

**Distribution of the Eastern Pipistrelle**  
**(*Perimyotis subflavus*) in Southwest Nova Scotia**  
**Relative to Landscape Factors**

**Lesley J. Farrow**

A Thesis Submitted to  
Saint Mary's University, Halifax, Nova Scotia, Canada  
in Partial Fulfillment of the Requirements for  
the Degree of Master of Science in Applied Science

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Halifax, Nova Scotia

Supervisor:	Dr. Hugh Broders
Supervisory Committee:	Dr. Colleen Barber
	Dr. Hugh Millward
External Examiner:	Dr. Soren Bondrup-Nielsen



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# **Certification**

**Distribution of a Disjunct Population of Eastern Pipistrelle (*Perimyotis subflavus*)  
in Southwest Nova Scotia Relative to Landscape Factors**

by

Lesley Farrow

**A Thesis Submitted to Saint Mary's University, Halifax, Nova Scotia,  
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**May 18, 2007**

## **Examining Committee:**

**Approved: Dr. Soren Bondrup-Nielson, External Examiner  
Department of Biology, Acadia University**

**Approved: Dr. Hugh Broders, Senior Supervisor  
Department of Biology**

**Approved: Dr. Colleen Barber, Supervisory Committee  
Department of Biology**

**Approved: Dr. Hugh Millward, Supervisory Committee  
Department of Geography**

**Approved: Dr. Stavros Konstantinidis, Program Co-ordinator Rep**

**Approved: Dr. Philip Giles, Graduate Studies Rep**

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## **Certification**

**Name:** Lesley J. Farrow  
**Degree:** Master of Science in Applied Science  
**Title of Thesis:** Distribution of the Eastern Pipistrelle (*Perimyotis subflavus*) in  
Southwest Nova Scotia Relative to Landscape Factors

**Examining Committee:**

Dr. Soren Bondrup-Nielsen, External Examiner, Acadia University

Dr. Hugh Broders, Senior Supervisor

Dr. Colleen Barber, Supervisory Committee

Dr. Hugh Millward, Supervisory Committee

Dr. Malcolm Butler, Program Coordinator

Dr. Kevin Vessey, Dean of Graduate Studies

**Date Certified:** May 18, 2007

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**Distribution of the Eastern Pipistrelle**  
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**By Lesley J. Farrow**

**Abstract**

The eastern pipistrelle (*Perimyotis subflavus*) in Nova Scotia has a restricted range, exhibits distinct behavioral characteristics, and is likely isolated from conspecific populations. In the region they require clumps of *Usnea* lichen for roosting, which is typically found in mature spruce and balsam fir trees. This association may make this population vulnerable to forest alteration. The goal of this research was to increase local knowledge of eastern pipistrelle ecology in Nova Scotia, contributing towards their conservation. Specifically, I acoustically monitored the activity of eastern pipistrelles at 90 river sites (40 in 2005 and 50 in 2006) throughout southwest Nova Scotia using Anabat II detectors to determine the regional distribution of the population and quantify the effects of landscape composition on species activity while controlling for night and site effects. The results of echolocation monitoring indicate that the eastern pipistrelle occurs within a minimum area of 10 020 km<sup>2</sup> mostly in the interior of southwest Nova Scotia. The best landscape predictor of the magnitude of eastern pipistrelle activity was non-forested land area within commuting distance of river sites, suggesting that eastern pipistrelles are less active in landscapes where forests are cleared for agriculture, settlements and timber production. Therefore this forest associated species may be negatively impacted by intensive forestry practices in the region, which can eliminate potential roosting habitat for bats.

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**CHAPTER 1:**

**Distribution of the eastern pipistrelle**  
**(*Perimyotis subflavus*) in southwest Nova Scotia**  
**relative to landscape factors:**

**An Introduction**

## 1.1 Introduction

Fragmentation of formerly continuous landscapes and the loss of native habitat are considered to be major threats to global biological diversity and central issues in conservation biology (Fahrig 1997, Hagan *et al.* 1996, Saunders *et al.* 1991). One of the most important and large-scale causes of habitat loss and fragmentation is the expansion and intensification of human land use (Andren 1994). The persistence of populations of species in today's world is increasingly dependent on the ability of individuals to survive within and move among remnant habitat patches in human-modified landscapes (Daily & Ehrlich 1996). In light of these anthropogenic pressures, it is important to gain an understanding of species' distributions, spatial patterns of activity and resource requirements.

Bats are small, mobile and long-lived with low reproductive potential (Fenton 1997, Findley 1993). These characteristics are thought to facilitate stable populations in unchanging landscapes, but may combine to make them especially sensitive to changes in environmental conditions (Fenton 1997, Kunz 1982). This may place them at risk of population decline in the presence of habitat loss or alteration (Soule 1986). Growing evidence suggests that many bat species are declining around the world and habitat loss has been identified as the major contributor to these trends (Mickleburgh *et al.* 2002). In order to adequately protect bats and their habitats, we need detailed knowledge and understanding of their patterns of habitat use (Fenton 1997).

Habitat is defined in this thesis as the biotic and abiotic resources and conditions that allow the occupancy, survival and reproduction of individuals of a species in an area (Hall *et al.* 1997). Resource requirements for bats include sites that are suitable for

roosting and foraging. Roost area requirements represent a critical habitat component for many bat species (Fenton *et al.* 1998) and depending on roost type, availability may be related to forest age and structural complexity (Crampton & Barclay 1998). Bats with specific tree-roost requirements are particularly vulnerable to disturbance created by forest harvesting, which tends to eliminate old trees and reduce structural complexity. Forestry practices could have a negative impact on their roosting ecology by the direct loss of roost sites and disruptions in roosting areas (Grindal & Brigham 1999, Vonhof & Barclay 1996).

The eastern pipistrelle (*Perimyotis subflavus*) is one of seven bat species recorded in Nova Scotia (Broders *et al.* 2003, van Zyll de Jong 1985). This species, traditionally placed in the genus *Pipistrellus*, was one of only two representatives of the pipistrelles in the Western Hemisphere (Barbour & Davis 1969, Fujita & Kunz 1984, van Zyll de Jong 1985). More than 20 years ago, however, Menu (1984) recommended taxonomic revision of the American pipistrelles based on comparative morphological studies that suggested *P. subflavus* was distinct from both *P. hesperus* and the true Pipistrelles. They recommended that *P. subflavus* be placed in a separate genus called *Perimyotis*, in reference to the *Myotis*-like tragus and dentition of *subflavus* (Hoofer *et al.* 2006). Hoffer (2003, 2006) provided additional morphological and genetic evidence demonstrating the significant divergence between the eastern pipistrelle and the true pipistrelles. Subsequently, recognition of *P. subflavus* within the genus *Perimyotis* is becoming widely accepted.

The eastern pipistrelle is a small (7-8 g; Fujita & Kunz 1984), non-migratory species that is widely distributed and common throughout the eastern United States

(Barbour & Davis 1969, van Zyll de Jong 1985). This species reaches the northern limit of its range in southern coastal New Brunswick and in southern Nova Scotia (Figure 1.1; Broders *et al.* 2001, Broders *et al.* 2003, van Zyll de Jong 1985). Its range extends south to the Gulf of Mexico, through eastern Mexico (Findley 1954) to Guatemala and Honduras (Figure 1.1; Barbour & Davis 1969, Fujita & Kunz 1984, van Zyll de Jong 1985). Since this species occurs in very small numbers in coastal southern New Brunswick (fewer than 100 echolocation records over 1383 detector nights of sampling; Broders *et al.* 2001) and is rare in southern Maine (Zimmerman & Glanz 2000), it has been suggested that the Nova Scotia population of eastern pipistrelles may be isolated to an area in southwest Nova Scotia, separated from the main part of the species' range farther south by hundreds of kilometers (Broders *et al.* 2003). Given this isolation, the population may represent a nationally significant population, justifying special attention (Broders *et al.* 2003).

Populations at the periphery of the species' range may be subjected to different environmental conditions and may, in the face of reduced gene flow, diverge from conspecific populations behaviorally, morphologically, or physiologically (Lesica & Allendorf 1995, Lomolino & Channel 1995). Consequently, these populations can have special conservation value because they may be ecologically and genetically distinct from those inhabiting the central part of their range (Lesica & Allendorf 1995). Quinn and Broders (unpublished data) provided evidence of behavioural divergence of the Nova Scotia eastern pipistrelles with regards to distinct roosting behaviour. Conspecific populations of eastern pipistrelles roost in a variety of roost types, including living and dead tree foliage (Carter *et al.* 1999, Davis & Mumford 1962, Veilleux & Veilleux 2004,



Veilleux *et al.* 2003, 2004), buildings (Whitaker 1998, Winchell & Kunz 1996), rock crevices (Lacki & Hutchinson 1999), and Spanish moss (Carter *et al.* 1999, Davis & Mumford 1962). In Nova Scotia colonies of females roost almost exclusively in clumps of *Usnea* lichen, often found in spruce trees in stands with an abundance of *Usnea* growth (Figure 1.2; Quinn & Broders, unpublished data). In a concurrent study, Quinn and Broders (unpublished data) also found that *U. trichodea* was nearly four times more likely to be found in spruce and fir tree species than other tree species in Kejimikujik National Park, Nova Scotia. Lichens are subject to slow growth rates and low dispersal potential and as a result, lichen diversity and abundance have been shown to vary with forest age (Esseen *et al.* 1996, Lesica *et al.* 1991, Neitlich & McCune 1997, Price & Hochachka 2001), making them particularly sensitive to environmental changes such as habitat alteration (Esseen *et al.* 1996).

