships is lacking. Because exploitation of resources in western Canadian boreal forests is relatively recent, there is a poor understanding of how many boreal-dependent organisms might be affected by industrial development.

Bats (Order Chiroptera) are a diverse component of boreal forest communities, but until recently, they have received little research attention due to their cryptic lifestyle. Growing concerns over the conservation of biodiversity in forested landscapes, as well as significant improvements in research techniques, have facilitated an increase in research on bats. Much of the earlier research focused on identifying the basic ecology, behaviour and occurrence of some species of bats in various geographic regions. With increases in industrial activity, more recent work has dealt with the effects of forest harvest on bat activity and population structure, both in Canada and abroad. Compared to other areas, bat research has been limited in Alberta. Stand age associations, roosting preferences, and occurrence have been examined in certain areas of the province, yet much of Alberta has not been surveyed for bats, and the habitat requirements of some species remain poorly understood. While one species of bat in the province has been listed as threatened (Holroyd et al. 1994, Alberta Environmental Protection 1996, Caceres and Pybus 1997), the status of other species that occur in Alberta is not well understood.

Management practices may impact bat species both positively, through development of foraging areas (Grindal 1995), and negatively, through loss of roosting habitat (Thomas and West 1991). However, little research has been done in Alberta on a landscape scale to examine these potential impacts. In addition, the effect that retention of trees or vegetation following timber harvest may have on bats has not been examined. The basic ecology and habitat needs of some species need to be better understood before landscape level research can be done effectively.

With recent expansion of forest harvesting and other industrial developments throughout northern Alberta, understanding the habitat requirements and status of bat populations is likely an essential element needed for their conservation.

Ecology of Bats in Alberta

Boreal forests support as many as 8 of the 9 bat species identified in Alberta, all of which are insectivorous and belong to a single family: Vespertilionidae (Pybus 1994). Of these 8 species, 6 are considered almost exclusively forest bats and another 2 are known to utilize forests as well as other habitats (Pybus 1994, See Table 1.1). Relatively little is known about the distributions of some bat species (Pybus 1994). Range extensions still frequently occur in neighboring British Columbia, where significant efforts have been invested in bat survey work.

Although bats, the only true flying mammals, are highly mobile, the home range of individual bats is thought to be influenced by roost site availability and proximity to drinking and foraging sites (Kunz 1982). For example, although bats do not always roost as close to foraging areas as possible (Brigham 1991), Silver-haired Bats in northeastern Washington selected roost trees within 3.5 km of riparian capture sites (Campbell et al. 1996), although they were capable of traveling much further.

Table 1.1: Species and general habitat of bats identified in Alberta (Pybus 1994).

Common Name	Latin Name	Natural Summer Habitat
Big Brown Bat	*Eptesicus fuscus*	Forests: tree cavities
Silver-haired Bat	*Lasionycteris noctivagans*	Forests: tree cavities, bark
Hoary Bat	*Lasiurus cinereus*	Forests: tree foliage
Little Brown Bat	*Myotis lucifugus*	Forests: tree cavities, bark
Long-legged Bat	*Myotis volans*	Forests: tree cavities, bark
Western Long-eared Bat	*Myotis evotis*	Forests: tree cavities, bark, stumps
Northern Long-eared Bat	*Myotis septentrionalis*	Forests: tree cavities
Small-footed Bat	*Myotis ciliolabrum*	Caves and clay banks*
Red Bat	*Lasiurus borealis*	Forests: tree foliage**

* Occurs mainly in arid regions of southern Alberta.
** Infrequent visitor to Alberta.

Roosting

Roosting requirements of bats, particularly for maternity roosts and hibernacula, can be stringent, and the features that satisfy these needs are often uncommon, unknown or difficult for researchers to locate. Forest-dwelling bats, in particular, are thought to be at risk due to the decreasing area of forested land and the reduction of late seral stages in modern forest management (e.g., Thomas and West 1991, Crampton and Barclay 1998). In Alberta, Caceres and Pybus (1997) indicate that forest bats do best in landscapes containing large areas of older forest, that support the large, structurally diverse live and dead trees on which most forest bats rely for roosting. The Northern Long-eared bat (*Myotis septentrionalis*), for example, is currently on the "Blue-list" of species at risk in Alberta (Alberta Environmental Protection 1996), based on its relative rarity and apparent reliance on mature forest habitats (Caceres and Pybus 1997).

In boreal mixed-wood forests, overall bat activity levels are greater in areas with larger diameter trees (Crampton and Barclay 1998) that possess the appropriate roosting microhabitat (sloughing bark, cavities, flaws brought on by damage or decay) (Thomas and West 1991, Christy and West 1993). However, the structural diversity of the landscape may also influence bat occurrence and abundance, as many forest bat species roost in tree cavities or under loose bark of older, decaying dead trees (Vonhof and Barclay 1996, Brigham et al. 1997, Sedgeley and O'Donnell 1999), but often use forest edges or openings to feed and travel (Grindal 1995). Nevertheless, roosting requirements are thought to be a limiting factor in maintaining bat populations (e.g., Campbell et al. 1996, Vonhof and Barclay 1996), as forests appear to contain a plentiful food supply (insects) and provide sufficient foraging habitat along edges or forest clearings (Grindal 1995).

Roost requirements vary with the biological and reproductive needs of individual bats, and depend on morphology (body size), sex and reproductive state. Smaller bats, such as the *Myotis* species, are able to utilize narrow crevices and small cavities in trees that are inaccessible to larger bats. Males and females of a given species often use different roost structures and often occupy different elevational zones (Barclay 1991). Barclay (1991) suggests that, while male Little Brown Bats were captured in high elevation areas, no females were found because they may not have been able to meet the high energy demands of reproduction in such a harsh climate. Reproductive females of some species gather in maternity colonies to rear young, while males have been observed roosting alone or in small bachelor groups (O'Donnell and Sedgeley 1999). During the reproductive period, bats, especially females and young, have strict thermal needs. While male bats enter torpor during the day, and are thus able to utilize cooler roost sites (Hamilton and Barclay 1994), females have a reproductive constraint on their ability to enter torpor, because fetal growth rates and lactation depend on maintaining a high body temperature (Racey 1982). Clustering behaviour aids their ability to thermoregulate by creating more stable roost temperatures, which support fetal and juvenile development. Because males have lower reproductive energy demands, and are able to persist in less favourable habitats, the availability of maternity-roost structures may be the most important factor in conserving bat populations.

Foraging

All species of bats found in Alberta feed on insects, usually in relatively close proximity to their roosts (Cross 1988). For this reason, bat occurrence is often associated with wet zones, where feeding and drinking conditions are optimal (Cross 1988, Hayes et al. 1995). Bats generally emerge from day roosts shortly after sunset and remain active throughout the night, resting periodically at temporary night roosts, where several species may aggregate (Christy and West 1993, Lewis 1993). Some species may fly several kilometers from their day roosts before reaching a suitable riparian feeding location (Christy and West 1993) if water is not available in the immediate vicinity.

Although bats will forage throughout the night, two peaks of feeding activity coincide with elevated levels of nocturnal insect activity: the first few hours after sunset and the last few hours before sunrise (Christy and West 1993, Erickson and West 1996).

Breeding Chronology

Alberta bat species breed prior to hibernation or migration, in late September and early October, but fertilization is delayed, as females store sperm over the winter (Racey 1982). Females do not become pregnant until the following spring or early summer (Racey 1982), and gestation lasts from seven to ten weeks, depending on environmental conditions (Tuttle and Stevenson 1982). In temperate zones such as Alberta, pups are typically born in June or July, and develop quickly. At three to six weeks of age, juvenile bats can fly, and are fully independent and able to forage for insect prey (Nagorsen and Brigham 1993).

As a result of this chronology, there are three distinct periods that affect the behaviour and biological needs of non-hibernating, female bats (early pregnancy, parturition, and juvenile independence/breeding), which may cause overall bat activity levels to fluctuate within the same year. For example, during late summer, bat activity levels may increase as juveniles gain independence and begin to fly, thus increasing the number of bats that are flying and foraging. As a result, research aimed at determining the relative bat activity in different areas needs to account for such seasonal fluctuations by surveying during each biologically significant period.

Objectives

Recent expansion of forestry operations in the boreal landscape of west-central Alberta makes this region a prime target area for bat research. Previous bat work in this region is scarce, so this project provided important baseline information on bat occurrence and distributions, and permit examination of the efficacy of various forest management strategies aimed at conserving biological diversity. The objectives of this thesis are thus multi-faceted. Because baseline information on the presence and distribution of bat species in west-central Alberta is limited, the first objective of this project was to add to the existing knowledge base through trapping efforts and use of ultrasonic detection devices (see Chapter 2). Secondly, this project explored the relationship of bat diversity and activity to forest composition and potential roost availability (see Chapter 3). Thirdly, the effects of structure retention in cut blocks on bat activity at pond sites were investigated (see Chapter 4). Lastly, this research aimed to provide recommendations to forest managers regarding the conservation of bat populations in the geographical region of focus.

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CHAPTER 2: BAT OCCURRENCE AND DISTRIBUTION IN WEST-CENTRAL ALBERTA

Introduction

In the past, much of the bat research in North America focused on the basic biology, behaviour, population structure, echolocation, or roosting ecology of single species. While research in these areas continues, rising concerns over the conservation of biodiversity has shifted the focus of some recent work to examining the effects of forest management on bat communities. However, in comparison to other jurisdictions, research in Alberta is less wide-spread, and managers in this province have insufficient information to address the potential impacts of forest harvest on bat populations.

Although range maps have been developed for Alberta bat species, many areas of the province have not been surveyed for bats. The distribution maps for some areas are largely based on incidental sightings, particularly for portions of west-central Alberta, where bat inventories have never been conducted. Although bat surveys in some areas of Alberta have verified the presence of species, there is a need for broader information on bat occurrence and distribution. It is important to understand the composition of the bat community in an area in order to implement habitat management strategies that will specifically benefit those species.

The objective of this component of my research was to inventory the bat populations in three distinct sub-regions of west-central Alberta. The species occurrence and distribution information gained from this work was used to supplement other elements of my research, and to establish baseline information for future bat studies.

Study Areas

This study was conducted in west-central Alberta, on Crown land managed under various land tenures held by Weyerhaeuser Company Ltd. and other quota holders, for timber and other resource rights. This area has been developed extensively by the oil and gas industry and, as a result, is traversed by a multitude of seismic lines and pipelines. Timber harvest has taken place in this region throughout the last century, but current demands for wood products have significantly increased the amount of harvest.

Surveys were conducted in three distinct ecoregions. The first two months of the 1998 sampling season were spent near Nordegg, Alberta, just east of Jasper National Park in the Boreal Uplands ecoregion (Alberta Energy and Natural Resources 1980; henceforth referred to as the Wapiabi area; Figures 2.1 and 2.2). Initially, all survey work was planned for this remote area because it had recently been allocated for timber production, but had not yet been harvested. However, the high elevation (1,400 to 1,800 meters; Canada Department of Energy, Mines and Resources 1978) and resultant poor weather (snow, rain, and cold temperatures), lasting from early May through June, limited the success of the project. Subsequently, the focus of this project was moved eastward, where conditions were more conducive to bat research because of the lower elevation (850 to 1,050 meters; Alberta Forestry Lands and Wildlife 1993) and higher average daily temperatures. As a result, late summer 1998 and all 1999 sampling took place in the forests that lie within the Boreal Foothills ecoregion near Drayton Valley, Alberta (Alberta Energy and Natural Resources 1980; henceforth referred to as the Drayton Valley area; Figures 2.1 and 2.2). In 1998, late summer sampling was also conducted near Grande Prairie, Alberta in the Boreal Mixedwood ecoregion (Alberta

Energy and Natural Resources 1980; henceforth referred to as the Grande Prairie area; Figures 2.1 and 2.3).

The Wapiabi and Drayton Valley study areas are located at the interface of the foothills vegetation zone and the boreal forest zone of west-central Alberta, which is characterized by cold winters and warm but variable summers (Kershaw et al. 1998). During the summer, daily rain showers are not uncommon in this region, and freezing temperatures can occur on any night of the year (Kershaw et al. 1998). The plant community in this area is diverse, making this region one of the most biologically productive areas of Alberta (Kershaw et al. 1998).

Survey sites in the Wapiabi area were located in the vicinity of the Blackstone River, just north of Nordegg, Alberta (117°N/53°W). The forests in this region are predominantly white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta*), and deciduous species are scarce. Drayton Valley survey sites were southwest of the town of Drayton Valley, Alberta, in the areas south and west of Rose and Wolf Creeks, north of the Baptiste River, and east of the O'Chiese Indian Reserve (115°N/53°W). This region is dominated by trembling aspen (*Populus tremuloides*) and lodgepole pine, and contains significant components of white spruce, black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), balsam poplar (*Populus balsamifera*) and paper birch (*Betula papyrifera*). Survey sites in the Grande Prairie area were south of Grande Prairie, Alberta, in the area south of the Wapiti River and west of the Smoky River (119°N/55°W). This region is dominated by lodgepole pine, aspen and white spruce, and contains significant components of balsam poplar, black spruce, balsam fir, and paper birch.

Figure 2.1: Province of Alberta, showing Weyerhaeuser Company's Grande Prairie and Drayton Valley Forest Management Areas.

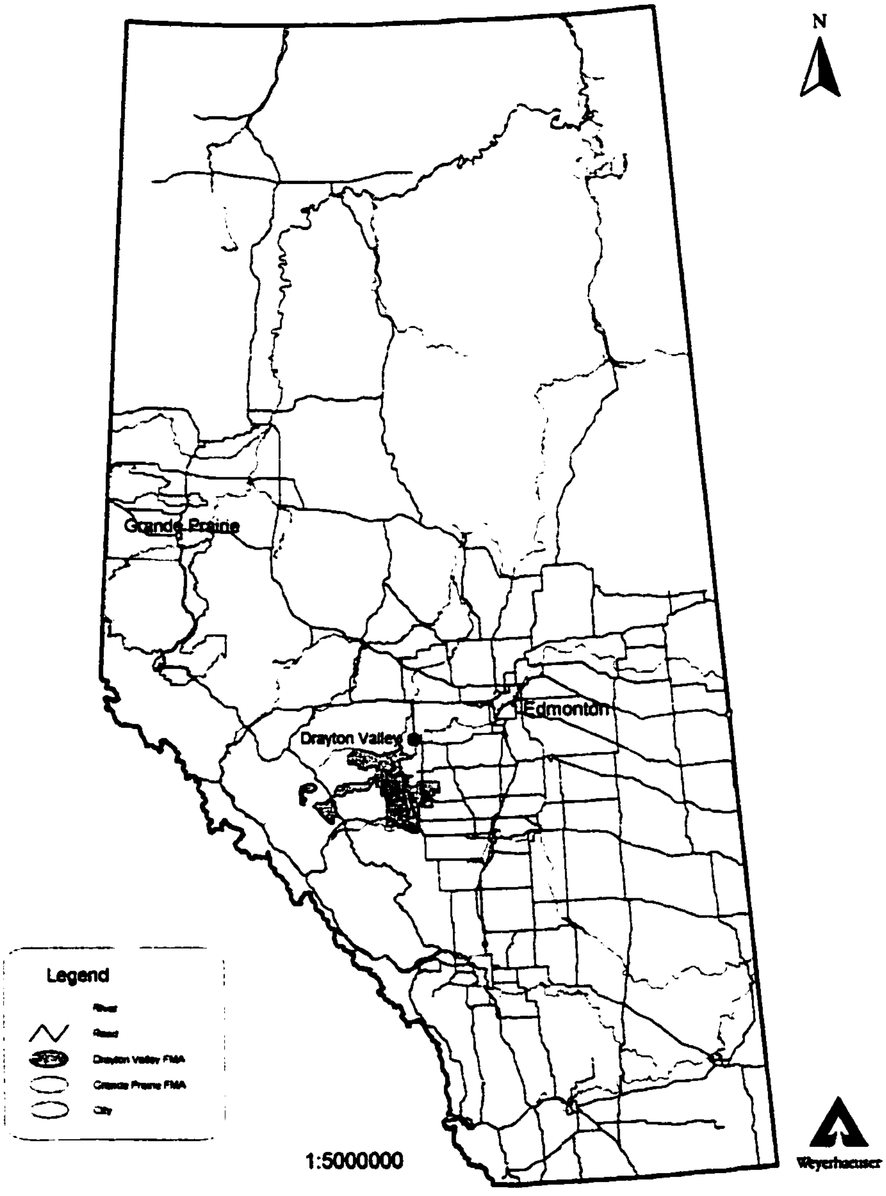


Figure 2.2: The Drayton Valley study region. The Wapiabi study area is part of the western-most portion of the Drayton Valley study region.