The fidelity of bats to particular roost structures varies greatly depending on the species, roost type and time of year (Veilleux & Veilleux 2004). Many bat species regularly switch roosts and use a relatively large number of roosts in a given season (Lewis 1995). Females of most temperate North American bat species form maternity colonies during late spring and early summer, within which gestation, parturition and weaning of young occur (Kunz 1982). Evidence in Nova Scotia suggests that female eastern pipistrelles remain faithful to small roost areas both within and between years (Quinn & Broders, unpublished data). Veilleux & Veilleux (2004) also provide evidence for female eastern pipistrelle fidelity to relatively small roost areas during a single summer. It is important from a conservation perspective to understand roost fidelity and roost area relationships because they reveal the minimum resource requirements of

maternity colonies, and therefore the area that is required to maintain bat populations (Lewis 1995, Veilleux & Veilleux 2004).

Despite these advances in our knowledge of the roost requirements of this small peripheral population of bats, many gaps in our understanding of the dynamics of this population exist. Prior to this study, the summer distribution of the population remained poorly documented, though it had been recognized that they are restricted to the southwest region of the province in the summer (Rockwell 2005). Within this region, limited ultrasonic monitoring suggested that they are patchily distributed, with pockets of high relative activity. For my thesis research, I was interested in providing additional insights into the distribution and local ecology of this isolated population. More specifically, I was interested in determining the summer distribution of the population in southwest Nova Scotia and identifying additional areas of high activity of the species through the use of remotely placed ultrasonic detectors. The results of this stage of my research are presented in Chapter 2. In Chapter 3, I investigate the relationship between the magnitude of their activity and site and landscape factors to determine if activity of foraging and commuting eastern pipistrelles at river sites is related to the composition of the surrounding landscape to gain some insight into why they are patchily distributed. I then attempt to quantify the effects of important landscape factors on species activity to assess the value of a systematic acoustic survey program to monitor landscape elements associated with eastern pipistrelle activity. A synthesis of the results and conclusions of this research is provided in Chapter 4.

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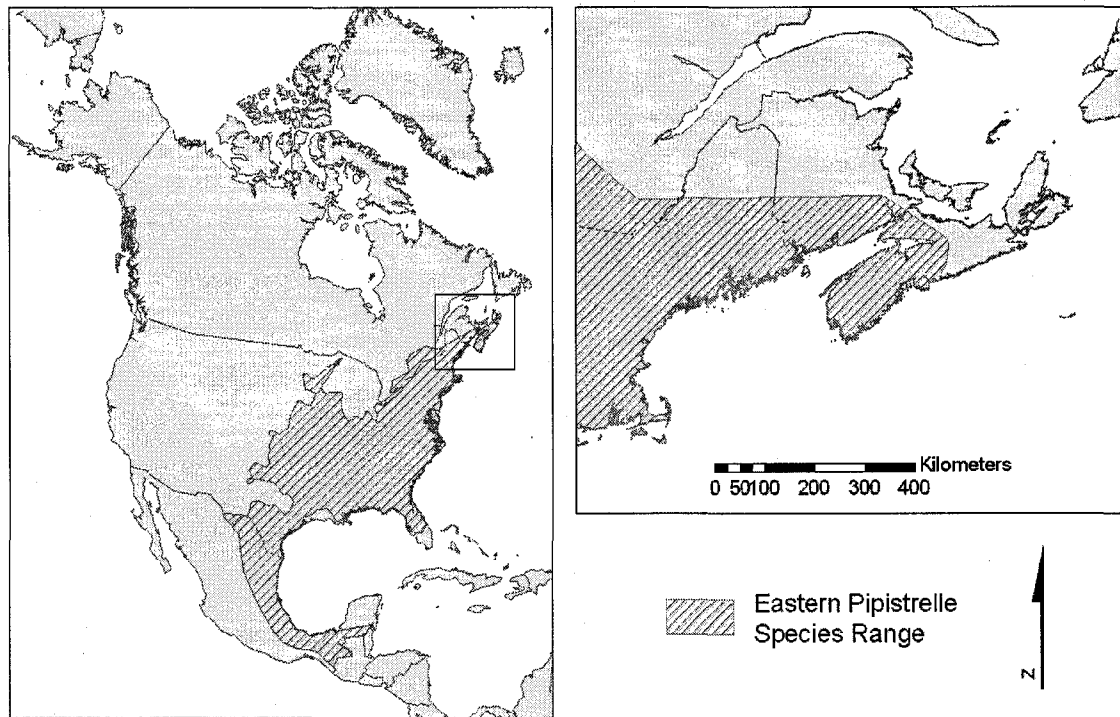
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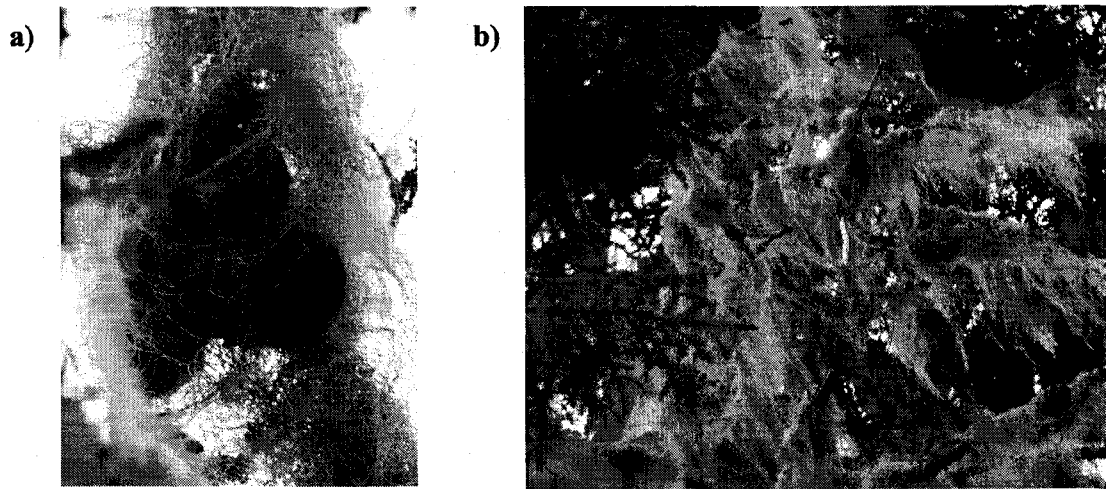
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### 1.3 Figures



**Figure 1.1.** Species range of the eastern pipistrelle (*Perimyotis subflavus*) in North America. The inset shows the northeast limit of the range (England & Bat Conservation International 2003).



**Figure 1.2.** A colony of female eastern pipistrelles roosting in *Usnea* lichen (a) and an abundant growth of *Usnea* in a spruce tree (b), providing conditions appropriate for roosting eastern pipistrelles in southwest Nova Scotia (Photos by L. Farrow).

**CHAPTER 2:**  
**Distribution of the eastern pipistrelle**  
**in southwest Nova Scotia**

## 2.1 Introduction

The loss of native habitat is considered to be one of the major threats to global biological diversity (Fahrig 1997, Hagan *et al.* 1996). In the face of threats to naturally occurring populations, it is critical to have knowledge of species' distributions, which is one of the most basic parameters of ecology. Without this knowledge, it is difficult to assess a species' status, abundance, and resource requirements. Thorough knowledge of species' distributions at multiple spatial scales assists conservation managers and ecological researchers to identify species-specific features of the environment important for survival, areas of likely occurrence of individuals and the effects of disturbance on populations. Identification of regional distributions and patterns of activity should also provide quantitative baseline data to facilitate future research on assessing long-term population trends.

The eastern pipistrelle was first recorded in Nova Scotia by Bleakney (1965), who reported 16 specimens collected between 1959 and 1965. Several individuals were reported by Taylor (1997) during fall and mid-winter counts at hibernacula in 1996 and 1997. Throughout this time, however, the summer distribution of the species in Nova Scotia remained poorly documented (Broders *et al.* 2003). In 2001, Broders (2003) conducted echolocation and trapping surveys at three sites in southwest Nova Scotia and discovered an apparent concentration of eastern pipistrelles at Kejimkujik National Park in central southwest Nova Scotia (Figure 2.1). Subsequent echolocation monitoring of mainland Nova Scotia in 2003 confirmed the presence of a significant population of this species in the province and suggested that the population is restricted to southwest Nova Scotia in the summer (Rockwell 2005).

All of the current data in Nova Scotia indicate that the province's population of eastern pipistrelles is small, behaviourally distinct, and isolated from conspecific populations (Broders *et al.* 2003). Further research was required to determine the regional distribution of the population in Nova Scotia and to increase our understanding of local resource requirements of the species in order to determine the conservation status of the population. Presently, the Nova Scotia Department of Natural Resources (2002) lists the status of eastern pipistrelle in the province as 'yellow', indicating that they are sensitive to human activities and natural events. They are currently not listed nationally.

Due to their nocturnal behaviour and their capability for flight, bats have traditionally been a difficult group of animals to study (Vaughan *et al.* 1997). The advent of acoustic detectors, however, has produced some important advances in our knowledge of the distributions and patterns of habitat use of bats (Crampton & Barclay 1998, Erickson & West 2003, Fenton 1997, Grindal & Brigham 1999, Jung *et al.* 1999, Zimmerman & Glanz 2000). They provide a useful tool for assessing various aspects of bat biology and behavior without being subject to the sampling biases associated with capture methods (Hayes 2000, O'Farrell & Gannon 1999, Thomas *et al.* 1987), though they are subject to other biases (Barclay 1999). Many bat species can be identified using acoustic detectors based on the distinctive nature of their echolocation calls (Fenton & Bell 1981, O'Farrell *et al.* 1999b), and as a result their use as a means of surveying bat populations and communities has attained widespread use in field studies (Broders *et al.* 2006, Brooks & Ford 2005, Erickson & West 2003, Fenton & Bell 1981, Hayes 2000, Lance *et al.* 1996, Patriquin & Barclay 2003). Despite these advances, reliable identification of some species and the approaches used for their identification remain

controversial (Barclay 1999, Corben & Fellers 2001, Fenton *et al.* 2001, Hayes 2000, O'Farrell *et al.* 1999a, O'Farrell *et al.* 1999b, Thomas *et al.* 1987). In Nova Scotia, echolocation calls of the eastern pipistrelle are distinctly different from those of sympatric bat species and can be identified relatively easily (Broders *et al.* 2001, Broders *et al.* 2003, MacDonald *et al.* 1994). The use of acoustic detectors provides an opportunity to gain a better understanding of the regional distribution of this species.