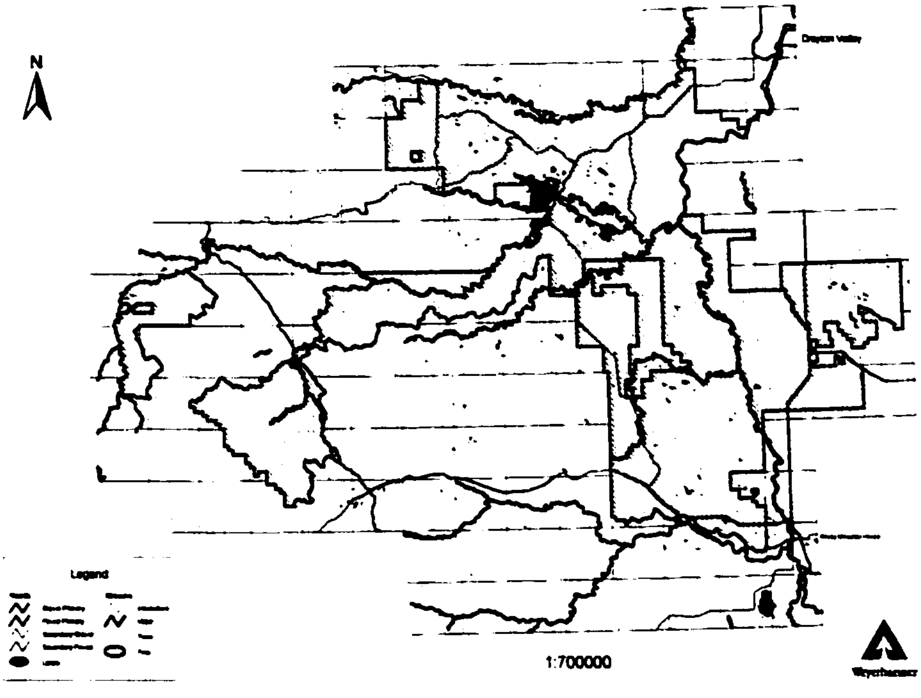
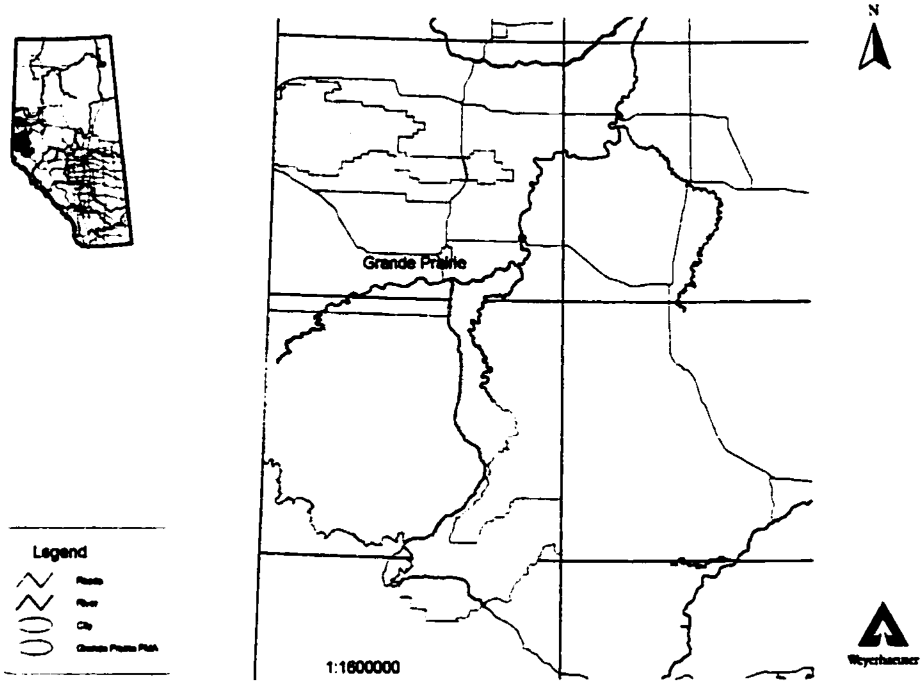


Figure 2.3: The Grande Prairie study region.



Methods

Bat Echolocation Survey and Monitor Techniques

Bats use echolocation to travel (maneuvering, orientation, etc.) and to feed (prey identification and capture). Anabat II® ultrasonic detection systems (Titley Electronics, Ballina, N.S.W., Australia), which record bat echolocation pulses on audio tape as bats fly through a location, were used to sample the bat community and to monitor bat activity. Detectors convert the high frequency echolocation signals of bats into a form audible to humans by dividing the frequency of signals by a set ratio. This conversion allows the researcher to count the number and type of signals per unit time. Ultrasonic bat detection permits distinction between series' of echolocation pulses (henceforth referred to as a pass) used for general flight (commuting) and those used for foraging. Each type of signal is distinct, in that commuting passes are relatively consistent in their repetition rate, while foraging signals are a series of increasingly frequent pulses that often end in a "buzz". Specialized hardware (Zero Crossing Analysis Interface Module, Titley Electronics) and software (Anabat 5, Titley Electronics) allow the identification of species or species groups from recorded echolocation signals, and were applied in this research to examine the composition and habitat associations of the bat community.

In 1998 and 1999, Anabat® systems equipped with cassette tape recorders (Radio Shack CTR-101) were deployed along narrow seismic lines and at the edge of ponds in order to record bat occurrence. Each detector was placed on the ground, and was pointed up at 45° from horizontal. On seismic lines, detectors were aimed parallel to the forest edge, and at pond sites the detectors were aimed over open water. Sensitivity settings were normally set at 6, but were decreased if noise from insects or wind continually triggered the detector. If the sensitivity dial had to be set lower than 4, recording was discontinued, as the range of the detectors may have been significantly diminished at this setting (de Oliveira 1998).

Capture Techniques

Throughout the summers of 1998 and 1999, bats were captured using a varying number and arrangement of mist nets. Nets were placed across narrow seismic lines, in small forest gaps, across small streams, and over standing water. Nets were opened 30 minutes before sunset, and were continually monitored for up to 5 hours, or until weather conditions became incompatible with trapping (temperatures dropped below 6° Celsius, high wind or heavy precipitation). Trapping locations were selected using aerial photographs, Alberta Vegetation Inventory maps, Phase III Forest Inventory maps, and ground searches. Specific net sites were selected based on logistical considerations of trapping, such as accessibility, safety, and the ability to arrange nets in an effective manner, as well as the probability of capturing bats. Beaver ponds were the most widely used locations, as there appeared to be more bat activity in these areas, thus increasing the likelihood of capturing the greatest number of individuals.

At each site, mist nets covered an area up to 5 meters high and up to 40 meters wide. Captured bats were immediately removed from nets and placed in holding bags for a minimum of one hour, so that mass measurements were not influenced by the amount of recently ingested food. Standard qualitative (species, sex, age, reproductive condition) and quantitative (forearm length, ear length, hind foot length, mass) measurements were taken on each bat. Age determination was made based on the degree of ossification of finger joints (Nagorsen and Brigham 1993). Site and weather information was also recorded for each night of trapping, including presence or absence of flying insects, percent cloud cover, amount and type of precipitation, wind speed, and ambient temperature every 15 minutes throughout the trapping session. Bats were released following the closure of survey nets, in order to eliminate the possibility of recapturing, and thus double counting, the same individuals on the same night. Releases took place at the site of capture and, in order to develop a reference call library, taped recordings using an ultrasonic bat detector were made of each individual as it was released.

Analytical Procedures

Taped bat passes, defined as a series of at least 2 search phase echolocation pulses, were summarized to determine the general distribution of detections among sites, and trends in activity patterns. Passes were further grouped into species categories, using zero-crossing analysis and signal processing software (Anabat V, Titley Electronics, Ballina, N.S.W., Australia), in order to document species occurrence. Foraging activity was documented by identifying feeding buzzes, a series of short-duration, high-repetition pulses associated with an attack on prey, that often follow a pass. Feeding buzzes were assigned a species based on the species determination of the pass that immediately preceded each buzz.

Echolocation pulses of some species of bats were not distinguishable from one another. As a result, passes were grouped into categories, based on similar quantitative and qualitative characteristics. These were associated with a particular species or group of species, based on comparisons to passes of known identity. A reference table of known bat pulse frequencies, durations and shapes was developed for this purpose, from pulse characteristics obtained from the literature (Table 2.1; Fenton and Bell 1981, Barclay 1986, Thomas and West 1989, Christy and West 1993, Kalko and Schnitzler 1993, Obrist 1995, Lippert and Runde unpublished data, Betts 1998, Barclay 1999, O'Farrell et al. 1999). This table was used only as a guideline for call identification, as call characteristics vary between geographical regions (Thomas et al. 1987, Parsons 1997).

Individual bat passes were identified to species, where possible, and to species groups, where a single species determination was not possible. Groupings of passes were based on overlapping minimum frequency ranges and similar pulse shapes (Table 2.1).

Table 2.1: Reference guideline of known bat call characteristics. Attributes of calls in the 5 species-groups were developed from call characteristics of the species contained within each group. Full names for species abbreviations are provided in the text.

Species or Species Group	**Minimum Frequency (kHz)**	**Duration of Pulse (milliseconds)**	**Pulse Shape**
LACI	16.9-22.0	6.2-10.3	Flat and long-tailed
LANO	25.0-28.0	8.0-16.0	Reverse J: Steep initial sweep with a long tail
EPFU	27.3-33.0	2.0-10.0	Reverse J: Steep initial sweep with a short tail
MYSP	35.0	1.0-5.0	Reverse J: Steep initial sweep with a short tail
LANO/EPFU	25.0-33.0	2.0-16.0	Reverse J: Steep initial sweep with a short tail
LANO/LACI	16.9-28.0	6.2-16.0	Flat and long-tailed, or steep initial sweep and short-tailed
NONMYSP	<35.0	Variable	Variable, or not apparent
UNKN	Variable	Variable	Variable, or not apparent

For this study, three species and five categories of call types were distinguished. Species and grouped categories included: Silver-Haired Bat (*Lasionycteris noctivagans* - LANO), Hoary Bat (*Lasiurus cinereus* - LACI), Big Brown Bat (*Eptesicus fuscus* - EPFU), *Myotis* Group (Little Brown Bat/*M. lucifugus*, Long-legged Bat/*M. volans*, Western Long-eared

Bat/*M. evotis*, and Northern Long-eared Bat/*M. septentrionalis* - MYSP), Silver-Haired/Big Brown Group (LANO/EPFU), Silver-Haired/Hoary Group (LANO/LACI), Non-*Myotis* Group (NONMYSP) and Unknown Group (UNKN). Calls made by Non-*Myotis* Group bats showed characteristics of those made by Silver-haired, Big Brown, or Hoary Bats, but single species identification could not be made. Calls in the Unknown Group were identified as having been made by a bat, but no further distinction could be made, as the signal was either weak or distorted.

Trapping effort was standardized by calculating net-nights, where one net used on one night was equal to one net-night. For example, if 3 nets were used during a single night, that trapping session counted as 3 net-nights.

Results

Wapiabi

Surveys in the Wapiabi region took place between May 19 and July 3, 1998. Ultrasonic detection (25.3 hours over 17 nights) and tape analysis verified the occurrence of 4 bat species or species groups in this region (*Myotis* bats, Silver-Haired Bat, Hoary Bat and EPFU/LANO Group). Bats belonging to the *Myotis* Group accounted for the majority of passes and feeding buzzes (Table 2.2). Trapping efforts (26.1 hours over 38 net-nights) did not result in the capture of any bats.

Table 2.2: Species occurrence in the Wapiabi region, Alberta. Percentage of total is shown in brackets.

Species or Species Group	Number of Passes	Number of Feeding Buzzes
MYSP	186 (83.7)	37 (86.0)
LACI	34 (15.3)	6 (14.0)
LANO	1 (0.5)	0 (0)
EPFU/LANO	1 (0.5)	0 (0)
Total	**222 (100)**	**43 (100)**

Grande Prairie

In the Grande Prairie region, surveys took place between August 3 and 13, 1998. Ultrasonic detection (14.4 hours over 6 nights) revealed the presence of 4 bat species or species groups in this region (*Myotis* bats, Silver-Haired Bat, Hoary Bat, and Unknown Group). Big Brown Bats were not detected at any of the study sites. The majority of passes were made by *Myotis* bats, while the majority of foraging buzzes were made by Silver-Haired Bats (Table 2.3).

Eight bats, representing two species, were captured (16.5 hours over 10 net-nights): the Little Brown Bat (n = 4) and the Northern Long-Eared Bat (n = 3). One bat, identified as belonging to the *Myotis* Group, escaped from the holding bag prior to examination, so data on the species, sex, and age of this individual are not available. All seven of the identified captures were juveniles (See Appendix 2.1).

Table 2.3: Species occurrence in the Grande Prairie region, Alberta. Percentage of total is shown in brackets.

Species or Species Group	Number of Passes	Number of Feeding Buzzes
MYSP	363 (73.5)	17 (32.7)
LANO	118 (23.9)	33 (63.5)
LACI	9 (1.8)	1 (1.9)
UNKN	4 (<0.1)	1 (1.9)
Total	**494 (100)**	**52 (100)**

Drayton Valley

Surveys in the Drayton Valley region were conducted between July 15 and August 24, 1998, and between May 25 and August 5, 1999. In 1998, ultrasonic detection (81.6 hours over 32 nights) verified the presence of 5 species or species groups (*Myotis* bats, Silver-haired Bat, Hoary Bat, Big Brown Bat, and Unknown group). Bats belonging to the *Myotis* Group accounted for the majority of passes and foraging buzzes (Table 2.4).

Trapping efforts (58.5 hours over 68 net-nights) resulted in the capture of 12 bats representing 4 species (Table 2.5). Three additional bats were entangled in nets, but escaped before identification could be made. The first capture occurred on July 23, 1998. This individual was a post-lactating, female Silver-Haired Bat, caught along a narrow seismic line. The remaining 11 captures were made at pond sites, and all were juveniles (see Appendix 2.2).