Distributional studies often focus on determining the presence or absence of individuals of species at sample sites and do not provide any indication of their relative abundance or differential use of these sites (Cowley *et al.* 2000, Loeb & O'Keefe 2006). Through the use of acoustic methods, however, we have the opportunity to determine an index of the magnitude of eastern pipistrelle activity at a site. Bat activity has been quantified using various methods including determining the amount of time a tape recorder recorded echolocation call sequences (Perdue & Steventon 1996), the number of files recorded (Erickson & West 1996, Parker *et al.* 1996), the number of passes recorded (Crampton & Barclay 1998, Hayes 1997) and the number of kilobytes of recorded activity (Broders 2003). However the majority of these methods of determining bat activity fails to take into account the length of individual call sequences and therefore can lead to under- or overestimates of activity in an area. For example, they do not differentiate commuting from foraging bats, which tend to have longer call sequences and therefore activity in foraging areas may be underrepresented. Calculation of the total number of calls recorded at a site is another method to quantify bat activity that takes into consideration the length of individual call sequences and therefore should provide an activity index with the greatest level of resolution.

Riparian areas and other freshwater areas are documented in the literature as important foraging areas for many bat species (Grindal *et al.* 1999, Law & Chidel 2002, Vaughan *et al.* 1997, Zimmerman & Glanz 2000). A number of studies investigating habitat use of eastern bat species have recognized that the eastern pipistrelle, in particular, forages predominantly over water (Brack & Mumford 1984, Broders *et al.* 2001, Broders *et al.* 2003, Davis & Mumford 1962, Fujita & Kunz 1984, LaVal *et al.* 1977, Rockwell 2005), suggesting the importance of watercourses for foraging by this species. Through this research I seek to delineate the regional distribution of this small, peripheral population of eastern pipistrelles in southwest Nova Scotia by the use of passive acoustic detection at river sites throughout the region. Within their summer distribution, I was also interested in gaining a better understanding of their spatial patterns of activity at a regional scale by identifying additional areas of high relative activity to determine where they are likely most abundant. This study will also provide quantitative baseline data on the activity of the eastern pipistrelle in the region which will facilitate the assessment of long-term trends in this small, peripheral population.

## **2.2 Methodology**

### **2.2.1 Study Area**

The study took place in southwest Nova Scotia, Canada, a region covering approximately 22 000 km<sup>2</sup> (Figure 2.1). Nova Scotia lies within the Acadian Forest Region, a transitional zone between the coniferous Boreal Region to the north and the Deciduous Region to the south (Davis & Browne 1996a, p.9). The past several hundred years of human occupation, however, have seen the conversion of much of Nova Scotia's

forests to early successional forest types (Mosseler *et al.* 2003). Southwest Nova Scotia currently supports diverse mixed wood forests of red spruce (*Picea rubens*), white spruce (*P. glauca*), black spruce (*P. mariana*), balsam fir (*Abies balsamea*), white pine (*Pinus strobus*), red pine, (*P. resinosa*), eastern hemlock (*Tsuga canadensis*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), white birch (*Betula papyrifera*), yellow birch (*B. alleghaniensis*), American beech (*Fagus grandifolia*), white ash (*Fraxinus americana*) and red oak (*Quercus rubra*) (Davis & Browne 1996a, p.9). Nova Scotia is one of the earliest areas settled by Europeans in North America and as a result its forests have been intensively cut for lumber or cleared for agriculture (Davis & Browne 1996a, p.9). Human-caused disturbance, mainly through forestry practices, remains a dominant force throughout the region, resulting in very few remnants of old growth Acadian forest (Davis & Browne 1996a, Mosseler *et al.* 2003).

Nova Scotia has a maritime climate, experiencing milder winters and cooler summers than inland due to the marine influence of the Atlantic Ocean (Davis & Browne 1996a, p.97). Variations in temperature and precipitation in southwest Nova Scotia are, to a certain extent, governed by distance from the Atlantic coast, with the majority of this area dominated by average July temperatures of around 18°C, though this drops to as low as 11°C along the southwest coast (Davis & Browne 1996a, pp. 46-47, 99). The areas around the LaHave drainage basin, Kejimikujik Lake, and the Annapolis and Gaspereau Valleys tend to warm up earlier and experience hotter summer temperatures than the rest of southwest Nova Scotia (Davis & Browne 1996a, p.47). Average total annual precipitation for the area is between 1200 and 1600 mm. Surface water is abundant throughout the region, making up some of the largest watersheds and rivers in the



province, including the Mersey (3030 km<sup>2</sup>), Medway (2012 km<sup>2</sup>), and LaHave (1700 km<sup>2</sup>) watersheds (Davis & Browne 1996a, p.152).

### **2.2.2 Field Methods**

The study was designed such that sites monitored in 2005 were distributed over a wide spatial scale in southwest Nova Scotia to delineate the summer distribution of the population. Sampling efforts in 2006 were designed to reveal spatial patterns of activity throughout their summer distribution and identify additional areas of high relative activity. Note here that what is considered a large scale to an ecologist is a small scale to a geographer or cartographer, who express scale as a ratio (e.g. 1:50 000 is a smaller scale than 1:10 000; Wiens 1989).

Acoustic sampling took place along forested river edges in an effort to record the echolocation calls of foraging bats to serve as an index of eastern pipistrelle foraging activity. Sites were selected based on a number of criteria. The main goal of site selection was to gain a good spatial spread of sample sites throughout the region. Locally, sites were selected along open-canopy, forested sections of rivers to maximize the ability to compare the results of acoustic sampling between sites. There was no set minimum river width requirement, but for context, river width ranged from was 7.5 to 75 m. Additionally, sites had to be accessible by vehicle and greater than or equal to 1000 m from any other site in a given year of sampling (some sites between years were less than 1000 m apart).

Field data collection took place from 21 June to 18 August, 2005 and 5 June to 19 August, 2006. Sites were sampled periodically using fully-automated, broadband Anabat

II detectors connected to CF Storage Zero Crossing Analysis Interface Modules (ZCAIM; Titley Electronics Pty. Ltd., Ballina, NSW, Australia). Six systems were used in 2005, and nine in 2006, that were calibrated to reduce variability in their sensitivity with a Transonic IX-L Electronic Repeller (Bird-X, Inc. Chicago, IL, USA) using the methods suggested by Larson and Hayes (2000). The systems were set to automatically power on prior to sunset (19:00) and power down following sunrise (07:00) to conserve battery power. Supports were constructed from 5 × 5 cm pine to suspend the detectors from trees such that the systems were located approximately 3 m from the water surface with the microphone oriented parallel to the forest edge, unobstructed by surrounding vegetation (Figure 2.2). This was to maximize the quality of the recorded echolocation calls by reducing interference and also to maximize the comparability among sites by placing the detectors in areas of similar clutter (open areas over water), because ultrasound typical of the frequencies used by echolocating bats are not equally detectable in all clutter conditions (Hayes 2000, Patriquin *et al.* 2003).

Variability in bat activity at a site between nights can be substantial (Broders 2003, Hayes 1997, 2000) in response to a variety of factors, including insect abundance (Barclay 1991, de Jong & Ahlen 1991, Grindal & Brigham 1999, Kusch *et al.* 2004), air temperature (Vaughan *et al.* 1997), rainfall (Fenton 1970, Grindal *et al.* 1992), wind, and interspecific competition (Hayes 1997). To account for this variability, each site was sampled for a total of six or nine nights (Hayes 1997) during two or three sampling periods (each period consisted of 3 consecutive nights) from June to August. Due to the large spatial extent of the study area, sites were sampled systematically in time, such that sites in close proximity were generally sampled for the same three nights.

### 2.2.3 Lab Methods

Many North American bat species can be identified by analyzing certain structural characteristics of their search-phase echolocation calls, including the minimum and maximum frequencies, call duration, and patterns of frequency change over time (Fenton & Bell 1981, O'Farrell *et al.* 1999b). The Anabat II detector was designed to facilitate the identification of free-flying bats and its associated software (Analook; C. Corben, [www.hoarybat.com](http://www.hoarybat.com)) displays changes in frequency over time of the dominant harmonic of echolocation calls (Corben & Fellers 2001).

In Nova Scotia, eastern pipistrelle calls are distinctly different from those of all sympatric species and can be identified relatively easily (MacDonald *et al.* 1994). Broders (2001) reports the means for the minimum, maximum, and characteristic frequencies of eastern pipistrelle echolocation search-phase calls in New Brunswick as 38.7, 46.3 and 38.8 kHz, with a mean duration of 7.3 ms. Recorded call sequences of eastern pipistrelles were identified using a combination of quantitative and qualitative methods based on the call characteristics reported by Broders (2001) and MacDonald (1994) using frequency-time graphs in Analook.

Acoustic surveys are often used to assess a species occurrence at a site (Ekman & de Jong 1996, Russ & Montgomery 2002). A bat pass is often defined as a sequence of at least two search-phase echolocation calls (Walsh & Harris 1996). The occurrence of at least one bat pass at a site was used as an indication of the presence of eastern pipistrelles (Sherwin *et al.* 2000). The number of calls over all eastern pipistrelle sequences per night of sampling was determined in Analook and is assumed to reflect the amount of use of the site (Hayes 2000). One limitation of acoustic detection is that multiple passes of a

single individual and single passes of several individuals cannot be differentiated (O'Farrell *et al.* 1999b). Therefore, counts of bat passes represent an index of the magnitude of activity and cannot be interpreted as population size estimates.

Geographic coordinates for all sample sites were obtained using a Garmin eTrex Legend hand-held Global Positioning System (Garmin International Inc.) and map datum WGS84. Coordinates were recorded when the unit reported an error of less than 10 m. All sites were plotted in a GIS (ArcGIS 9.1, ESRI GIS and Mapping Software, California, USA) to produce maps of their range in the region. The average number of calls per night at each site was also plotted to investigate spatial patterns in the magnitude of activity at sites and identify sites with high activity levels relative to the remaining sample sites.

## 2.3 Results

In 2005 40 river sites (Figure 2.3) were sampled over 267 detector nights recording 528 eastern pipistrelle echolocation sequences (4,894 echolocation calls) at 19 river sites (Figure 2.4). Based on these findings, the regional distribution of the eastern pipistrelle during the summer was delineated in central southwest Nova Scotia (Figure 2.4). Activity of the eastern pipistrelle was mostly restricted to the interior of southwest Nova Scotia however sampling did not take place on North Mountain so I cannot comment on their presence or absence north of the Annapolis and Cornwallis Rivers. The thirteen sites located outside of the delineated regional distribution are mainly in the far southwest and along the Atlantic Coast. In 2006 an additional 50 sites were sampled

within the distribution (Figure 2.5) over 366 detector nights recording 913 eastern pipistrelle call sequences (11716 echolocation calls) at 39 of these sites (Figure 2.6).

Based on the results of monitoring in 2005 and 2006, it was determined that the eastern pipistrelle occurs within a minimum area of 10 020 km<sup>2</sup> in southwest Nova Scotia. Within this area they are patchily distributed with activity greatest within the Mersey and Medway River watersheds, and lower levels of activity on the LaHave, Gaspereau and Annapolis Rivers (Figure 2.7). In the two years of this study, the most northern record of an eastern pipistrelle was on the Cornwallis River, Kings County (373919 E 4991504 N), while the most southern was on the Upper Clyde River, Shelburne County (298722 E 4863633 N). To the east, sequences were recorded on the St. Croix River, Hants County (418560 E 4979287 N) and the farthest west they were recorded was on the Sissiboo River in Digby County (279533 E 4925510 N) (Figure 2.8).

## **2.4 Discussion**

The results of echolocation monitoring indicate that the eastern pipistrelle occurs within a minimum area of 10 020 km<sup>2</sup>, mostly in the interior of the southwest region of Nova Scotia, though they could be present on North Mountain along the Fundy Coast. Previous echolocation sampling of mainland Nova Scotia indicated that the range of the eastern pipistrelle was restricted to the southwest region in the summer (Rockwell 2005). The low sampling intensity of the study however, left many questions regarding the distribution of the species in the region unanswered. Based on the results of intensive echolocation sampling presented in this paper, we now have a more comprehensive

understanding of their distribution and have delineated the range for the eastern pipistrelle in southwest Nova Scotia.

Within the summer distributional range that was delineated, activity of the eastern pipistrelle is greatest in areas recognized as some of the warmest in the region in the summer, including the areas around Kejimikujik Lake and the LaHave river, and the valleys to the northeast (Davis & Browne 1996a, p.47). The species was absent from sites located in the far southwest and from most sites along the Atlantic Ocean. The waters of the Atlantic Ocean and the Bay of Fundy are relatively cold (8 to 12 °C) and have a strong influence on average air temperatures over southwestern Nova Scotia in spring and summer. Along the coast, temperatures are frequently 4 to 6 °C cooler than inland (Davis & Browne 1996a, Environment Canada 2007). Therefore, the distribution of the eastern pipistrelle in southwest Nova Scotia appears to be governed, to some extent, by average summer temperatures. Cooler temperatures along the coast may restrict the range of the eastern pipistrelle to inland areas that are less influenced by the cooling effects of the marine environment.

Isolation of this southern affiliated population to warm areas of southwest Nova Scotia is characteristic of greater than 60 other southern affiliated species of aquatic and terrestrial flora and fauna (Davis & Browne 1996a, p.262). These include the southern flying squirrel (*Glaucomys volans*) (Lavers 2004, Lavers *et al.* 2006), the white-footed mouse (*Peromyscus leucopus*), the eastern ribbon snake (*Thamnophis sauritus*) and the Blanding's turtle (*Emydoidea blandingii*) (Davis & Browne 1996a, p.262,305-306, Mockford *et al.* 1999). This trend is likely explained by post-glacial warming and cooling following the most recent glaciation event (the Wisconsin glaciation; Davis &

Browne 1996a, p.57-59). The post-glacial warming period known as the hypsithermal interval took place approximately 8000 to 4000 years ago (Pielou 1991). During this period, temperatures in present-day Nova Scotia were as much as 2°C above their present levels, allowing colonization of Nova Scotia by warm-temperate species from the south (Davis & Browne 1996a, p.305-306). This period was followed by gradual cooling and a moister climate, affecting many southern affiliated species by either, reducing their populations and isolating them to warmer areas in the southwest of the province, or by loss of the species altogether. Subsequent climatic conditions have not permitted the re-expansion of these restricted populations and as a result, they have become disjunct and restricted to areas within southwest Nova Scotia (Davis & Browne 1996a, p.305-306).

Peripheral populations are those populations that occur near the outer limits of the species' geographic range (Lesica & Allendorf 1995). These populations are often relatively small and isolated from central populations, with a resulting reduction in gene flow. Peripheral populations that have been geographically isolated for several thousand years likely experience different environmental conditions than in their central range and therefore are expected to be genetically and morphologically distinct due to differential effects of natural selection (Lesica & Allendorf 1995). The eastern pipistrelle is absent from northern New Brunswick (Broders *et al.* 2001, McAlpine 1976) and does not occur in Newfoundland (Grindal 1999), and is therefore at the northern limit of its range in Nova Scotia (van Zyll de Jong 1985). Selection is expected to be most effective at causing divergence when peripheral populations occupy areas that are very different from those in the center of their range (Lesica & Allendorf 1995, Lomolino & Channel 1995). Current evidence suggests that Nova Scotia eastern pipistrelles are distinct in terms of

their roosting behaviour in *Usnea* lichen, possibly suggesting that the population has adapted to live at the limit of its physiological tolerance on the northern periphery of the species' range. Therefore, this population may be important for the maintenance of the species' genetic diversity and ability to adapt to environmental change, and as a source of future speciation events (Lesica & Allendorf 1995).

Within the regional distribution that has been delineated, activity of the eastern pipistrelle is patchily distributed (Figure 2.7). There are areas of high activity relative to the remaining sites, and other areas where the eastern pipistrelle was absent. This appears to be partially explained by warmer summer temperatures, but presumably, bats choose to spend the most time in areas that provide the most favorable or abundant resources. There may also be selection for these areas based on the abundance of particular habitat elements. Habitat selection by bats is strongly influenced by their requirements for suitable roosting areas, a critical habitat component for bats (Fenton *et al.* 1998, Kunz 1982). The Nova Scotia eastern pipistrelle roosts in clumps of *Usnea* lichen, typically found in stands of spruce and fir tree species (Quinn & Broders, unpublished data). It is unlikely that foraging habitat is a limiting factor on the distribution of the population, due to the abundance of rivers and lakes in southwest Nova Scotia (Davis & Browne 1996b). Further investigations to determine the reasons for the apparent concentrations of eastern pipistrelle activity may give insight into the selection of foraging sites based on their proximity to suitable roosting habitat at a large scale. This would improve our understanding of the dynamics of this population and will help to conserve habitat elements important for this small, and possibly significant, population.



Changes in landscape structure may be jeopardizing naturally occurring populations by reducing numbers and isolating remaining subpopulations. Bats with specific tree-roost requirements are particularly vulnerable to disturbance created by forest harvesting, which tends to eliminate old trees and reduce structural complexity (Crampton & Barclay 1998). Forestry practices could have a negative impact on their roosting ecology by the direct loss of roosting sites (including snags, which are important roost structures for many species; Miles *et al.* 2006) and disruptions to roosting areas (Grindal & Brigham 1999, Vonhof & Barclay 1996). To manage landscapes we need to have biological indicators of landscape and habitat changes. Unlike many other groups of organisms, which can be very time and labor intensive to monitor, bat activity is relatively inexpensive and easy to monitor (Fenton 1997).

The baseline data presented in this paper represent the most comprehensive study of the distribution and activity patterns of the eastern pipistrelle over a wide geographic area in the region and will facilitate future monitoring of trends in the activity of this species on a regional scale. If the eastern pipistrelle is selecting areas based on the abundance of particular habitat elements, such as mature spruce and fir stands, monitoring their activity may give some indication as to the abundance and connectivity of these habitat elements at the landscape scale. Therefore the study of the eastern pipistrelle may have value as an indicator of changes in landscape structure and connectivity over long time scales, with a decrease in activity indicating loss of landscape elements associated with eastern pipistrelles. Greater understanding of their habitat requirements at the landscape scale and an assessment of the value of a monitoring program to detect changes in their activity patterns would be beneficial.