Table 2.4: Species Occurrence in the Drayton Valley region, Alberta (1998). Percentage of total is shown in brackets.

Species or Species Group	**Number of Passes**	**Number of Feeding Buzzes**
MYSP	796 (72.3)	35 (61.4)
LANO	141 (12.8)	11 (19.3)
EPFU	60 (5.5)	7 (12.3)
LACI	53 (4.8)	3 (5.3)
UNKN	51 (4.6)	1 (1.7)
Total	**1101 (100)**	**57 (100)**

Table 2.5: Capture results for 1998 bat surveys in the Drayton Valley region, Alberta.

	Little Brown Bat	**Western Long-eared Bat**	**Long-Legged Bat**	**Silver-Haired Bat**	**Total**
Adult male	0	0	0	0	**0**
Juvenile male	4	1	0	1	**6**
Adult female	0	0	0	1	**1**
Juvenile female	1	0	2	2	**5**
Total	**5**	**1**	**2**	**4**	**12**

In 1999, ultrasonic work (279 hours over 31 nights) verified the presence of all 8 species or species groups (refer to Table 2.1). The *Myotis* Group accounted for the vast majority of passes and foraging buzzes (Table 2.6). The call frequency ranges for all detected species fell within the ranges reported in the literature (Table 2.2, 2.7). For this study, only minimum frequency is reported because the maximum frequencies for all species, particularly those belonging to the *Myotis* Group, were highly variable and difficult to determine accurately.

Table 2.6: Species occurrence in the Drayton Valley region, Alberta (1999). Percentage of total is shown in brackets.

Species or Species Group	Number of Passes	Number of Feeding Buzzes
MYSP	4,438 (84.1)	843 (96.8)
LANO	500 (9.5)	15 (1.7)
LACI	199 (3.8)	8 (<0.1)
EPFU	56 (1.1)	5 (<0.1)
NONMYSP	42 (0.8)	0 (0)
EPFU/LANO	23 (0.4)	0 (0)
LACI/LANO	6 (0.1)	0 (0)
UNKN	12 (0.2)	0 (0)
Total	**5,276 (100)**	**871 (100)**

Table 2.7: Observed values of minimum frequency for species or species groups detected in the Drayton Valley region during 1999.

Species or Species Group	Observed Range of Minimum Frequency (KHz)	Observed Tonal Quality of Call
MYSP	34.0 – 47.0	High frequency click
EPFU	26.0 – 31.0	Relatively low frequency click
LANO	23.5 – 28.5	Click to moderate ping
LACI	17.0 – 26.0	Strong ping
EPFU/LANO	26.0 – 29.0	Click to moderate ping
LACI/LANO	23.0 – 26.0	Moderate to strong ping

Trapping efforts (64.8 hours over 76 net-nights) resulted in the capture of 40 bats representing 4 species (Table 2.8). Twenty-five percent of all captures occurred on one night (June 22, 1999; see Appendix 2.3). The first bat capture was on May 27, 1999, and the first juvenile bat was caught on July 21, 1999. The Northern Long-Eared Bat (adult male) was captured on the final night of trapping, August 5, 1999, at a site that lies to the south of the presumed range map (Caceres and Pybus 1997). An attempt was made to develop reference calls of captured bats as they were released at the capture site, but analysis revealed poor quality audio recordings, which made development of reference tapes impossible.

Table 2.8: Capture results for 1999 bat surveys in the Drayton Valley region, Alberta.

	Little Brown Bat	**Northern Long-eared Bat**	**Long-Legged Bat**	**Silver-Haired Bat**	**Total**
Adult male	28	1	2	1	**32**
Juvenile male	0	0	1	0	**1**
Adult female	1	0	2	3	**6**
Juvenile female	0	0	1	0	**1**
Total	**29**	**1**	**6**	**4**	**40**

My original protocol included attaching radio transmitters to breeding females of one target species, *Lasionycteris noctivagans* (Silver-Haired Bat). One individual captured in 1998 was appropriate for telemetry and was fitted with a transmitter. This bat was not located after 10 days of searching using telemetry. Another female Silver-Haired Bat, in the early to mid- stage of pregnancy, was captured and equipped with a transmitter on June 14, 1999. This bat was not located after 7 days of searching using telemetry. No other female Silver-Haired Bats fit the criteria for attachment of transmitters, as they showed no signs of reproduction. In addition, no females of other species captured showed signs of reproduction, so transmitter attachment was not considered for these individuals.

Discussion

Species Occurrence and Distribution

Combined trapping efforts and ultrasonic surveys successfully verified the presence of 2 bat species expected to occur in the Grande Prairie region, and all bat species and species groups that were expected to occur in the Wapiabi and Drayton Valley study areas. Surveys also slightly extended the southern border of the range map (by 2.2 km) of the Northern Long-Eared Bat, which is Blue Listed in Alberta (Caceres and Pybus 1997).

The presence of all bat genera expected to occur in the Drayton Valley study area suggests that suitable bat habitat was available, but critical habitat features are still not well understood. The capture of a large proportion of juveniles to adults in 1998 surveys indicates that trapping efforts aimed at capturing reproductive females for radio-telemetry were initiated too late in the season. The capture of the post-lactating female bat suggests that the reproductive period for bats in the Drayton Valley region was near its end at the time of capture. Although I initiated trapping efforts earlier in the season during 1999, the generally low capture rates did not permit telemetry to be conducted. Thus, I was not able to evaluate the status of the bat populations in this region. Future efforts aimed at evaluating the status of bat populations should include a combination of ultrasonic, trapping and telemetry surveys, in order to verify species occurrence and to identify critical habitat features.

The capture of a large proportion of males to females in Drayton Valley during 1999 suggests that the climate in the area I sampled may be harsh for bats. Previous work by Barclay (1991) found a high proportion of males to females in harsh environments (high elevation), presumably because males have a lower reproductive energy demand and are better able to utilize habitat in cooler climates. This, combined with the fact that weather patterns during the summer of 1999 were consistent with historical weather data (Environment Canada 1985), suggests that the observed sex ratio in Drayton Valley during 1999 is likely representative of the sex ratio for this area in other years. However, my sampling took place over a relatively small area, and information relating to these ratios may not be transferable across the boreal landscape.

The absence of Big Brown Bat detections in the Grande Prairie study sites is notable. This species is considered to be a generalist, and uses a variety of habitats for foraging, including forest canopy and over open water (Nagorsen and Brigham 1993). The limited sampling duration, and resultant small sample size for this region may have been a factor in the lack of detection of this species, and more extensive surveys need to take place over a longer duration in order to adequately inventory this region. Nevertheless, capture of juveniles of both Little Brown and Northern Long-Eared Bats strongly suggests the presence of breeding populations of these species in the area. The dates of capture (August 6, 9 and 13) indicate that maternity roosts of both species were present within the immediate geographical region, because it is unlikely that juveniles had begun to disperse or migrate this early in the season.

Methodology

When surveying an area to determine the presence of bat species, many techniques can be deployed. However, each sampling technique has limitations. Ultrasonic detectors are limited in range, and many bat species are often not detected acoustically, because the intensity of their echolocation signals is too low to be picked up by the microphone (O'Farrell and Gannon 1999). For example, the Western Long-eared

Bat, which occurs in all three regions sampled in this study, emits relatively quiet, low intensity echolocation pulses that may not be detected unless the bat is within extremely close range of the microphone (Nagorsen and Brigham 1993). Also, not all call sequences recorded from bat detectors are useable. Some sequences are plagued by interference, or are simply not strong enough to allow accurate species identification. Capture techniques, although useful for distinguishing *Myotis* species, in particular, also have limitations. Some species of bats, such as Big Brown and Hoary Bats, are known to fly and forage at altitudes clearly beyond the reach of nets, and are therefore better sampled acoustically (Nagorsen and Brigham 1993). In this study, acoustic sampling alone detected 3 species and 1 species aggregate, while capture techniques provided identification of 5 species. Combined, both techniques allowed verification of 7 species of bats, all of which were expected to occur in the study area according to published range maps. These results support the recommendation that combined capture and acoustic sampling provides the most effective inventory (see also O'Farrell and Gannon 1999).

Ultrasonic detection of bats, relative to trapping efforts, is expensive. The equipment necessary for ultrasonic detection is more costly than that needed for trapping. In addition, although time spent in the field is less than that required for trapping efforts, ultrasonic detection requires extensive, follow-up laboratory work. Recordings of bat echolocation signals made in the field, in my experience, take an additional 1.5 times to analyze in the laboratory. For example, if 100 hours of field recordings were made, it would take 150 hours of laboratory work to analyze the tapes, for a total of 250 hours.

Nevertheless, the use of remote ultrasonic detection devices allows researchers to use field time to conduct other surveys, such as trapping, simultaneously.

The echolocation signals used by bats may vary within an individual (Kalko and Schnitzler 1993, Obrist 1995), within populations (Obrist 1995), and among populations (Parsons 1997, Thomas et al. 1987). The identification of bat species using reference calls from other geographic areas can result in misidentification of species. Thus, caution must be taken when attempting to extrapolate information between regions. Although I attempted to document reference calls for bat species in my study region, poor quality recordings resulted in failure to do so. However, I was able to develop a classification procedure that allowed me to identify bat species, or aggregates of species that share common echolocation call characteristics, for my study region.

Conclusions

The combination of ultrasonic and trapping surveys used in this research successfully verified all seven species expected to occur in west-central Alberta. Ultrasonic detection worked well for detecting Silver-haired Bats, Big Brown Bats, Hoary Bats, and species belonging to the *Myotis* Group. Trapping did not result in detection of Big Brown or Hoary Bats. However, this method was effective in identifying Silver-haired bats, and allowed differentiation between all four *Myotis* species. As a result, I recommend that both methods be deployed in research where species identification is required.

Species belonging to the *Myotis* Group occurred far more frequently than all other species in the geographic regions sampled, based on ultrasonic surveys. *Myotis* bats also accounted for the majority of captures. These results support current understanding that *Myotis* bats are the most abundant species in the boreal forests of Alberta.

Although all seven species expected to occur in west-central Alberta were detected, the methods deployed were not able to determine the status of bat populations in the regions studied. To do so, research spanning several years, that utilizes a combination of trapping, telemetry and ultrasonic methods, would be necessary.

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Appendix 2.1: Data from bats captured in 1998 (n = 7) in the Grande Prairie region, Alberta. Age is either A (adult) or J (juvenile). An "*" indicates that data are not available.

Date	Species	Sex	Age	Reproductive Condition	Forearm (mm)	Ear (mm)	Hind Foot (mm)	Mass (g)
8/06	*M. lucifugus*	M	J	—	34.0	12.0	*	7.4
8/07	*M. septentrionalis*	F	J	—	35.4	15.3	*	7.4
8/07	*M. septentrionalis*	M	J	—	36.0	15.0	*	6.9
8/07	*M. lucifugus*	M	J	—	36.0	11.0	*	6.9
8/08	*M. lucifugus*	F	J	—	35.0	10.3	*	6.9
8/09	*M. septentrionalis*	M	J	—	36.1	15.2	*	6.9
8/13	*M. lucifugus*	M	J	—	37.0	12.5	*	9.0

Appendix 2.2: Data from bats captured in 1998 (n = 12) in the Drayton Valley region, Alberta. Age is either A (adult) or J (juvenile). An "*" indicates that data are not available.

Date	Species	Sex	Age	Reproductive Condition	Forearm (mm)	Ear (mm)	Hind Foot (mm)	Mass (g)
7/23	*L. noctivagans*	F	A	Post-lactating	41.7	11.1	7.4	13.0
8/04	*M. evotis*	M	J	—	36.6	18.0	10.4	7.2
8/05	*M. lucifugus*	F	J	—	40.6	12.0	9.8	7.4
8/05	*M. volans*	F	J	—	37.8	10.9	9.8	6.9
8/09	*M. lucifugus*	M	J	—	34.3	13.2	9.6	6.2
8/09	*M. lucifugus*	M	J	—	39.6	12.2	9.6	9.5
8/11	*M. lucifugus*	M	J	—	40.0	13.0	10.9	10.2
8/11	*L. noctivagans*	F	J	—	41.2	11.4	8.4	13.0
8/12	*M. lucifugus*	M	J	—	39.6	13.3	9.7	10.8
8/12	*M. volans*	F	J	—	38.0	11.2	8.8	8.0
8/19	*L. noctivagans*	M	J	—	42.6	13.0	9.0	*
8/19	*L. noctivagans*	F	J	—	43.2	14.0	9.6	*

Appendix 2.3: Data from bats captured in 1999 (n = 40) in the Drayton Valley region, Alberta. Age is either A (adult) or J (juvenile).

Date	**Species**	**Sex**	**Age**	**Reproductive Condition**	**Forearm (mm)**	**Ear (mm)**	**Hind Foot (mm)**	**Mass (g)**
5/27	*M. volans*	M	A	Non-reproductive	37.5	12.9	7.2	6.5
6/03	*M. lucifugus*	M	A	Non-reproductive	39.9	12.3	10.5	8.4
6/03	*M. lucifugus*	M	A	Non-reproductive	38.9	11.3	9.6	7.5
6/03	*M. lucifugus*	M	A	Non-reproductive	39.8	13.3	9.4	7.9
6/09	*M. lucifugus*	M	A	Non-reproductive	38.5	12.5	9.9	6.7
6/14	*L. noctivagans*	F	A	Early to mid-pregnancy	41.0	13.0	8.5	13.4
6/17	*M. volans*	F	A	Non-reproductive	40.1	10.8	9.1	7.4
6/17	*M. volans*	F	A	Non-reproductive	37.9	12.6	8.9	7.3
6/17	*M. volans*	M	A	Non-reproductive	34.2	11.3	8.3	6.4
6/22	*M. lucifugus*	M	A	Non-reproductive	40.1	11.4	10.5	8.6
6/22	*M. lucifugus*	M	A	Non-reproductive	38.2	11.2	9.9	7.3
6/22	*M. lucifugus*	M	A	Non-reproductive	38.0	11.7	10.6	7.7
6/22	*M. lucifugus*	M	A	Non-reproductive	36.8	11.9	9.7	7.9
6/22	*M. lucifugus*	M	A	Non-reproductive	39.0	10.8	9.4	7.8
6/22	*M. lucifugus*	M	A	Non-reproductive	39.0	12.8	11.2	7.1
6/22	*M. lucifugus*	M	A	Non-reproductive	39.0	14.5	9.2	8.0
6/22	*M. lucifugus*	M	A	Non-reproductive	40.2	14.0	11.8	7.8
6/22	*M. lucifugus*	M	A	Non-reproductive	40.2	14.4	10.5	7.3
6/22	*M. lucifugus*	F	A	Non-reproductive	37.8	13.8	8.6	6.7
6/28	*M. lucifugus*	M	A	Non-reproductive	38.2	14.1	9.7	7.5
6/28	*M. lucifugus*	M	A	Non-reproductive	39.8	14.9	9.9	8.3
6/28	*M. lucifugus*	M	A	Non-reproductive	38.0	13.6	11.1	8.0
6/28	*M. lucifugus*	M	A	Non-reproductive	40.9	12.3	11.1	9.8
6/30	*M. lucifugus*	M	A	Non-reproductive	37.6	14.0	8.6	8.5
7/12	*M. lucifugus*	M	A	Non-reproductive	41.6	15.2	10.8	9.1
7/21	*M. volans*	M	J	—	38.2	10.5	8.6	8.1
7/22	*M volans*	F	J	—	38.6	11.9	9.8	8.8
7/22	*M. lucifugus*	M	A	Non-reproductive	39.4	13.3	9.2	9.0
7/27	*M. lucifugus*	M	A	Non-reproductive	40.8	13.0	10.2	9.4
7/27	*L. noctivagans*	F	A	Non-reproductive	40.8	13.0	10.6	13.1
7/28	*M. lucifugus*	M	A	Non-reproductive	36.0	14.8	9.4	9.2
7/28	*M. lucifugus*	M	A	Non-reproductive	39.4	14.0	10.2	9.6
7/29	*M. lucifugus*	M	A	Non-reproductive	39.2	12.1	9.2	11.7
8/03	*M. lucifugus*	M	A	Non-reproductive	36.9	12.6	9.4	9.1
8/03	*M. lucifugus*	M	A	Non-reproductive	39.5	11.9	8.6	8.2
8/03	*M. lucifugus*	M	A	Non-reproductive	38.6	12.8	10.8	9.3
8/03	*M. lucifugus*	M	A	Non-reproductive	39.5	12.8	9.4	9.4
8/04	*L. noctivagans*	F	A	Non-reproductive	43.3	11.3	8.6	12.3
8/04	*L. noctivagans*	M	A	Non-reproductive	39.9	12.1	7.9	11.7
8/05	*M. septentrionalis*	M	A	Non-reproductive	36.8	15.4	8.4	7.2

CHAPTER 3: THE RELATIONSHIPS OF BAT DIVERSITY AND RELATIVE ACTIVITY TO FOREST COMPOSITION AND SNAG DENSITY

Introduction

Current forest practices are altering the natural composition and structure of boreal forests through clear-cutting, and, in some cases, replanting of single species stands. Bats, many of which are reliant on forests and forest structures for foraging and reproduction, may be affected by these changes, and by the general decrease in forest diversity. Current practices that significantly alter forest structure and decrease the variability in forest composition may have adverse affects on bats by lowering the availability of roost structures. It is important to understand the effects that current practices may be having on bat populations in order to conserve this unique group of species.