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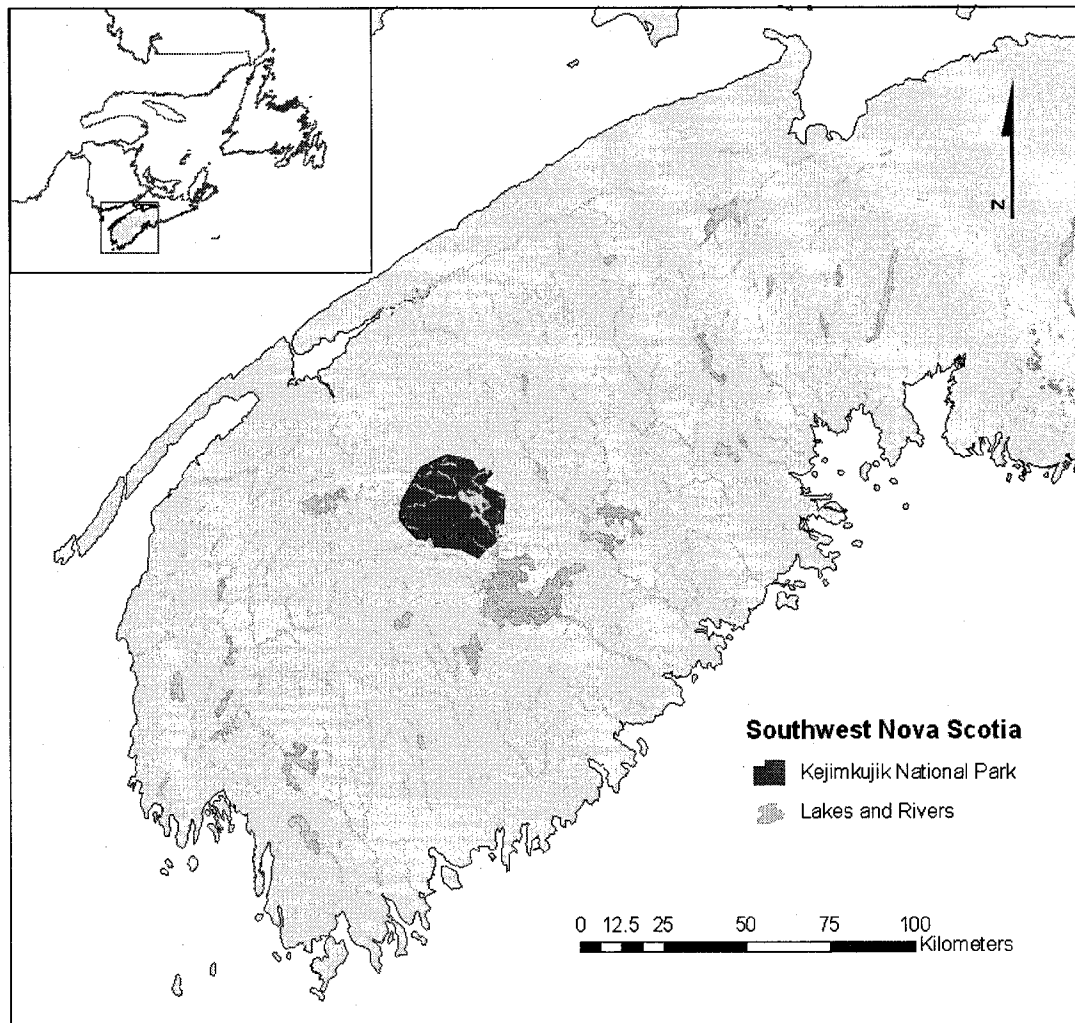
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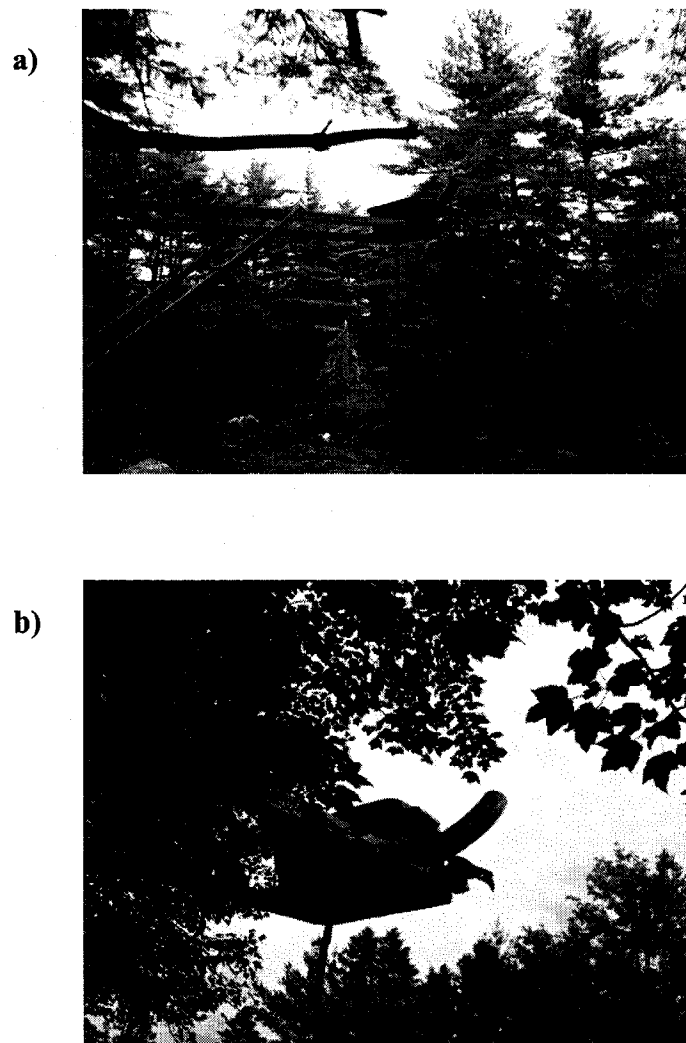
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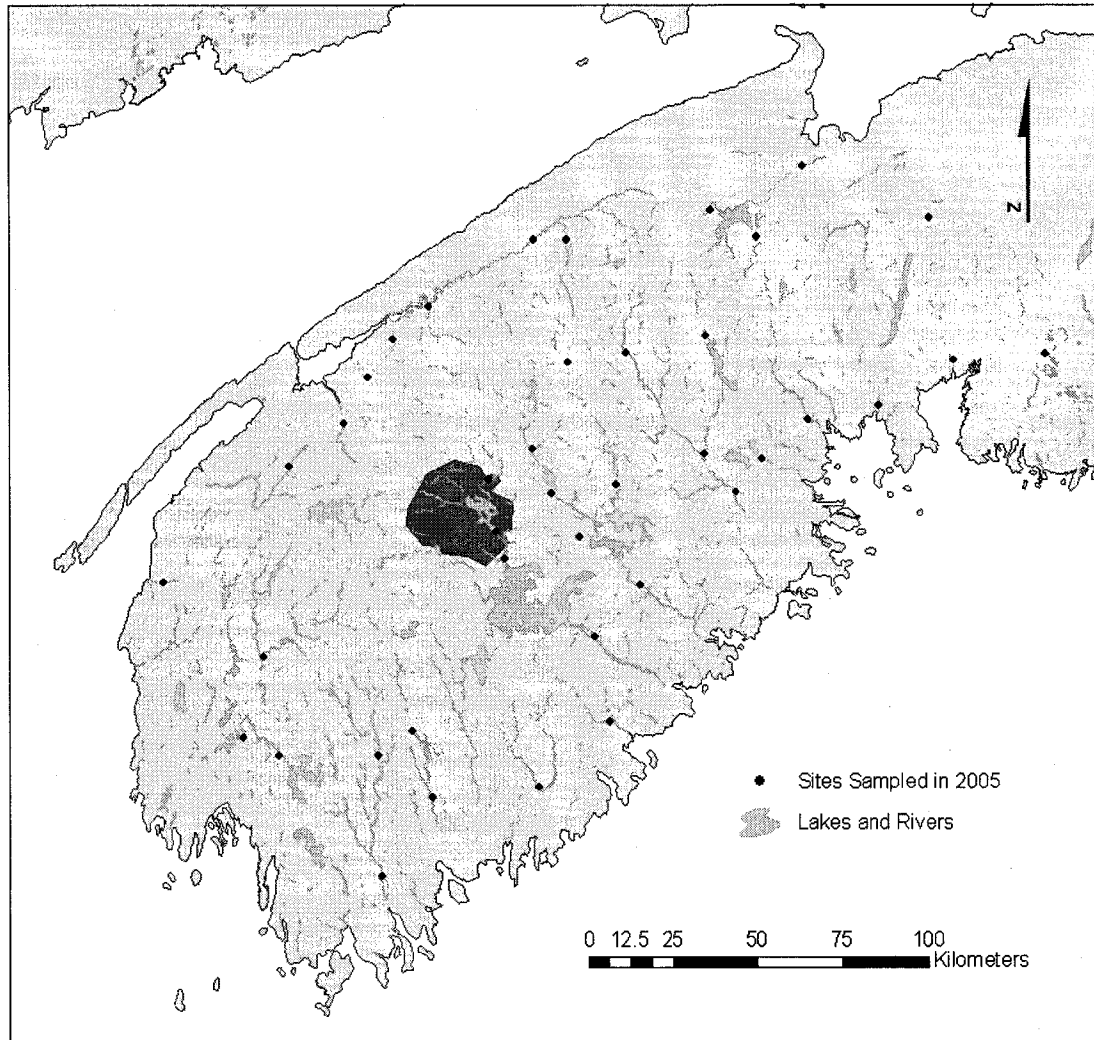
## 2.6 Figures



**Figure 2.1.** The study took place in an area covering approximately 22 000 km<sup>2</sup> in southwest Nova Scotia, Canada. The location of Kejimikujik National Park, where significant numbers of eastern pipistrelles were first discovered, is identified.