Previous studies have used telemetry to quantify the roosting needs of some species of bats, but the needs of other species are still not well understood. In temperate regions, many species prefer to roost in tall, wide-diameter, dead trees that are in a mid- to advanced stage of decay, and have low canopy closure (Campbell et al. 1996, Vonhof and Barclay 1996, Brigham et al. 1997, Crampton and Barclay 1998, Sedgeley and O'Donnell 1999). However, male and female bats often occupy different roosts, or different areas within the same roost, due to their unique energy demands (Hamilton and Barclay 1994). Reproductive female bats have higher energy demands than male or non-reproductive female bats, as they are solely responsible for the gestation and rearing of young. As a result, reproductive female bats may select warmer roosts than males or non-reproductive females, as warmer roost temperatures decrease the gestation period and increase the growth rate of juveniles (McNab 1982).

Based on their relatively high energy demands, it is likely that groups of reproductive female bats and their young, or maternity colonies, may have specific roosting needs, and may be more restricted in their ability to find suitable roost structures than males or non-reproductive females. Tree height, diameter, and decay stage, among other factors, may affect the temperature and humidity (microclimate) of a potential roost, and thus its likelihood of being suitable for use by reproductive female bats. Although the availability of maternity roost structures may be essential for the survival of bat populations in the boreal forest of Alberta, few studies have evaluated the relationship of roost availability to habitat type and relative activity levels of bats.

Currently, there is not enough information on forest utilization by bats in different habitat types to provide management recommendations relating to their conservation. To address this issue, I compared the habitat use of bats in three commercially valuable forest types. I also compared the potential roost availability within these same areas. This study was designed to determine the relationships of bat diversity and relative activity to forest type and density of potential roost trees. My specific objective was to compare the species richness and relative activity level of bats in mature forest stands dominated by trembling aspen, lodgepole pine, or white spruce, and to determine the density of potential roost trees (snags) within these same areas.

Based on my own personal field observations of structural diversity and bat activity in different forest types, which were recently substantiated by Kalcounis et al. (1999), I predicted that the relative activity levels of bats would be highest in aspen-dominated areas. In addition, I predicted that the potential roost availability would also be highest in aspen-dominated areas, due to the relative age of the forest stands used in this study. All stands surveyed were approximately the same age. As a result, and because deciduous trees tend to decay faster than conifer trees, I predicted that the aspen-dominated stands surveyed for my study would contain a higher number of dead or dying trees than their pine- and spruce-dominated counterparts.

Methods

Study Area

I conducted surveys in the Drayton Valley area of west-central Alberta (Alberta Energy and Natural Resources 1980; Figures 2.1 and 2.2; see Chapter 2 for a complete study area description). Sampling sites were southwest of the town of Drayton Valley, Alberta, in the areas south and west of Rose and Wolf Creeks, north of the Baptiste River, and east of the O'Chiese Indian Reserve (115°N/53°W). This region is dominated by trembling aspen and lodgepole pine, and contains significant components of white spruce, black spruce, balsam fir, balsam poplar and paper birch.

Sampling Design

To assess patterns of habitat use by bats in the Drayton Valley region, I identified four replicates of three distinct forest types (lodgepole pine, white spruce, and trembling aspen), for a total of 12 sites. These forest types were chosen due to their high commercial value and availability across the landscape. Stand compositions were determined from Alberta Vegetation Inventory maps and aerial photographs, and confirmed by ground surveys. Forests at sampling sites were comprised of at least 70% of the dominant tree species. Because older forests are known to be more important to bats for roosting compared to younger stands (Thomas and West 1991, Crampton and Barclay 1998), all survey sites selected were at least 98 years old.

Relative activity levels were determined using ultrasonic bat detectors (see Chapter 2). Each site was sampled 3-5 times, to account for seasonal variation in bat activity. Samples at each site were spread over a 1.5 month period, from mid-July through the end of August, 1998. Sampling began at 30 minutes before sunset (approximately 2100) and continued until approximately 0100.

Existing seismic lines within each site were targeted for detector placement, based on observed increases in insect and bat activity at forest edges (Grindal 1995). All seismic lines selected at each survey site were between 5 and 10 meters wide and contained little or no vegetation, other than grasses. At each survey location, the detector was placed on the ground and was oriented 45° from horizontal, facing parallel to the forest edge. Because a detector has a range of less than 40 meters, the detector was placed at least 50 meters away from non-target habitat, to eliminate inadvertent recording of bats not associated with the forest type of interest. If the sensitivity dial on the detector had to be lowered beyond 4 due to wind or rain, surveys for that night were discontinued because, at this level, bat echolocation signals may not be readily detectable.

Snag Sampling

Potential roost availability was quantified using 240 meter by 30 meter belt transect surveys in each of the 12 sites that were surveyed for bat activity. Belt transects were initiated at the forest-seismic line interface, adjacent to the site of detector placement, and ran perpendicular to the seismic line, into the forest. Each potential roost structure within each belt was characterized by measuring tree height, diameter at breast height, and decay class, which are known to be important in the selection of roosts by bat species occurring in the study area (Vonhof and Barclay 1996, Crampton and Barclay 1998). For this project, I defined a potential roost structure, or snag, to be a live tree that contained obvious defects, or a dead tree (Table 3.1). Only structures that were in decay stages 2 through 7 were examined, as bats are not known to commonly roost in structures of decay stage 1 or 8 (Table 3.1). In addition, only structures with a diameter at breast height equal to or greater than 15 centimeters were included in the inventory (Table 3.2), because bats are not known to roost in smaller structures.

Analytical Procedures

Relative bat activity was quantified by dividing the total number of echolocation passes by the duration of each survey period (passes per hour). To compare habitat use among forest types, relative bat activity was calculated for each night at each site, and averages of each site were used to estimate the relative activity for each treatment. Nightly activity was calculated as the number of bat echolocation passes per hour over the sampling period. Feeding buzzes, a high-repetition series of pulses associated with an attack on prey, were also counted to measure foraging rate (# buzzes per pass) within sites and among treatments.

Statistical Analysis

For data collected in the Drayton Valley region, mean relative activity levels were calculated for all species groups combined, and normality tests were performed. Patterns in commuting (non-foraging) activity among forest types were examined using an analysis of covariance (ANCOVA), with forest type as the main effect and ambient

Table 3.1: Decay classification scheme for live and dead trees (Crampton 1995, Vonhof and Barclay 1996).

Decay Stage	Decay Class	Description
1	Alive	Live, healthy, no obvious defects, all branches and top intact and alive.
2	Alive w/ defects	Live but unhealthy, obvious defects such as branch mortality, broken top, cracks or hollows present.
3	Well-developed canopy	Newly dead, shows little sign of decay, branches still present, bark tight.
4	Moderate canopy	Retains major branches but not smaller twigs, bark loosening, top may be broken.
5	Sparse canopy	Major branches gone or shortened, bark loose or lost, top may be broken. If burned, trunk still hard/solid.
6	Moderate decay	Branches lost, little or no bark. If conifer, sapwood soft or sloughing; if deciduous, trunk still firm. If burned, sapwood softening.
7	Extensive decay	Bark and top lost, extensive decay (both heart and sap rot), may be unsteady.
8	Decomposed	Extensive decay, both heartwood and sapwood soft and spongy, rotten wood can be pulled out with fingers.

temperature (readings taken one half hour after sunset) as a covariate. Post-hoc Bonferroni tests were used to test for relationships between means that showed a significant result. Post-hoc power analyses were performed to estimate the probability of committing a Type II error (not rejecting the null hypothesis when it is in fact false) in the analysis. Foraging rates among treatments were calculated by dividing the number of foraging buzzes by the number of echolocation passes. An ANCOVA was used to examine patterns among treatments, with forest type as the main effect, and ambient temperature as a covariate.

Table 3.2: Diameter classification scheme for potential roost structures.

Diameter Class	Diameter at Breast Height
1	15-25 cm
2	26-35 cm
3	36-45 cm
4	46-55 cm
5	56-65 cm
6	66-75 cm

Mean snag heights (continuous variable) were calculated for each forest type, and were compared using a one-way ANOVA. Post-hoc Bonferroni tests were used to test for relationships between means that showed a statistically significant result. Chi-Square tests were used to compare the observed number of snags in each diameter and decay class to an even distribution, in each treatment. This method was employed due to the categorical nature of these data. To evaluate the availability of roost structures across habitat types, snag density was calculated (snags/hectare). All analyses were performed using SPSS 10.0 software, and a significance level (α) of 0.05 (Zar 1996).

Results

Effect of Forest Composition and Habitat Type

In the Drayton Valley Region, bat activity at sampling sites was monitored for 142 hours, resulting in 1,101 recorded bat passes. The majority of passes were detected in white spruce habitat, followed by aspen and pine (Table 3.3). However, the sampling effort in each treatment varied. Aspen habitat supported the highest mean number of passes per hour, or relative activity, followed by spruce and pine habitats, respectively (Table 3.3).

Table 3.3: Bat activity across forest types. Percentage of total is shown in brackets.

Forest Type	Number of Passes	Relative Activity (passes/hour ± SE)
Aspen	411(37.3)	15.40 ± 3.03
Pine	218(19.8)	11.33 ± 4.27
Spruce	472 (42.9)	14.34 ± 3.70
Total	**1,101 (100)**	--

Examination of the relative activity data within each treatment revealed normal distributions in aspen and pine forest types. However, the distribution of data in spruce habitat deviated significantly from normal, so the entire data set was square root-transformed to normalize the data in all three treatments. The variances were similar among forest types (p=0.81, n=12; Levine's statistic). Analysis of covariance detected no significant difference in relative activity among forest types (p=0.17, F=2.23, n=12; power=0.33; Figure 3.1), however temperature had a significant effect on relative activity (p=<0.01, F=36.93, n=12; power=0.99).

Foraging Activity

In the Drayton Valley region, 57 feeding buzzes were detected over the sampling period, the majority of which were recorded in aspen habitat (Table 3.4). Ambient temperature did not have a significant effect on foraging rate (p=0.64, F=0.24, n=12; power=0.07), so this covariate was omitted and a simple ANOVA was performed, with forest type as the main effect. The mean foraging rate was higher in aspen habitat, as compared to spruce and pine forest, but differences were not significant (p=0.84, F=0.18, n=12; power=0.07; Figure 3.2). In all forest types, the majority of foraging buzzes were emitted by *Myotis* Group bats (Table 3.4).

Figure 3.1: Relative activity levels (square-root transformed) in aspen, pine and spruce forest types. Mean values are shown inside each bar. Error bars represent the 95% confidence interval of mean values. For each forest type, n=4.

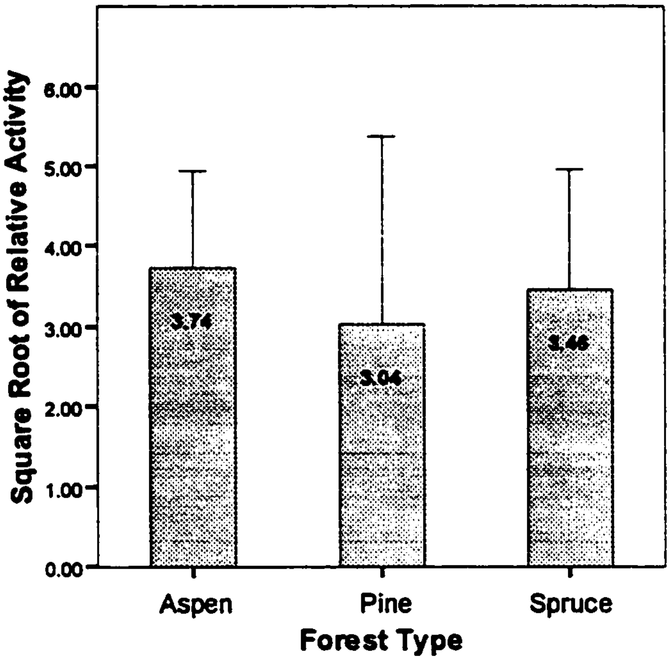


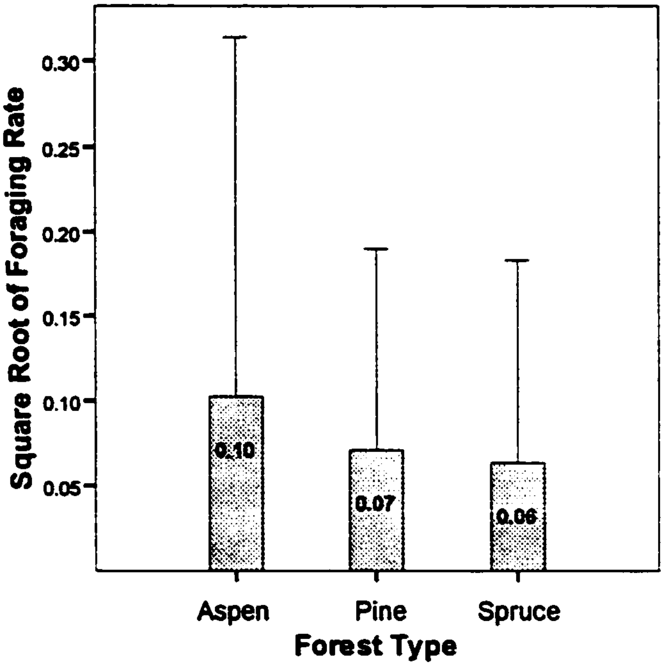
Table 3.4: Total foraging activity by species, and habitat type, in the Drayton Valley region. Percentage of total is shown in brackets.