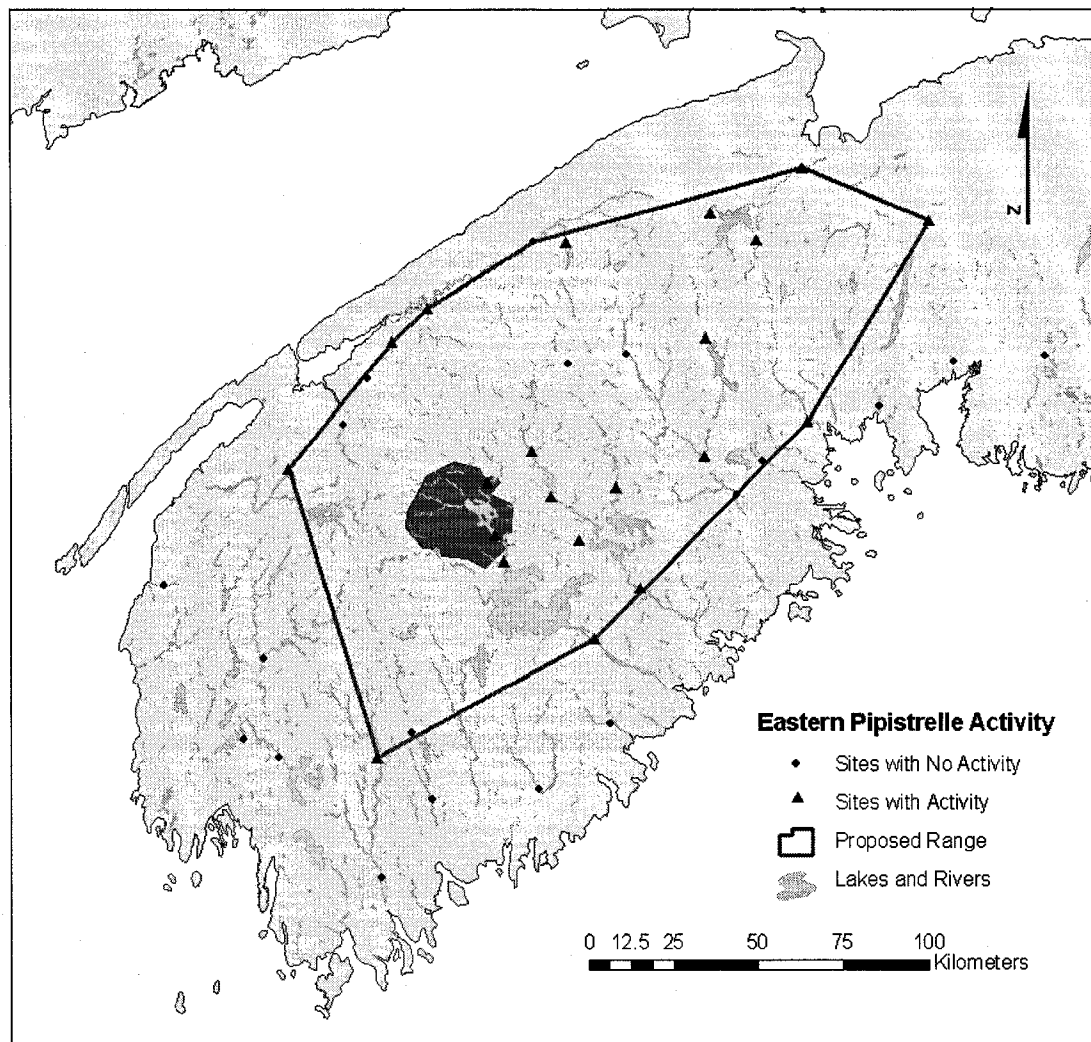


**Figure 2.2.** Anabat II detectors were suspended from trees along river edges (a) in southwest Nova Scotia to extend the microphone beyond surrounding vegetation (b).

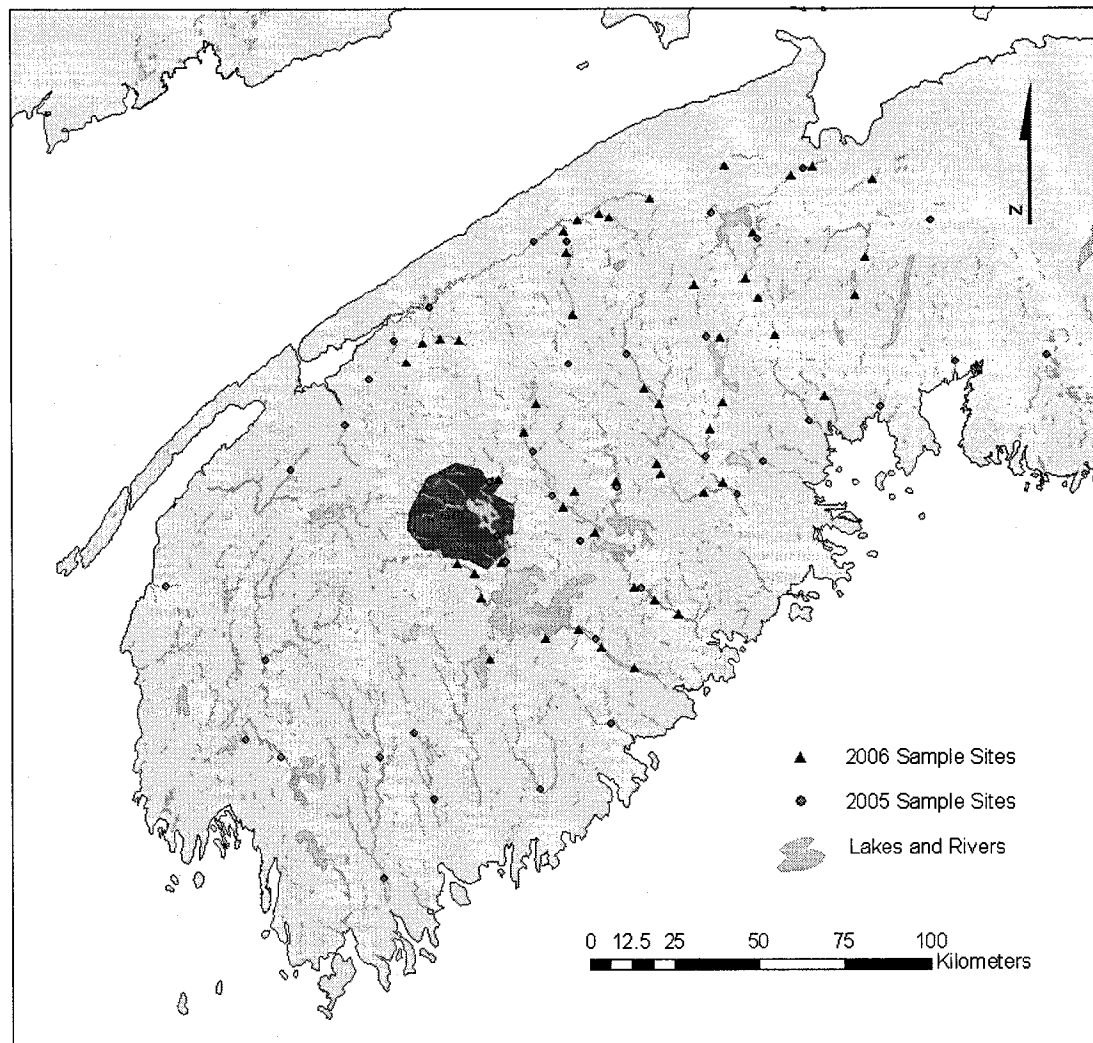


**Figure 2.3.** Forty sites located on forested rivers throughout southwest Nova Scotia were acoustically monitored for eastern pipistrelle echolocation activity from June to August 2005.

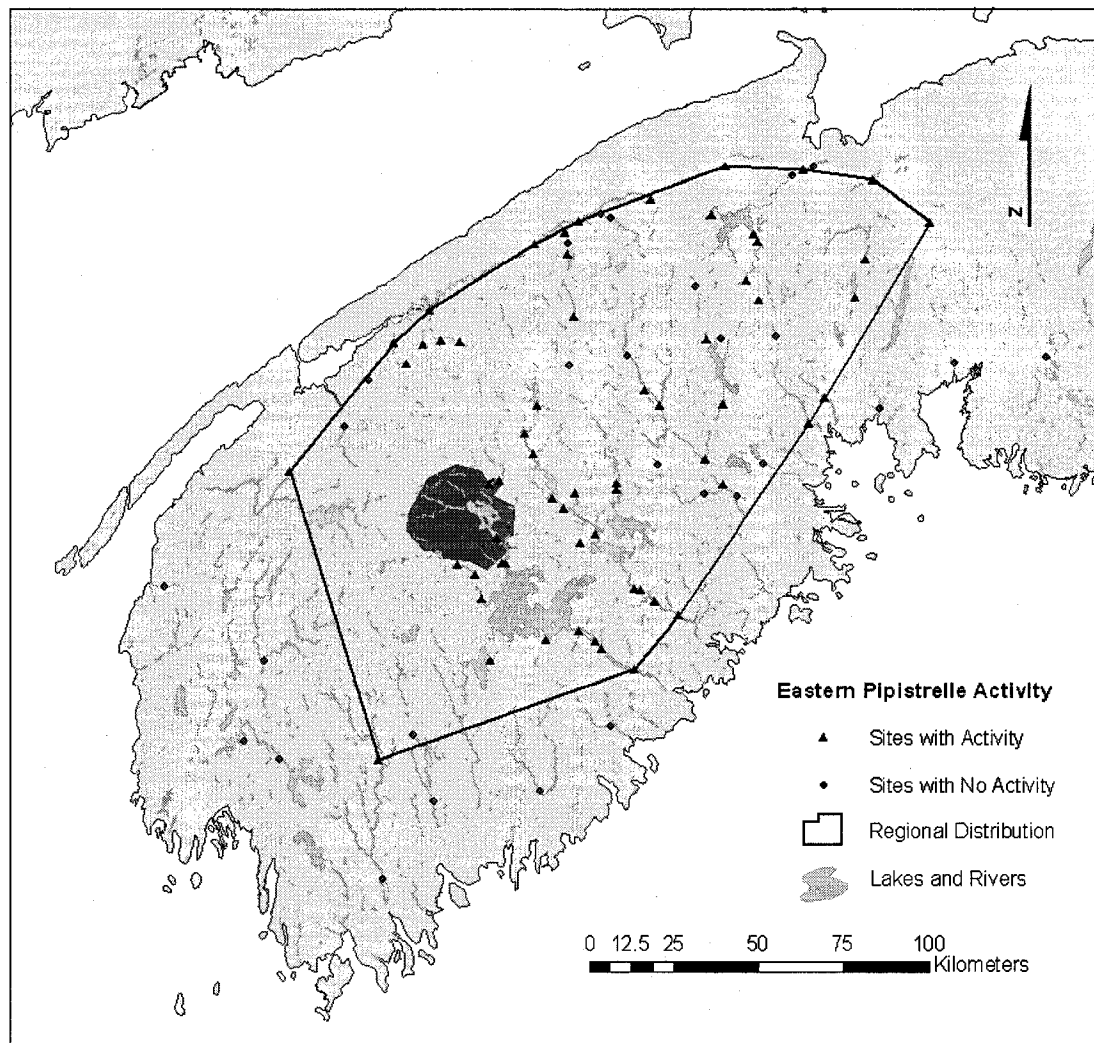




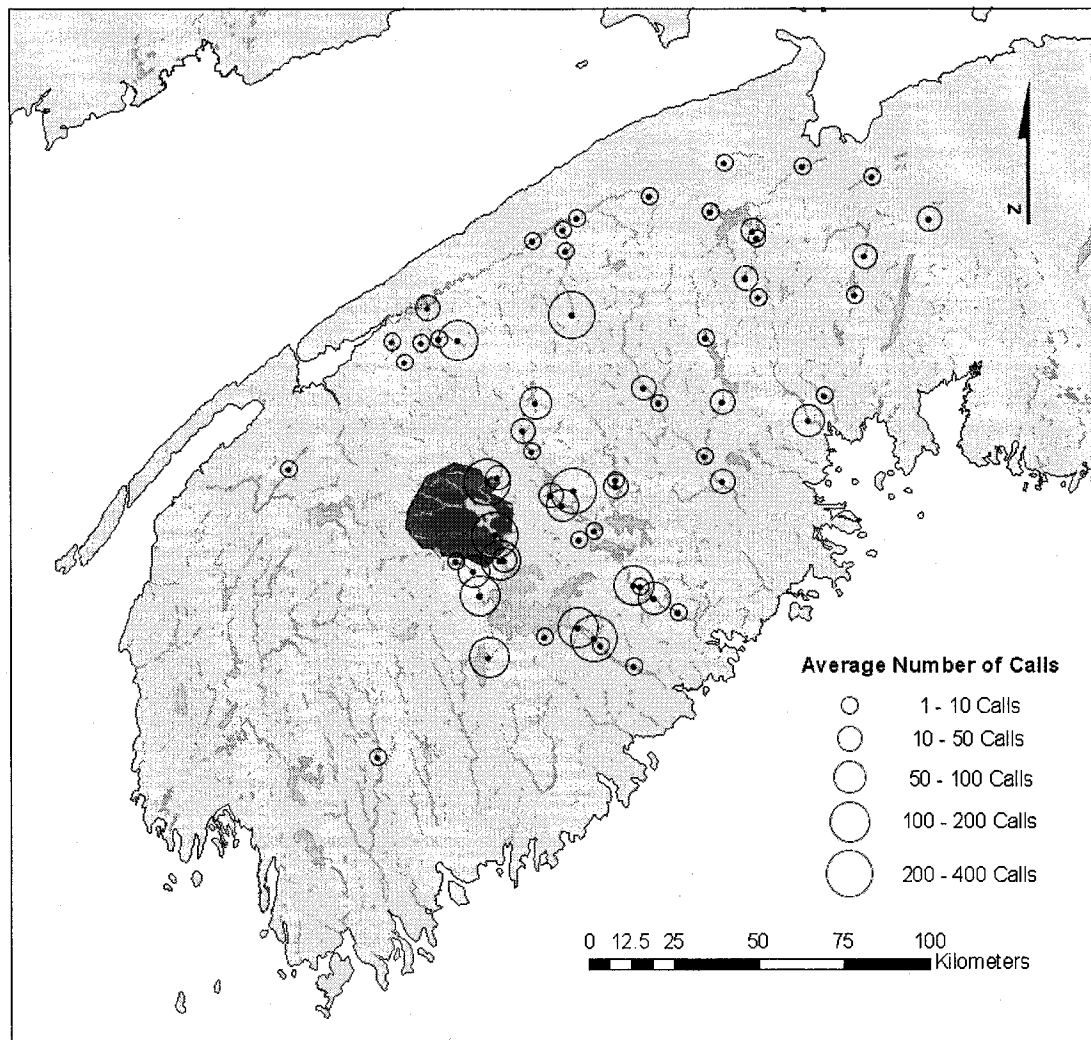
**Figure 2.4.** Sites where eastern pipistrelle echolocation call sequences were recorded from June to August 2005 and the proposed summer distribution of the eastern pipistrelle in southwest Nova Scotia, Canada.



**Figure 2.5.** An additional fifty sites located on forested rivers within the proposed summer distribution of the eastern pipistrelle in southwest, Nova Scotia based on monitoring in 2005 were acoustically monitored for eastern pipistrelle echolocation activity from June to August 2006.



**Figure 2.6.** The ninety sites monitored in 2005 and 2006 are shown according to whether eastern pipistrelle echolocation activity was recorded or not. The regional summer distribution of the population in southwest, Nova Scotia is outlined and is the minimum area covered by sites with recorded eastern pipistrelle activity, covering an area of approximately 10 020 km<sup>2</sup>.



**Figure 2.7.** Sites monitored in southwest, Nova Scotia in 2005 and 2006 with recorded eastern pipistrelle echolocation activity are shown with the average number of calls recorded per night of sampling.

## **CHAPTER 3:**

### **Activity of the eastern pipistrelle in southwest Nova Scotia relative to landscape factors**

### **3.1 Introduction**

One of the fundamental problems in ecology is to determine the causes of species' distributions and patterns of activity. Important spatial aspects of ecology include relationships between organisms and their environments that relate to place, such as the distribution of individuals, their movement and spatial patterns of activity. A good understanding of these aspects of species' ecology can give insight into the mechanisms and processes that help structure populations and are critical for successful species conservation plans. If concerns about the accelerating alteration of ecosystems are valid, then the evaluation of quantitative associations between the population sizes of species and landscape factors influencing their distribution is of high conservation importance (Walsh & Harris 1996a, p.47).

The use and development of species-environment distribution models in ecology has rapidly increased largely due to the rise of powerful statistical techniques and Geographic Information System (GIS) tools (Guisan & Zimmermann 2000). The intent of species-environment modeling is often to relate species distributions to certain landscape characteristics in order to infer whether a species exhibits preference for particular landscape elements and to identify areas that provide suitable resources for the species. The quantification of species-environment relationships has recently gained importance as a tool to assess the impact of accelerated human land-use and other environmental change on the distribution of species. Ecological patterns are dynamic and can be examined at multiple spatial and temporal scales (Wiens 1989). Spatial scale is an important consideration in any ecological research, as it has the potential to greatly influence the results and interpretations of ecological studies (Wiens 1989). Examination

of spatial patterns of activity at broader scales for example, may reveal emergent properties that are not evident at more local scales.

One important consequence of habitat loss is a disruption in the spatial continuity of remaining habitat patches across a landscape (Forman & Godron 1986, Freeman *et al.* 2003). Connectivity refers to the degree to which the landscape facilitates or impedes movement of organisms among habitat patches and is considered a vital element of landscape structure because of its importance to population viability (D'Eon *et al.* 2002, Noss 1991, Taylor *et al.* 1993). Fragmentation of native habitats that results in decreased connectivity is a wide-spread phenomenon that has a range of negative impacts on native species and ecosystems, depending on the nature of the disturbance and on the ecology of the affected species (Forman & Godron 1986, Saunders *et al.* 1991, Wiegand *et al.* 2005).

Connectivity in forested landscapes managed for wood production is an important concern for community composition (Forman & Godron 1986). Impacts of forestry practices may alter species diversity by reducing or increasing population sizes of various species due to decreases or increases in the quantity or quality of resources available to them. The loss of species, or isolation and fragmentation of populations from harvested landscapes, is a commonly researched topic related to forestry practices (Lindenmayer *et al.* 2000). As forests become further fragmented by human disturbance, it is necessary to determine how factors such as the size, shape and connectivity of remaining forest patches affect animal populations and communities (Forman & Godron 1986).

Evaluation of the effects of disturbance on ecological patterns and processes can provide important information relevant to conservation and management decisions. Ecosystem integrity refers to the maintenance of community structure and function

characteristic of a particular location (Noss 1990). In situations where there is interest in assessing ecosystem integrity of managed land, identification of species sensitive to environmental change presents opportunities for early indication of disturbance effects (Fleishman *et al.* 2000, Medellin *et al.* 2000). An indicator species of ecosystem integrity is a species whose viability is so closely associated with particular environmental conditions that its presence indicates the existence of those conditions (Lindenmayer *et al.* 2000, Simberloff 1998). Species such as this may be useful for monitoring changes in the environmental conditions that they depend on.

Bats may be well-suited as indicators of habitat disturbance (Fenton *et al.* 1992, Medellin *et al.* 2000) and recently there has been a surge of interest in characterizing bat habitat by monitoring echolocation calls using bat detectors (Crampton & Barclay 1996, Erickson & West 2003, Grindal & Brigham 1999, Humes *et al.* 1999, Patriquin & Barclay 2003, Zimmerman & Glanz 2000). The majority of the studies, however, have been conducted at the level of the forest stand. Bats are highly mobile and have the ability to travel large distances in a single night and consequently, it is important to understand associations of bats at landscape scales. The vagility of an organism, and therefore its ability to travel between discrete patches, is an important determinant of landscape connectivity. Highly mobile organisms such as bats may be useful for assessing the connectivity of landscape elements at broad geographical scales (D'Eon *et al.* 2002, Wiens 1989).

Roost sites represent critical resource requirements for bats and, since many bat species regularly switch roosts and use a relatively large number of roosts in a given season (Lewis 1995), a lack of suitable roost areas may limit bat populations (Kunz



1982). Selection of roost areas that are in close proximity to foraging sites should minimize energy costs associated with commuting (Waldien et al. 2000). Therefore, roost selection by bats may be limited by the availability of suitable roosting areas across landscapes and by their proximity to suitable foraging sites. Forestry practices have the potential to negatively impact the roosting ecology of forest associated bat species by the direct loss of roosting sites and impacts to roosting areas (Grindal & Brigham 1999, Vonhof & Barclay 1996). Quantitative data on the suitability of various stand and tree types to bat species would be beneficial to their conservation.