Species	Number of Buzzes			Total
	Aspen	Spruce	Pine	
Myotis Group	10	19	6	35 (61.4)
Silver-haired Bat	6	5	0	11 (19.3)
Big Brown Bat	7	0	0	7 (12.3)
Hoary Bat	3	0	0	3 (5.3)
Unknown	1	0	0	1 (1.7)
Total	27 (47.4)	24 (42.1)	6 (10.5)	57 (100)

Potential Roost Availability

A total of 8.64 hectares (2.88 hectares in each habitat type) were surveyed using belt transects, resulting in the measurement of 491 snags. Aspen-dominated sites had the highest number and density of snags, followed by spruce- and pine-dominated sites (Table 3.5). In aspen and spruce sites, *Populus* species snags were the most common, while in pine sites, *Pinus* species occurred most frequently (Table 3.5). Although snag density varied among forest types, these differences were not statistically significant (p=0.27, F=1.51, n=12; power=0.20).

Figure 3.2: Mean foraging rates (square-root transformed) for aspen, pine, and spruce forest types. Mean values are shown within each bar. Error bars represent the 95% confidence interval of mean values. For each forest type, n=4.



Across forest types, there were higher numbers of short and intermediate height snags, and fewer tall snags (Figure 3.3). Mean snag height in pine-dominated sites (13.2 ± 0.7 meters) was greater than mean snag height in aspen- (9.7 ± 0.4 meters) and spruce-

(9.2 ± 1.7 meters) dominated sites. These differences could be considered marginally significant, based on the small sample size and moderate power to detect differences (p=0.06, F=4.00, n=12; power=0.45).

Table 3.5: Number (#) and density (number per hectare) of snags, according to species, in three habitat types. Percentage of total number is shown in brackets.

Snag Species	Aspen		Spruce		Pine		Total	
	#	**Density**	**#**	**Density**	**#**	**Density**	**#**	**Density**
Populus species	181	62.85	55	19.10	11	3.82	**247 (50.3)**	**28.59**
Picea species	11	3.82	9	3.13	61	21.18	**81 (16.5)**	**9.38**
Pinus species	0	0	0	0	111	38.54	**111 (22.6)**	**12.85**
Birch	2	0.69	9	3.13	0	0	**11 (2.3)**	**1.27**
Fir	3	1.04	31	10.76	0	0	**34 (6.9)**	**3.94**
Unknown	0	0	3	1.04	4	1.39	**7 (1.4)**	**0.81**
Total	**197 (40.1)**	**68.40**	**107 (21.8)**	**37.15**	**187 (38.1)**	**64.93**	**491 (100)**	**56.83**

In each forest type, the number of snags decreased as the diameter increased (Figure 3.4). This decrease was most notable in pine-dominated sites, where no snags were detected in the three largest diameter classes. Differences among forest types in the number of snags in each diameter class were significant (p=<0.01, df=10, Pearson χ^2=166.92). Compared to an even distribution across diameter classes (expected distribution), aspen sites contained fewer snags than expected in diameter classes 1, 4, and 6, and more snags than expected in diameter classes 2, 3 and 5 (Table 3.6). Snags in pine sites were more numerous than expected in diameter class 1, and were less numerous than expected in all other diameter classes. Spruce sites contained fewer snags than expected in diameter class 1, while all other diameter classes had more snags than were expected.

Figure 3.3: Distribution of snags by forest type and height.

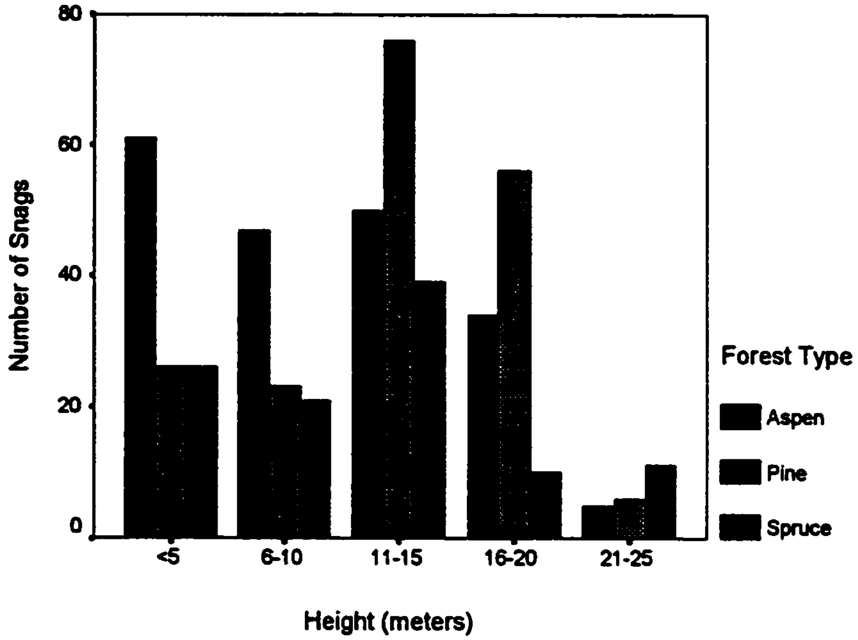


Figure 3.4: Distribution of snags by forest type and diameter at breast height.

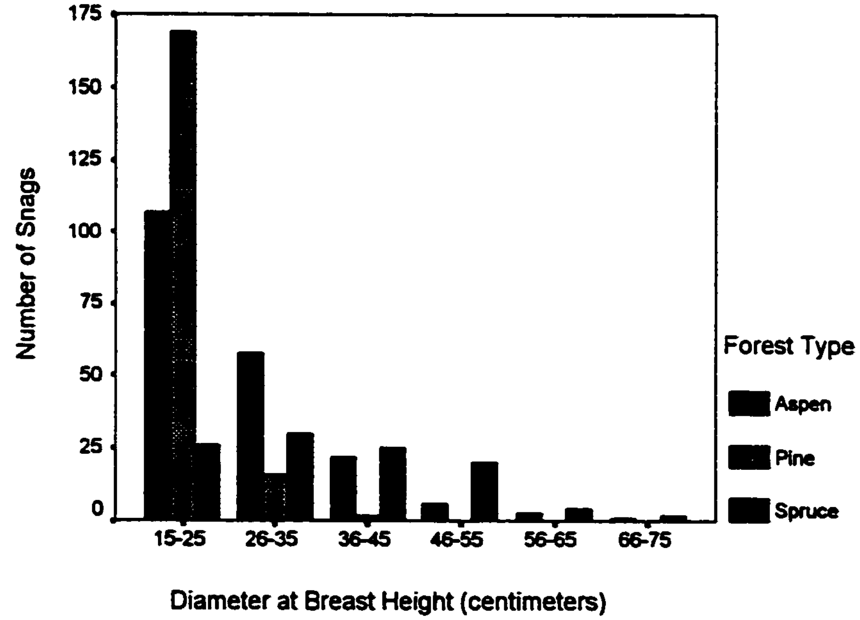


Table 3.6: Observed versus expected number of snags by diameter class, in each forest type.

		Number of Snags	Diameter Class						Total
			1	2	3	4	5	6	
Forest Type	Aspen	Observed	107	58	22	6	3	1	197
		Expected	121.2	41.7	19.7	10.4	2.8	1.2	197.0
	Pine	Observed	169	16	2	0	0	0	187
		Expected	115.0	39.6	18.7	9.9	2.7	1.1	187.0
	Spruce	Observed	26	30	25	20	4	2	107
		Expected	65.8	22.7	10.7	5.7	1.5	0.7	107.0
Total		Observed	302	104	49	26	7	3	491

The distribution of snags in aspen and pine sites indicated that the number of snags in the intermediate stage of decay are more numerous than snags in the early and late stages of decay in these habitats (Figure 3.5). In spruce sites, the number of snags in the decay stages were more uniformly distributed. Compared to an even distribution across decay classes (expected distribution), aspen sites contained fewer snags than expected in decay classes 2, 3, 4 and 7, and had more snags than expected in decay classes 5 and 6; pine sites had more snags than expected in decay classes 2, 3 and 4, and fewer than expected in classes 5, 6 and 7; spruce sites contained more snags than expected in decay classes 2, 6 and 7, and fewer than expected in classes 3, 4 and 5 (p=<0.01, df=10, Pearson χ^2=115.13; Table 3.7).

Snags with the combination of features important to bats (diameter class 3, decay class 3, 4 or 5; Campbell et al. 1996, Vonhof and Barclay 1996, Crampton and Barclay 1998) were sparse throughout the sampling area, and accounted for only 6.3% of all snags (Table 3.8). If the height is restricted to class 5, which is reported to be preferred by roosting bats (Crampton and Barclay 1998), potential roost snags become even less abundant, and account for less than 1% of all snags.

Figure 3.5: Distribution of snags by forest type and decay class.

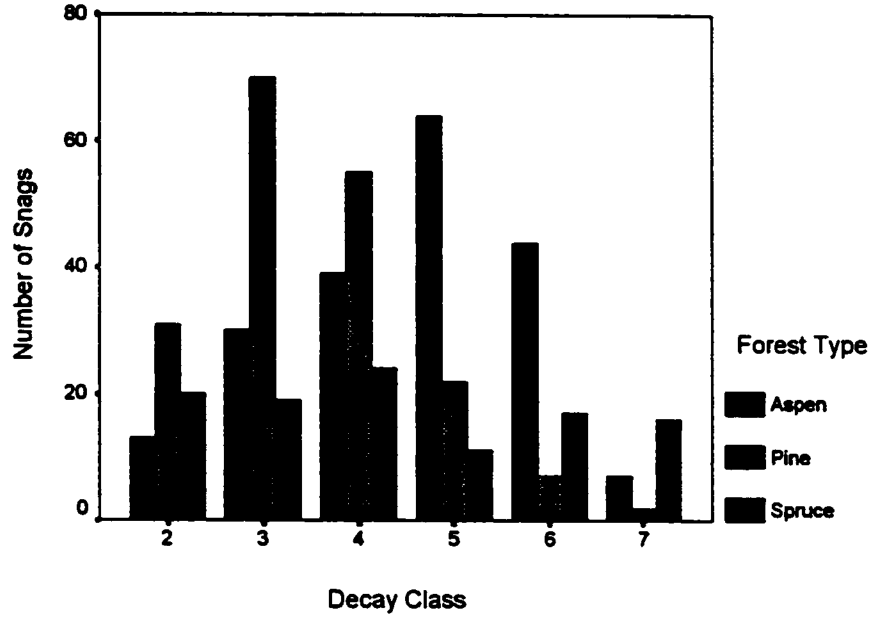


Table 3.7: Observed versus expected number of snags by decay class, in each forest type.

		Number of Snags	Decay Class						Total
			2	3	4	5	6	7	
Forest Type	Aspen	Observed	13	30	39	64	44	7	197
		Expected	25.7	47.7	47.3	38.9	27.3	10.0	197.0
	Pine	Observed	31	70	55	22	7	2	187
		Expected	24.4	45.3	44.9	36.9	25.9	9.5	187.0
	Spruce	Observed	20	19	24	11	17	16	107
		Expected	13.9	25.9	25.7	21.1	14.8	5.4	107.0
Total		Observed	64	119	118	97	68	25	491

Table 3.8: Abundance (#) and density of snags, according to forest type, in diameter class 3, decay classes 3, 4 and 5, and height class 5.

Forest Type	**Snags in Diameter Class 3 and Decay Class 3/4/5**		**Snags in Diameter Class 3, Decay Class 3/4/5, and Height Class 5**	
	#	**Density (#snags/ha)**	**#**	**Density (#snags/ha)**
Aspen	17	5.90	0	0
Pine	2	0.69	1	0.35
Spruce	12	4.17	2	0.69
Total	**31**	**3.59**	**3**	**0.35**

Discussion

Patterns of habitat use and potential roost availability were consistent with my predictions, but were not statistically significantly. I predicted that overall bat activity would be highest in aspen habitat. While the trend indicated that activity was higher in aspen habitats than in spruce and pine, the differences were not significant (p=0.17, F=2.23, n=12; power=0.33). Likewise, although, as predicted, aspen habitat contained a higher number and density of snags than did spruce and pine, the difference was not significant (*p*=0.27, F=1.51, n=12; power=0.20).

Patterns of Habitat Use

Forest type did not significantly influence bat activity in the Drayton Valley region, although the power of the analysis was low. My results also indicate that forest type was not important to bats foraging along narrow seismic lines. Compared to total activity, foraging activity was generally low across all sites, suggesting that seismic lines are used primarily by bats for commuting, and only occasionally for foraging. However, bats may opportunistically feed as they travel along narrow seismic lines. Nevertheless, my results indicate that bats do not regularly forage actively in these areas. In addition, my results indicate that foraging activity in the areas I studied was low compared to findings from other recent studies that took place in regions that lie to the east of my study area. Foraging activity in my study accounted for 5.2% of all bat passes, whereas, in central Ontario, Jung et al. (1999), and in central Saskatchewan, Kalcounis et al. (1999) observed higher levels of foraging activity (11.1% and 12%, respectively). My observed low foraging activity level, as compared to other studies, suggests that the areas I sampled (narrow seismic lines) are not typically used for foraging.

Ambient temperature affected bat activity, but not foraging rates. However, the low incidence of foraging buzzes, as compared to passes, across all sites resulted in low power to detect an effect from ambient temperature on foraging rate. In addition, a temperature effect on foraging rate may have been masked by the type of analyses performed, as foraging rate was calculated as a proportion of overall activity. It is possible that an effect of temperature on foraging activity may exist if relative foraging activity (number of buzzes per unit of time), as opposed to foraging rate, were examined.

Commuting bats may use cover to avoid wind and therefore reduce energy demands while in flight (de Jong 1995). Edge habitat fulfills this need by supplying open flight corridors in close proximity to forest cover, which serves as a wind barrier. Patterns in my relative activity data indicate that commuting bats are not restricted to a particular forest type when travelling along narrow seismic lines, and that aspen, pine and spruce forest provide commuting habitat for bats equally well. Additionally, the occurrence of all species and species groups in each of the forest types demonstrates that these areas are available habitat to all species of bats for commuting; forest type does not restrict use by bats of a particular species.

Potential Roost Availability

Snag surveys revealed that there was a low abundance of preferred, and ideal, roost structures in forested areas relative to total snag density, throughout the study area. Across forest types, less than 1% of all measured snags fit the strict diameter, decay stage and height criteria of a preferred maternity roost (n = 3 out of 491). On average, only 0.35 ideal snags per hectare were available to groups of female bats for roosting and rearing young. Although a clumped distribution of roost snags is known to be important to bats (Vonhof and Barclay 1996), such a distribution is not likely to occur across the areas I sampled, given the observed snag density. However, if the distribution of snags across the landscape is patchy, my sampling grids may not have adequately detected this resource.

The scarcity of preferred roost structures may also be explained by the general distribution of snags, according to height, diameter and stage of decay. For all forest types, the number of snags dropped noticeably in the tallest height classes. In addition, aspen and pine sites contained many small diameter snags, and few or no large diameter snags. Spruce sites contained fewer small diameter snags than the other two forest types, but also had very few large diameter snags. Stage of decay did not have as great an influence on availability as height and diameter, as the majority of snags fell into the decay classes that are preferred by bats for roost structures. It is the combination of all factors that leaves very few ideal roosts across the forest types examined.

The age of the forests examined in this study may also account for the observed low densities of preferred roost structures. The life-spans of aspen, pine and spruce trees are greater than typical harvest rotations. Aspen can live to be more than 140 years old, pine can live to be more than 180 years old, and spruce can live more than 200 years, but harvest rotations in the forests studied here range from 70-100 years for aspen, and 90-110 years for pine and spruce (W. Crosina, personal communication). None of the forest stands selected for this research were greater than 108 years old (oldest was of 1890 origin). It is possible that the stands studied here were simply not old enough to contain a significant component of dead or dying trees that exhibit the characteristics of an ideal bat roost.

Despite the low abundance of ideal roost structures observed in this study, as compared to total snag density, the availability and density of less preferred, yet useable structures may be much higher. Roosting bats have been known to use structures that do not fit the strict guidelines used in this study. For example, Vonhof and Barclay (1997) found both male and female Western Long-eared Bats (*Myotis evotis*) roosting in large-diameter stumps, which were located in clear cuts, and were much shorter than the ideal roost structures described here. Although bats may be flexible in their selection of roost sites (Brigham 1991), much of the research conducted on radio-tagged, reproductive female bats suggests that they prefer structures with certain height, diameter, and decay characteristics over randomly available structures (Campbell et al. 1996, Brigham et al. 1997, Crampton and Barclay 1998, Sedgeley and O'Donnell 1999). It is not known how the removal, or absence, of preferred structures will affect the roost site selection and roosting behaviour of bats in this region, over time.

This study has served as a basis for understanding the potential roost availability in mature forest types in the Drayton Valley region of Alberta. Although telemetry work has previously been used to determine the specific microhabitat requirements of some species of roosting bats in Alberta (Crampton and Barclay 1998), more work of this nature is necessary to assess the roosting needs of other species. Knowledge of these requirements is necessary to implement effective management strategies.

Implications for Management

The availability of foraging and roosting resources largely determines which habitat is suitable for use by bats. However, areas where bats commute may contain lower levels of both of these resources and still serve a valuable function. Findings from this research indicate that the value of commuting habitat, which connects foraging and roosting areas, is not dependent on the tree species that dominates the forest. Factors that affect the availability or density of cover, such as canopy height or closure, may be more important factors in determining which habitat is suitable for commuting.

The availability of roost structures depends on the particular needs of each bat species, and on the availability of live or dead trees that satisfy these needs. The scarcity of ideal roost structures, compared to the total number of snags in this study, is notable, however my results have not been compared to naturally occurring snag densities. In the future, a comparison of this type would clarify the availability of this resource. In addition, although less-preferred roosts may be relatively more abundant across the landscape, it is unknown what effect the lack of preferred roosts may have over the long term persistence of bat populations in this region. In addition, the ages at which forest stands are harvested may result in a lack of recruitment of structures that are preferred by bats for roosting. In conservation efforts for these species, it is important to retain not only the current standing dead structures, but also to retain live trees that will eventually mature, die and decay to the proper stage for the roosting and rearing of young bats.

Forest managers should encourage the retention of tall, wide diameter, dead standing structures whenever possible, as well as the retention of recruitment trees that serve an important role in the future conservation of bat species in the boreal forest.

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CHAPTER 4: THE EFFECTS OF POST-HARVEST STRUCTURE RETENTION ON BATS

Introduction

Bats roost in and rely on forest structures, such as damaged, dead or dying trees (snags), that are often reduced in number, or eliminated from the landscape, through forestry operations. As a result, bats may be among those species most vulnerable to the impacts of timber harvest (Thomas and West 1991). Previous reports suggest that the availability of roost structures may be a limiting factor in the persistence of forest bat populations (e.g. Campbell et al. 1996, Vonhof and Barclay 1996). Communal groups of females and young require warmer roosts than males, as the elevated roost temperature facilitates fetal growth and development of young (McNab 1982). As a result, females and their young may have more specific and demanding habitat requirements than do lone males, and may be affected more severely by decreasing structural diversity of forests caused by modern forest harvesting.

Given their ability to sustain true flight, bats are highly mobile, and can travel several kilometers in a short period of time. This mobility may allow bats to utilize patches of habitat, such as those created by some forest harvesting strategies, that are inaccessible to other terrestrial species. However, the energy demands incurred by increased flight distance may be limiting. Although bats are capable of flying long distances, the observed distance between foraging and roosting areas for many species is often less than a few kilometers (Campbell et al. 1996, Vonhof and Barclay 1996), presumably minimizing flight-related energy demands. Despite evidence showing that bats do not always roost as close to foraging areas as possible (Brigham 1991), retention of roost structures (standing trees and snags) near wet areas following timber harvest might benefit bats by providing roosting habitat in close proximity to important foraging sites.

Evolving forest practices and attempts by some forest companies to address biodiversity concerns have led to the retention of standing structure at various scales. For example, Weyerhaeuser Company Ltd. retains single live and dead trees, clumps of live and dead trees, and forested stream buffers to address issues specific to a particular site, and to provide habitat for certain species. More recently, structure has been retained throughout cut-blocks in order to address the rising concerns of biodiversity conservation on a larger scale. However, the arrangement and density of landscape-scale retention of trees and snags that would provide optimal habitat for many wildlife species, including bats, is unknown.

This study was designed to evaluate the response that bats may have to the retention of timber or snags following harvest in commercial forestry operations. My specific objective was to compare the species richness and relative activity level of bats at pond sites within uncut boreal forest to pond sites within cut-blocks that contained varying levels of post-harvest structure retention. Although I did not specifically examine the quality of habitat within the cut-blocks and stands where snags and trees were retained, I inferred that an increase in retention of standing structure in these areas would lead to an increase in potential roost availability, and therefore an associated increase in bat activity at nearby foraging sites (ponds).

I predicted that, at ponds, the relative activity level of bats would be highest within unharvested control sites, and lowest in sites containing the lowest levels of structure retention. Bats are often thought of as opportunists, in that they may tend to select foraging sites in proportion to the availability of insect prey (Hickey and Neilson 1995). Grindal (1995) found that insect abundance, and bat activity, was highest at forest edges as compared to interior forest and cut blocks. As a result, I predicted that bat activity would be highest in areas that contained the greatest amount of distinct forest edge habitat in closest proximity to water, in this case, unharvested control sites. I also predicted that species richness would be similar across sample sites, despite variation in the amount of retention of standing structure in the surrounding blocks, as microhabitat conditions were similar at pond sites (each contained a relatively large expanse of open water, surrounded by a concentration of remaining structure). Bats adapted to using structurally cluttered environments are able to maneuver in areas where a high degree of structure remains, and where open-adapted bats may not be found. However, pond sites surveyed in this study contained both open and cluttered microhabitats, and therefore I predicted that both open- and clutter-adapted bats would be able to utilize these areas.

Methods

Sampling Design

Sampling took place in the Drayton Valley area from May through August 1999. To assess patterns of habitat use by bats across a gradient of remnant structure densities, I selected three replicates of three distinct retention levels: low retention (1-5%), high retention (10-25%), and unharvested, for a total of 9 sites (Table 4.1, Figure 4.1). Unharvested sites were mature (100+ years), aspen-dominated (>70% aspen) stands. Prior to harvest, all low and high retention sites were comprised of mature, aspen-dominated forest, and all were harvested during the winter of 1998 (no more than 6 months before the initiation of this study).

Post-harvest structure retention levels were determined from aerial and ground surveys, and through examination of aerial photographs. Visual estimates of retention were taken from the air simultaneously by two observers, and were later confirmed by ground surveys. Study sites were then classified quantitatively through examination of aerial photographs (Table 4.2). Each study site was classified based on retention species (coniferous, deciduous or mixed-wood), percent cover (low=1-5%, high=10-25%, control=100%), retention type (single tree, clumps and patches) and the amount of each retention type (Table 4.1). Harvested sites selected for this study contained a varying degree and combination of single trees, clumps, and patches of standing material. All of the post-harvested study sites were of similar retention species (mixed-wood), except for one site that was dominated by conifer retention. A retention classification scheme developed by Weyerhaeuser Company Ltd. (1999) was utilized to make results from this study directly applicable to forest managers, thus percent cover was the independent variable used to test for differences in relative bat activity among retention levels.

The automated detectors used in this study (Anabat II® detectors with delay switches; Titley Electronics, Ballina, N.S.W., Australia), remotely recorded bat echolocation signals on audio tapes as they flew through or fed at a survey location (see Chapter 2 for details).

Each site was sampled 6 times, to account for seasonal variation in bat activity. Samples at each site were spread over a three-month period from late May to early August, with a minimum period of 7 days between samples of the same site. On any given night, one or two of the 9 sites were monitored. Sampling began at dusk (approximately 2000) and continued until dawn (approximately 0500). No sites were sampled in heavy rain or on stormy nights, due to the extremely low bat activity associated with these weather conditions, and due to repeated activation of the detector by raindrops, and movements of vegetation caused by high winds.

Table 4.1: Post-Harvest Structure Retention Classification Scheme (developed by Weyerhaeuser Company Ltd., Alberta, 1999).

Retention Species *(This refers to the dominant species retained on the block, not the land base.)*

C = coniferous
D = deciduous
M = mixed-wood

Percent Cover *(This is a broad cover category, based on the percentage of the block that is covered by any type of retention. It is the total amount of structure left on the block, and is not divided into different retention types.)*

1 = 1% - 5% of the block is covered by structure.

2 = 10% - 20% of the block is covered by structure.

3 = 25% or more of the block is covered by structure.

Retention Type *(This category reflects structure type, and not area covered.)*

S = single trees
C = clumps (a group of trees that numbers 10 or less)
P = patches (a group of trees that numbers greater than 10)

Amount of Retention *(This is a sub-set of the broad category of "Retention Type", and is based on stems/ha for single trees, number of clumps for clumps, and the number of patches for the patch category.)*

Single Trees	Clumps	Patches
1 = 1-5 stems/ha	1 = 1-5 clumps	1 = 1-2 patches
2 = 5-20 stems/ha	2 = 5-10 clumps	2 = 2-5 patches
3 = >20 stems/ha	3 = >10 clumps	3 = >5 patches

Example: A block with a final designation of "$M2S_2C_1P_1$" would represent a block that has mixed-wood retention, between 10 % - 20% cover, and that contains 5-20 stems/ha of single trees, 1-5 clumps of trees, and 1-2 patches of trees.

Figure 4.1: Aerial photographs of representative sample sites; (a) low retention, (b) high retention, (c) control.

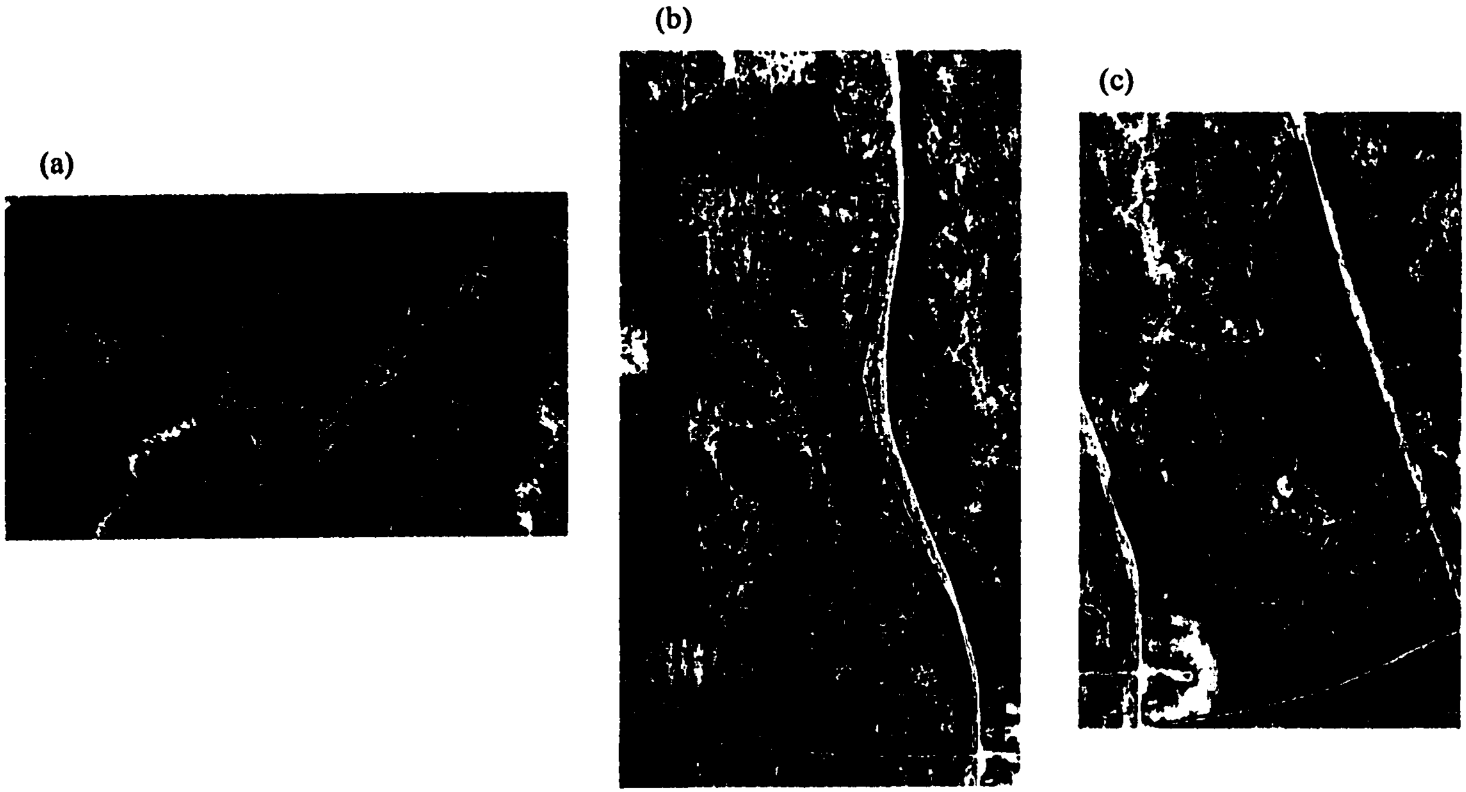


Table 4.2: Classification of study sites (not including unharvested, control sites) according to retention variables. *See Table 4.1 for details.

Site	Classification Code*	Percent Cover
Low 1	$M1S_1C_1P_1$	5%
Low 2	$M1S_1C_1$	5%
Low 3	$M1S_1C_1P_2$	5%
High 1	$M2S_2C_1P_1$	20%
High 2	$M3S_1P_3$	25%
High 3	$C2S_2C_1P_1$	10%

Wet areas (ponds) within each site were targeted for detector placement, based on the relative importance of these areas to bats for both drinking and foraging (Barclay 1991, Christy and West 1993). Three of the 9 ponds sampled were located in the center of the sample block, and were surrounded on all sides by the treatment habitat. The remaining 6 ponds were located near the borders of the treatment habitats, thus portions were adjacent to an alternate habitat type. Ponds varied in size, ranging from approximately 0.03 to 2.20 hectares. Each treatment (low, high, control) contained one small (<0.20 ha), one medium (0.30 to 0.50 ha), and one large (>0.80 ha) pond. At each survey location, Anabat® detector systems were placed on the ground at the waters' edge, and were oriented 45° from horizontal. Although some wet areas bordered non-treatment habitat, microphones were aimed over the open water towards the habitat of interest, to ensure detection of bats associated with the wet area, and treatment habitat, being surveyed. The same detector location was used each time a site was sampled.

Vegetation Sampling

Surveys were conducted around sample ponds in order to characterize the vegetative composition and structure on a coarse scale. At each detector location (n = 9), two 5-meter radius plots were surveyed for presence or absence of canopy, sub-canopy, shrubs, grasses/sedges and snags (Figure 4.2). If present, each type of vegetation was

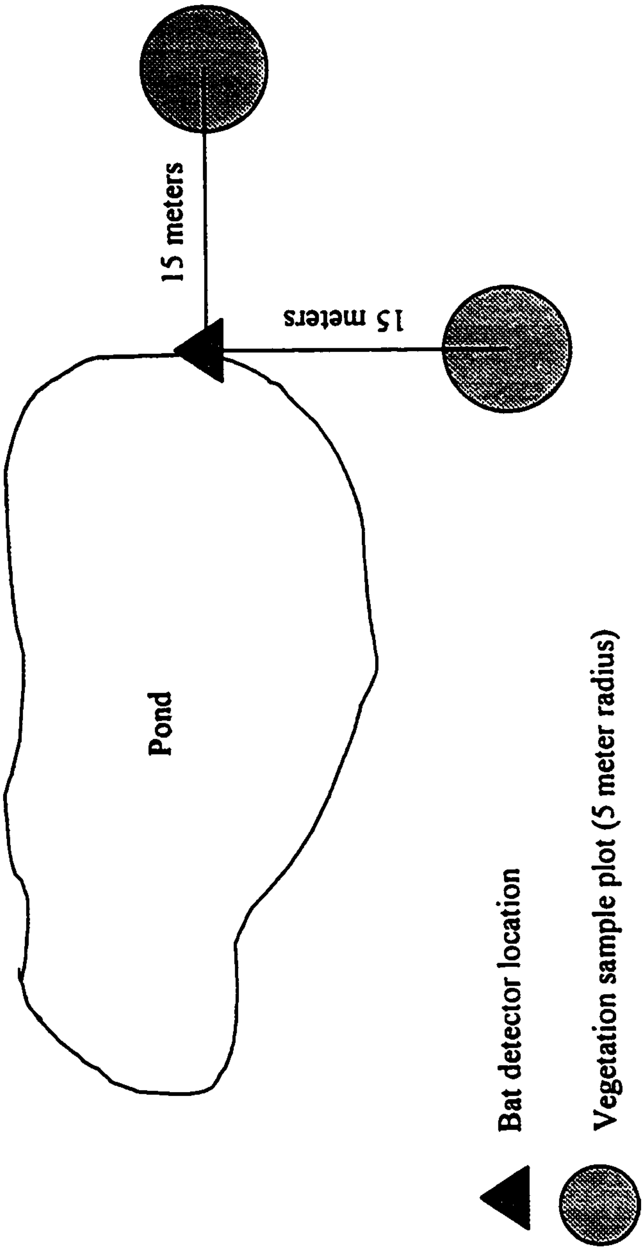


Figure 4.2: Schematic diagram of vegetation plot arrangement.

classified as either sparse (1-35%), moderately dense (36-70%), or dense (>70%). The dominant species of each vegetation type was also recorded. The center of one of the vegetation plots was positioned perpendicular to the water's edge, and 15 meters away from the detector location. The second plot was located 15 meters away from the water's edge, at a randomly selected 90° angle from the direction of the first plot. Measurements taken on all snags within each plot included species, height, diameter at breast height, and decay stage (See Chapter 3, Table 3.2 for a complete list of snag measurements).

Analytical Procedures

To compare habitat use among structure retention levels, relative bat activity and foraging rates were calculated using the same methods described in Chapter 3: *Analytical Procedures*.

Statistical Analysis

Relative (mean) activity levels were calculated for all species and species groups combined, and normality tests were performed. Differences in the relative bat commuting activity, and foraging rates, among retention levels were examined using an analysis of covariance (ANCOVA), with retention level as the main effect and ambient temperature and pond size as covariates. Any differences among treatments were further examined using Bonferroni multiple comparisons. Post-hoc power analyses were then performed to in order to estimate the probability of committing Type II errors (not rejecting the null hypothesis when it is in fact false). All analyses were performed using SPSS 10.0 software, and a significance level (α) of 0.05 (Zar 1996).

Results

Effect of Retention Level

Bat activity at sampling sites was monitored for 279 hours, resulting in 5,291 recorded bat passes. Each sampling night had at least one bat detection. Across treatments, the data set contained six values that were notably high. These values appeared to lie outside the reasonable bounds of the data, but could not be accounted for by aberrant weather, variations in site conditions, or vegetation structure. Normality testing of the data within each treatment resulted in distributions that deviated significantly from normal. Normality testing was also performed with these potential outliers excluded from the data set, but only 2 of the 3 treatments were normalized as a result. Because there was no apparent justification for excluding the potential outliers from the data set, they were included in all analyses. A transformation (log x) was used to normalize the relative activity data.

The majority of passes were detected in control sites, although the sampling period for each treatment varied slightly (Table 4.3). Control, high retention and low retention sites were surveyed for 88.4 hours, 89.6 hours, and 100.0 hours respectively.

Testing for homogeneity of variances showed that the within group variances were similar for the 3 retention categories (p=0.13; Levene's Test). The full ANCOVA model found no effect from ambient temperature (p=0.72, F=0.15, n=9; power=0.06) or pond size (p=0.69, F=0.18, n=9; power=0.06) on the relative activity level of bats. Subsequently, the coviariates were dropped from the model, and a simple ANOVA was used to analyze the data set. Activity levels were lowest in low retention sites (12.86 ± 4.13 (SE) passes per hour), intermediate in high retention sites (39.77 ± 28.50 passes per hour), and highest in control sites (53.69 ± 24.91 passes per hour). However, these differences were not statistically significant (*p*=0.64, F=0.48, n=9; power=0.10; Figure 4.3).

Table 4.3: Total bat activity by species, and retention type, in the Drayton Valley region. Percentage of total is shown in brackets. Full names for species abbreviations are provided in the text of Chapter 2.

Species	**Number of Passes**			**Total**
	Low Retention	**High Retention**	**Control**	
Myotis Group	937	1,714	1,803	**4,454 (84.2)**
Silver-haired Bat	86	168	246	**500 (9.5)**
Hoary Bat	21	97	80	**198 (3.7)**
Big Brown Bat	7	27	22	**56 (1.1)**
LANO/EPFU	3	4	16	**23 (0.4)**
LANO/LACI	3	0	3	**6 (0.1)**
NON-MYSP	22	4	16	**42 (0.8)**
UNKN	5	1	6	**12 (0.2)**
Total	**1,084 (20.5)**	**2,015 (38.1)**	**2,192 (41.4)**	**5,291 (100)**

Foraging Activity

Foraging activity was detected in all retention levels, and at each sample site, for a total of 871 feeding buzzes. Foraging buzzes were least abundant in low retention sites, intermediate in high retention sites, and most abundant in control sites (Table 4.4). *Myotis* Group bats accounted for 96.8% of all feeding buzzes (Table 4.4), but foraging activity was also documented for all other detected species. However, although commuting signals of all species were detected in all three treatments, foraging signals were less widely distributed across retention levels. Foraging buzzes made by *Myotis* Group bats and Silver-haired Bats were detected in all three treatments, while Hoary Bat foraging activity was detected in only control and high retention sites. Big Brown Bat foraging activity was detected in only one high retention site.

Examination of the foraging rate data revealed distributions that deviated significantly from normal in all three retention levels. As a result, and because there were some nights where foraging activity did not take place (zeros in the data set), the data were square-root transformed prior to analysis. Ambient temperature (p=0.50, F=0.54, n=9; power=0.09) and pond size (p=0.43, F=0.76, n=9; power=0.10) had no effect on foraging rate in the full ANCOVA model. Subsequently, covariates were removed from the model, and a simple ANOVA was used for analysis. Differences in foraging rates among treatment types were not statistically significant (p=0.92, F=0.08, n=9; power=0.06; Figure 4.4).

Figure 4.3: Relative bat activity (log-transformed) by structure retention level. Mean values are shown within each bar. Error bars represent the 95% confidence interval of mean values. For each retention level, n=3.

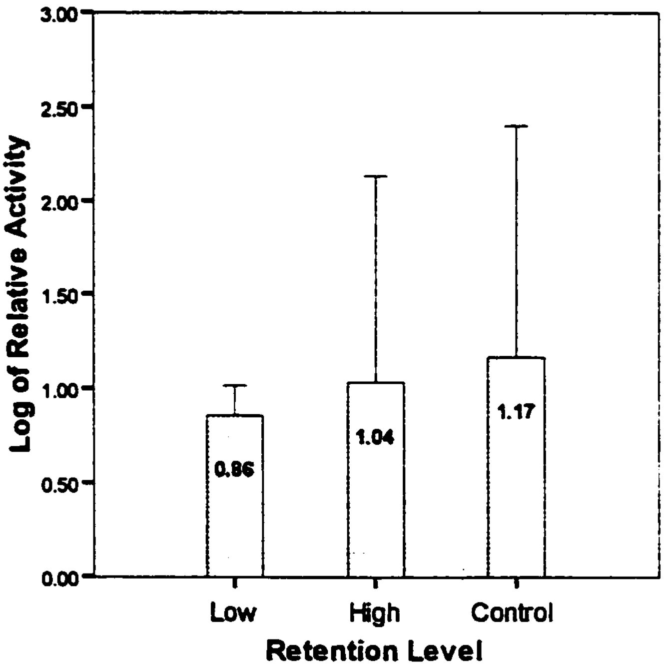
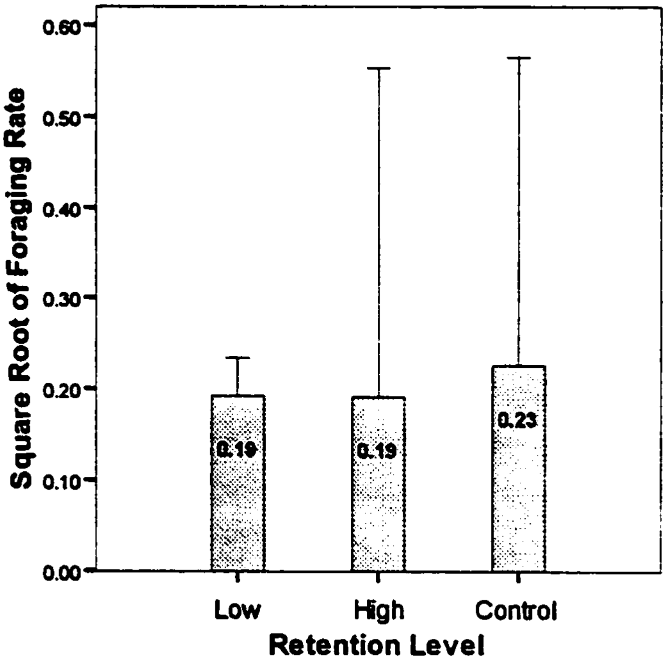


Table 4.4: Total foraging activity by species, and retention type, in the Drayton Valley region. Percentage of total is shown in brackets.

Species	**Number of Buzzes**			**Total**
	Low Retention	**High Retention**	**Control**	
Myotis Group	56	346	441	**843 (96.8)**
Silver-haired Bat	5	4	6	**15 (1.7)**
Hoary Bat	0	3	5	**8 (0.9)**
Big Brown Bat	0	5	0	**5 (0.6)**
Total	**61 (7.0)**	**358 (41.1)**	**452 (51.9)**	**871 (100)**

Figure 4.4: Foraging rates (square-root transformed) by structure retention level. Mean values are shown within each bar. Error bars show the 95% confidence interval of mean values. For each retention level, n=3.



Species Richness

Analysis of taped recordings identified 3 species and one species aggregate at sampling sites: Silver-haired Bat (LANO), Hoary Bat (LACI), Big Brown Bat (EPFU) and species belonging to the genus *Myotis* (MYSP). The Silver-haired Bat and the

Myotis aggregate were detected in all 9 sampling sites, while the Hoary Bat and Big Brown Bat were each detected in 8 of the 9 sites (Table 4.5). All species or species groups were well distributed among treatment types, consistent with my prediction.

Vegetation

Two plots per site, or 18 plots in total, were surveyed for vegetation. Appendix 4.1 presents the data set from vegetation surveys, which were based on qualitative measurements. The density of canopy cover ranged from sparse to dense across treatments, and was either trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), or white spruce (*Picea glauca*). A layer of young trees, or sub-canopy layer, was observed in all three treatments, ranging from sparse to moderately dense, the majority of which was deciduous (only one plot was dominated by a coniferous sub-canopy layer). All but one of the 18 vegetation plots contained a shrub layer, the density of which ranged from sparse to dense. The dominant shrub species in each plot was either prickly rose (*Rosa acicularis*), gooseberry/currant (*Ribes* species), blueberry

Table 4.5: Species occurrence in the 9 sampling sites ([1] These species are adapted for flight in open areas; [2] Species in this aggregate are adapted for flight in cluttered areas (Grindal 1995)).

Site	Species or Aggregate Detected
Low 1	EPFU[1], LACI[1], LANO[1], MYSP[2]
Low 2	EPFU, LACI, LANO, MYSP
Low 3	EPFU, LACI, LANO, MYSP
High 1	EPFU, LACI, LANO, MYSP
High 2	EPFU, LANO, MYSP
High 3	EPFU, LACI, LANO, MYSP
Control 1	EPFU, LACI, LANO, MYSP
Control 2	LACI, LANO, MYSP
Control 3	EPFU, LACI, LANO, MYSP

(*Vaccinium* species), willow (*Salix* species), alder (*Alnus* species) or trembling aspen (*Populus tremuloides*). All 18 plots contained grasses, ranging from sparse to dense in distribution. A low abundance of snags was observed in high retention plots and in control plots, but snags were absent in low retention plots (high retention, n=2 snags; control, n=4 snags). Beyond the availability of snags, no obvious qualitative differences existed in the structure of vegetation surrounding sampling sites among treatment types.

Discussion

Patterns of Habitat Use

Bat activity within a locale can depend on the availability of foraging and roosting resources (Crampton and Barclay 1998, Vonhof and Barclay 1996, Grindal 1995). However, data from this study indicate that bat activity at ponds is not affected by the level of structure retention following harvest of the surrounding area. This suggests that pond sites provide the same quality commuting and foraging habitat for bats irrespective of the forestry context in which they occur, with respect to levels of standing structure. However, statistical tests of the related data were not powerful, and trends indicated that both total activity and foraging activity were lower in low retention sites. Additionally, foraging rate in narrow seismic lines (0.05 buzzes/pass; refer to Chapter 3) was lower than foraging rate at ponds (0.16 buzzes/pass), indicating that ponds are more valuable habitat to bats than narrow seismic lines for foraging.

In future studies, more replicates within each treatment, or an increase in the number of samples at each site, are needed in order to increase the sample size, and thus the power of the analysis. Based on the variance characteristics of my results, I would recommend more sample sites, as opposed to more samples at existing sites, as the variance was greatest between sites. As well, ultrasonic work in this study was focused at pond sites, and therefore the results can only speak to the quality of those specific areas as bat habitat. To examine the quality of the forest or harvested area independently from pond sites, future research should also involve ultrasonic work away from ponds. While prior research in Alberta has examined other aspects of bat habitat, such as forest-age associations (Crampton and Barclay 1998), and although my work assessed bat activity patterns at ponds, no work has yet addressed habitat quality away from ponds in relation to structure retention. Detector placement within the forest or harvested area, paired with surveys at ponds in the same block, would be the next step in determining if and how the retention of structure affects bat commuting and foraging activity.

Species Richness

The type of echolocation system, and wing morphology, of a particular bat species largely determines what habitats are available to that species for travelling and foraging (Kalko and Schnitzler 1993, Grindal 1995, Obrist 1995). Species that are able to echolocate at multiple frequencies and intensities are those to which the widest variety of habitats are available (Kalko and Schnitzler 1993). Bats adapted to using cluttered environments are able to maneuver in areas where a high degree of structure remains, and where open-adapted bats may not be found. However, in this study, both clutter- and open-adapted bats were detected in all nine sampling sites, across all three treatments.

There may be several reasons why the species richness was similar among structure retention levels. First, the treatment sites, although varied in the densities of remaining standing structure in the surrounding area, were relatively uniform in general configuration. Each sampling area contained an expanse of open water, bordered by a ring of standing structure. This landscape arrangement effectively created similar pond habitats among treatments, which supported the same group of species, regardless of retention level in the surrounding area. Secondly, each sampling area contained a mixture of both open (water) and cluttered (standing structure) habitat, although to a varying degree. These areas were, therefore, available to species that specialize in open areas, as well as those species that are adapted for flight in more cluttered environments.

Implications for Management

Structure retention in harvested areas is a management tool used to enhance the conservation of wildlife species. However, results from this study indicate that this practice does not affect overall bat activity, or bat species richness, at pond sites within harvested areas. Subsequently, this study does not warrant specific recommendations regarding the retention of standing structure in harvested areas. Patterns of bat activity observed in this study indicate that maintenance of a concentration of live and dead trees around ponds is effective at maintaining the quality of these areas for bats. However, analyses in this study were not powerful, due to a small sample size, and may not have detected differences in bat activity among retention levels. Therefore, the results from this work must be taken in context and with caution. Furthermore, although results from this research suggest that ponds in areas that contain varying levels of retention are equally good habitat for all species of commuting and foraging bats, they do not address how the level of structure retention in harvested areas effects bats in the absence of ponds.

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Appendix 4.1: Data from 18 vegetation plots at pond sites, with varying levels of structure retention, near Drayton Valley, Alberta. For each plot at each site, density (D) and dominant vegetation species (S) are reported for canopy layer, sub-canopy layer, and shrub layer. Density of grasses is reported, as well as the number of snags observed in each plot. Density categories are represented numerically (0 = absent, 1 = sparse (1-35% cover), 2 = moderately dense (36-70% cover), 3 = dense (>70% cover)). Dominant species are represented with 2-letter codes (prickly rose = RO, gooseberry/currant = RI, blueberry = VA, willow = SA, alder = AL, trembling aspen = PO, white spruce = PI, paper birch = BE).

Site	Plot	Canopy		Sub-Canopy		Shrubs		Grasses	Number of Snags
		D	S	D	S	D	S	D	
Low 1	1	0		2	BE	2	RO	3	0
	2	0		0		2	PO	3	0
Low 2	1	0		0		2	PO	2	0
	2	0		0		2	PO	3	0
Low 3	1	3	PI	0		0		1	0
	2	2	PI	2	AL	2	SA	3	0
High 1	1	0		1	PO	1	VA	3	0
	2	0		0		2	RO	3	1
High 2	1	0		0		1	SA	3	0
	2	0		0		1	RO	3	1
High 3	1	1	BE	0		2	VA	2	0
	2	0		0		2	AL	1	0
Control 1	1	0		0		2	VA	3	1
	2	0		1	AL	3	RO	2	0
Control 2	1	2	PO	1	PO	1	RI	2	2
	2	3	PO	1	AL	3	VA	1	0
Control 3	1	0		0		1	SA	3	0
	2	1	PO	1	PI	2	PO	2	1

Appendix 4.2: Summary data for 9 sites surveyed in 1999, for bats and vegetation, near Drayton Valley, Alberta. Presence of canopy and sub-canopy are summarized numerically (0 = not detected in either of the two vegetation plots, 1 = detected in one of two vegetation plots, 2 = detected in both vegetation plots). Species richness indicates the number of species or aggregates detected out of 4. Mean values for relative bat commuting and foraging activity (passes or buzzes per hour) are reported for each site. Standard error of the means for foraging activity were all <0.01.

Site	Percent Cover	Vegetation		Species Richness	Bat Activity	
		Canopy	Sub-Canopy		Commuting (x ± SE)	Foraging (x)
Low 1	5	0	1	4	8.08±1.38	0.32
Low 2	5	0	0	4	9.42±2.24	0.59
Low 3	5	2	1	4	21.08±15.20	2.08
High 1	20	0	1	4	14.47±3.56	1.66
High 2	25	0	0	3	8.17±5.36	1.32
High 3	10	1	0	4	96.66±71.78	44.46
Control 1	85	0	1	4	90.00±47.71	15.94
Control 2	80	2	2	3	6.00±2.05	0.66
Control 3	80	1	1	4	65.04±38.85	38.24

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FOREST MANAGEMENT

Conclusions

The summer habitat requirements of Alberta forest bat species are complex, and involve several ecological components. First, adequate shelter in the form of roost structures is essential for individual bats, and particularly for colonies of females and young (Christy and West 1993, Nargorsen and Brigham 1993, Vonhof and Barclay 1996). Second, areas that have a high insect abundance, such as wet sites, play an important role as foraging habitat (Christy and West 1993, Nagorsen and Brigham 1993). Additionally, some bat species may utilize flyways, such as forest edges or narrow openings in the canopy, to travel between roosting and foraging sites. Bat activity in different forest types, and in areas of different levels of structure retention, reflects the availability of useable habitat in these areas, be it for roosting, foraging or commuting. The goals of this study were to examine aspects of bat habitat requirements that may be key variables in the selection of habitat by bats (forest type and potential roost availability), and to determine the effect of structure retention in known foraging sites on patterns of bat activity.

In terms of commuting and foraging, bats exhibited similar levels of activity along narrow seismic lines in mature aspen-, pine- and spruce-dominated forest. Comparison of activity levels among forest types indicates that commuting bats are not restricted to a particular forest type when travelling from one site to another along narrow cut-lines, and that forest type does not influence species richness.

Preferred roost structures were scarce in mature aspen-, pine- and spruce-dominated stands examined in this study, as compared to overall potential roost availability. Although some standing structures had attributes appropriate for roosting, they were lacking in the combination of characteristics that make a structure ideal as a roost for colonies of female bats and their young. Reproductive females of some bat species require tall, large diameter structures, that are in a particular stage of decay, to fulfill their roosting habitat requirements (Christy and West 1993, Brigham et al. 1997, Crampton and Barclay 1998, Sedgeley and O'Donnell 1999). Currently, there is a paucity of these structures in the areas I studied. In future conservation efforts, it will be important to retain standing dead structure that meets the ecological needs of roosting bats, and to retain live trees that will eventually mature, die and decay to the proper stage for roosting and rearing of young bats. Spatial configuration of these attributes should also be considered, as several suitable roosts in close proximity may be required (Vonhof and Barclay 1996). As outlined in Lee et al. (1995), information on decay and fall down rates of snags, and success of live tree retention in harvested areas, would be required prior to implementation of management prescriptions that address retention issues. In addition, the number and spatial arrangement of retained structures should be consistent with naturally occurring snag densities.

My results suggest that the amount of retention in a cut-block after it has been harvested does not affect relative bat activity or foraging rates at pond sites within these areas. However, to test for effects of structure retention more comprehensively, cut blocks containing no standing structure should be added to the study design. Also, sampling the interior of a cut block would allow evaluation of the value of structure retention for bats, independent of wet areas, as the latter may bias bat activity due to the relative availability of insects at these sites.

Limitations of this research

This project attempted to address some of the complex issues surrounding bat ecology and the maintenance of biodiversity in the boreal landscape, but the conclusions are constrained by limitations of the study design (scope, sampling intensity and duration). First, this study did not take into account the specific habitat and microhabitat requirements of all boreal bat species, as some of this information does not currently exist or is not well understood. As a result, conclusions from this research cannot predict the effect that structure retention or snag density may have on potential roost availability, for some species. Furthermore, some species were not distinguishable with methods used in this study. For example, the *Myotis* Group represented 4 species. Subsequently, results apply to the group as a whole, but not to the individual species within that group. Second, data were collected from a small sub-sample of the boreal landscape, and may not represent the foraging and general bat activity in other areas. Therefore, extrapolation of the information in this study across geographic regions is not appropriate. Third, this was a short-term study, the components of which were conducted over one-year periods. As a result, the relative foraging and general bat activity levels observed may not represent the variation over a longer time period. Lastly, there are factors that clearly influence bat activity levels that were not addressed in this research. For example, insect abundance and timing of insect hatches were not measured. Also, weather fluctuations, such as humidity, and moon phase may have had an effect on activity, but were not examined. With these limitations in mind, results from this study can be used to provide some recommendations for forest management.

Summary and Recommendations for Forest Management

Several issues relating to the conservation of bats in the boreal forests of Alberta were addressed through this study. A summary of findings, and some recommendations for forest managers, are presented below.

1. All seven of the forest bat species expected to occur in the study region were verified through combined ultrasonic and trapping efforts. The capture of a Northern Long-eared Bat (*Myotis septentrionalis*) occurred 2.2 km south of the nearest reported case, and slightly extended the range map for this species. As in other studies (see O'Farrell and Gannon 1999), the combination of ultrasonic and trapping methods provided the most effective inventory of bats, and I recommend the use of this procedure in future bat studies where species identification is required.

2. Narrow seismic lines running through mature aspen-, pine- and spruce-dominated forest provide commuting habitat equally well for all bat species or species aggregates. Narrow seismic lines are used by bats, primarily for commuting, and occasionally for foraging, and this use is not affected by the composition of the surrounding forest. However, the influence of forest age, canopy height and closure were not investigated. In future studies, factors that effect the availability or density of cover, and thus habitat suitability, should be investigated.

3. Compared to total snag abundance, this study revealed a low abundance of tall, large-diameter, moderately decayed snags across forest types in mature boreal forest stands. These structures are essential to the reproductive success of many forest bat species, and, thus the maintenance of healthy bat populations. In addition, the recruitment of these potential roost structures may be limited in the future, due to the use of rotation periods that are shorter than the age of maturity of forest tree species. Dead or dying standing material, that fits the criteria of a potential bat roost (see Chapter 3), should be maintained following harvest, and live trees should be retained to serve as future bat roosts. However, the abundance and spatial arrangement of both live and dead retention was not investigated in this study, and are unknown.

4. The amount of structure retention in a cut block did not significantly affect bat commuting or foraging activity at pond sites within these harvested areas. However, the data collected for this project may not have been sufficient to detect differences. As well, I did not examine the effect of structure retention on use of harvested areas, independent of pond sites. Given this, and the potential value of structure retention for other species, I recommend that structure in harvested areas continue to be retained wherever possible.

Suggested Areas for Future Research

Several areas exist in which further research would enhance the ability of forest mangers to effectively plan for the conservation of boreal bat species. First, this study assessed the potential roost availability in mature forest types in the Drayton Valley region of Alberta, but only for those bat species whose microhabitat requirements have been studied in forested ecosystems, and are well understood (Silver-haired Bat (Campbell et al. 1996, Vonhof and Barclay 1996, Crampton and Barclay 1998), Western Long-eared Bat (Vonhof and Barclay 1996, Vonhof and Barclay 1997), Big Brown Bat (Brigham 1991), Little Brown Bat (Crampton and Barclay 1998)). Telemetry work on other species (Hoary Bat and Long-legged Bat) is necessary to verify their roosting needs in boreal forests. Although there is a need for more information on the general roosting ecology of bats, it is urgently needed for those species that are thought to be most reliant on forest ecosystems, such as the Northern Long-eared bat (Caceres and Pybus 1997). Once the specific microhabitat requirements are identified for these species, effective management strategies can be implemented.

Second, although survey methods employed in this study verified the presence of all bat species expected to occur in the region, the generally low capture rates and absence of telemetry work did not allow an evaluation of the status of bat populations. More research, specifically telemetry surveys involving tracking adult female bats to maternity roosts, is required to assess the current status of bat populations. Such knowledge would provide a basis to develop management approaches relating to bat conservation.

Third, with current technology, researchers using ultrasonic detection equipment as their primary means of data collection are limited in their ability to accurately distinguish between some species of bats during tape analysis (Fenton and Bell 1981, Thomas et al 1987, Obrist 1995, Betts 1998, Barclay 1999, O'Farrell et al 1999). At this time, researchers must rely largely upon their own personal experience and skill, making analysis of taped echolocation signals a somewhat subjective process. I was able to identify Silver-haired Bats, Big Brown Bats, and Hoary Bats by recorded signals, but Little Brown Bats, Long-legged Bats, Western Long-eared Bats and Northern Long-eared bats could not be distinguished. This inability to detect, or differentiate between, *Myotis* species is problematic for the Northern Long-eared Bat, which is of conservation concern. Development of a reference library of bat calls for regions throughout Alberta, as well as advancements in species identification software, would tremendously benefit bat researchers using these methods. This information and technology is necessary to make bat call analysis a more exact science.

Fourth, short-term studies serve a valuable function in research, but long-term studies are greatly needed in the area of bat ecology. The difficulty with long-term studies, especially for bats in boreal forests, is that financial support may be difficult to obtain, and the logistical difficulties surrounding the study of bats are always an issue. Unlike many other wildlife species, bats cannot be lured to traps, and can readily detect the presence of nets through their echolocation. This complicates trapping efforts, in that bats must be ambushed, rather than passively trapped, and capture success is poor in areas where potential flyways (trap sites) are abundant. Despite the inherent challenges, experimental approaches that include pre-harvest as well as post-harvest data collection, and extend over a longer period of time than available for this project, are desirable. In general, such studies permit more accurate assessment of ecological relationships and trends, and would enhance the development of the most effective management strategies for bats.

Lastly, the patterns of habitat use observed in this study suggest that retention of standing structure in cut blocks maintains the bat activity around wet areas at or near what it was prior to harvest. Results also indicate that a retention level of 5-25% is sufficient to achieve this. However, this study focused its sampling efforts at ponds in harvested areas, where there is a bias for increased bat activity, due to the relatively high insect abundance at these sites. In addition, power to detect differences among sites was low. By sampling the interior of cut blocks, away from ponds or wet areas, the value of harvested areas containing standing structure as bat habitat could be more thoroughly evaluated. Furthermore, results from this research can be used to determine the sampling intensity necessary for more powerful statistical tests, and data from this study can be used to design more rigorous bat studies in the future.

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