The majority of the Maritimes provinces is characterized as Acadian Forest, but the past several hundred years of human occupation have seen the conversion of much of Nova Scotia's forest to early successional forest types (Mosseler *et al.* 2003). In Nova Scotia, colonies of female eastern pipistrelles roost in clumps of *Usnea* lichen in relatively small roost areas in mature stands of spruce species (Quinn & Broders, unpublished data). In a concurrent study, Quinn & Broders (unpublished data) also found that *U. trichodea* was nearly four times more likely to be found in spruce and fir tree species than other tree species in Kejimikujik National Park, Nova Scotia. Common forest management practices alter forest landscapes in ways that limit opportunities for lichen growth and dispersal and lichens have been found to be less abundant in young, managed stands compared to mature forest (Price & Hochachka 2001). In Nova Scotia, Cameron (2002) found *U. trichodea* abundance to be greatest in old growth forests, indicating an association between this lichen and mature forests.

All of the current data support the contention that the Nova Scotia population of eastern pipistrelles is relatively small, distinct, and isolated from conspecific populations.

Within Nova Scotia, the eastern pipistrelle appears to have specific roosting requirements for mature spruce stands with an abundance of *Usnea* growth. Therefore, the viability of this species may be related to the amount and connectivity of this forest type over the large spatial scale of their distribution in southwest Nova Scotia. If their patterns of activity are related to this forest type in a predictable manner, then changes in their activity patterns over time may reflect changes in the abundance of this forest type at the landscape scale. Activity of this species is also relatively cheap and easy to monitor using ultrasonic detection. Therefore the study of this species may have value for monitoring and assessing changes in landscape structure and connectivity, with a decrease in activity indicating a loss of landscape elements associated with eastern pipistrelles. Further research is necessary to quantitatively characterize habitat requirements of the eastern pipistrelle to determine the conservation status of the population.

### **3.1.2 Objectives**

In Chapter 2, it was determined that the eastern pipistrelle is patchily distributed over a relatively wide geographic area in southwest Nova Scotia. The purpose of the research presented in this chapter is to gain additional insight into the causes of this patchy distribution. More specifically, I was interested in determining if this bat species responds to landscape structure and if so, what are the important landscape factors influencing their spatial patterns of activity. This paper presents a landscape-scale approach to identify and quantify landscape elements affecting the distribution and magnitude of activity of eastern pipistrelles in southwest Nova Scotia. The expectation is

that, because bats are very mobile and can travel several kilometres in a single night, the eastern pipistrelle may respond to various elements of the surrounding landscape in a predictable and quantitative manner.

### **3.3 Methodology**

#### **3.2.1 Study Area**

This study took place within the 10 020 km<sup>2</sup> summer distribution of the eastern pipistrelle in southwest Nova Scotia delineated in Chapter 2 of this thesis. A detailed description of the study area is provided in the Methodology section of Chapter 2.

#### **3.2.2 Field Methods**

Twenty-seven of the forty sites monitored in 2005 were located within the delineated summer distribution of the eastern pipistrelle in southwest Nova Scotia. These 27 sites were ultrasonically monitored to quantify bat activity from 21 June to 18 August, 2005 by the methods described in Chapter 2. In 2006, an additional 50 forested river sites were selected within the defined summer distribution and were acoustically sampled from 5 June to 19 August, 2006 using the same methods. Each site was sampled two or three times for three nights each over the entire sampling period.

Recognized factors that explain variation in the magnitude of bat activity include nightly temperature (Vaughan et al. 1997) and prey availability (Grindal & Brigham 1999, Hayes 1997, Kusch *et al.* 2004). To quantify these effects, a Pro Series HOBO Temp/Humidity data logger (Onset, Bourne, MA, USA) was deployed with each system and recorded temperature on an hourly basis from 19:00 to 06:00. Because sampling was

only conducted at forested river edges and because insect biomass (i.e. prey) is positively correlated with temperature (Grindal & Brigham 1999, Hayes 1997, Taylor 1963), the effects of prey availability on bat activity were assumed to be non-significant when temperatures were accounted for, and therefore potential prey biomass was not sampled. At each site, river width was calculated as the average of three measurements (at the monitoring site, 25 m upstream and 25 m downstream).

### **3.2.3 *Lab Methods***

Eastern pipistrelle echolocation call sequences were identified as described in Chapter 2.

### **3.2.4 *GIS Analysis***

Geographic coordinates for sample sites were plotted in a Geographic Information System using ArcGIS 9.1 (ESRI GIS and Mapping Software, California, USA). Digital forest and land-use cover data of the study area were provided by the Nova Scotia Department of Natural Resources. These data were interpreted and digitized by NSDNR from 1:10 000 aerial photographs, with updates completed by re-interpretation of new photography, digital satellite images, field silvicultural activities and additional field data. Forest stands delineated in the data were a minimum of 1 ha in size. These data were used to quantify landscape factors within commuting distance of each site. Commuting distance was assumed to be 5 km, which is the greatest distance an eastern pipistrelle has been observed to travel from trap site to roost site at Kejimikujik National Park (Quinn & Broders, unpublished data).

The land-use and forest resource data were summarized into six broad patch types to reduce the number of landscape variables to a reasonable number, given the sample size (Table 3.1). The area of individual polygons was calculated in ArcGIS 9.1 and was summed within a 5 km buffer around each site to determine the area of the landscape attributes within commuting distance of each site. Specifically, the landscape attributes used were spruce and balsam fir dominated forest stands, other softwood dominated forest stands, shade-intolerant hardwood dominated forest stands, shade-tolerant hardwood dominated forest stands, freshwater resources (including lakes, rivers and wetlands) and non-forested land areas (A more detailed description of the variables is provided in Table 3.1). For the forest stand variables, a minimum canopy height requirement of 11 m was imposed, which is the minimum roost tree height recorded for maternity colonies of eastern pipistrelles at Kejimikujik National Park (Quinn & Broders, unpublished data).

### ***3.2.5 Statistical Modeling***

The goal of statistical modeling was to assess the effects of landscape-scale attributes on the activity of eastern pipistrelles while controlling for night and site-specific effects. Data in the two years of this study were modeled separately so that data collected in year two could be used as an independent dataset for validation of year one results. To determine those landscape attributes that affect the activity patterns of the eastern pipistrelle in the region, an information-theoretic approach to model selection was used. These methods allow the selection of a best approximating model, given the data,

and allow ranking and weighting of the remaining models in a pre-defined candidate set (Burnham & Anderson 2002).

A set of ten *a priori* chosen quantitative models was compiled, representing qualitative hypotheses to explain the magnitude of eastern pipistrelle activity based on an understanding of their local ecology in the region and a review of the literature (Table 3.2). These models were then ranked in terms of their support based on the data using Akaike's Information Criterion (AIC) which represents an estimation of the relative Kullback-Leibler distance based on Fisher's maximum log-likelihood (Burnham & Anderson 2001, Burnham & Anderson 2002). Information-theoretic approaches also allow for multimodal inference, in which formal inferences are based on more than the best model, thus rejecting the notion that there is a simple "true model" in the biological sciences. Instead, use of the strength of evidence for each model of the candidate set, based on a philosophy of thoughtful, science-based *a priori* logic, is strongly advocated (Burnham & Anderson 2002).

Average temperature (Table 3.1) for each night of sampling was incorporated into all of the candidate models to control for the effects of nightly temperature on activity. The candidate model set consisted of models of the effects of individual site and landscape factors and combinations thereof based on expectations of how the eastern pipistrelle responds to landscape composition. For example, model 6 (Table 3.2), containing the variables temperature (temp), area of spruce and balsam fir dominated stands (aspb) and area of lakes, rivers and wetlands (awet), predicts that the eastern pipistrelle is responding to the amount of suitable roosting habitat (spruce-fir dominated

forest stands) within commuting distance of foraging areas (freshwater lakes, rivers and wetlands) when temperature is controlled for.

The purpose of this analysis was to determine if activity of eastern pipistrelles is associated with landscape attributes recognized as important for roosting colonies of females (i.e. spruce and balsam fir dominated forest stands; Quinn & Broders, unpublished data) compared to other forest types. Therefore, it was expected that their activity would be positively correlated with the area of this forest type and would not be strongly influenced by the other forest types, though there may be a negative relationship associated with them because an increase in their area could suggest a decrease in the area of spruce and balsam fir dominated forest. It was also expected that there may be selection for sites with a high freshwater resource component, important for foraging by this species (Brack & Mumford 1984, Broders *et al.* 2001, Broders *et al.* 2003, Davis & Mumford 1962, Fujita & Kunz 1984, LaVal *et al.* 1977) and therefore a positive relationship with the area of rivers, lakes and wetlands. Finally, current evidence suggests that, in Nova Scotia, the eastern pipistrelle is a forest associated species and therefore it was also expected that the magnitude of their activity may be negatively correlated with the area of non-forested land at the landscape-scale.

Eastern pipistrelle activity, quantified as the number of echolocation calls recorded per night, was not normally distributed, a condition typical of many count data. Several transformations of this variable were investigated but each resulted in model residuals that violated the assumption of normality. To account for this, nightly activity was classified into 5 levels such that level zero represented nights with no recorded activity, levels 1 to 3 had class widths of 200 calls and level 4 included nights with

greater than 600 calls. The frequency of site nights across these levels was distributed in a Poisson fashion.

Poisson family (log link) generalized linear regression models (McCullagh & Nelder 1989, Sokal & Rohlf 1995) were fit using the S statistical language in S-Plus 2000 software (Mathsoft Inc., Cambridge, MA). The generalized linear model assumes that the link function (log) relates to the predictor variables in a linear manner (i.e.  $\log(y) = \beta_0 + \beta_1x_1 + \beta_2x_2$ ). Therefore, the relationship between the magnitude of activity and each independent predictor variable was investigated for linearity through the use of scatter plots in Systat 12 (Systat Software Inc.). Potential co-linearity of the predictor variables was also investigated in Systat 12 by calculating a correlation matrix of the predictor variables with the expectation that if any two variables had a Pearson correlation  $> 0.80$ , one of the variables would be removed from the analysis. Prior to model selection, a Pearson  $\chi^2$  goodness of fit statistic for the global model, the model containing all of the predictor variables, was calculated to determine if the chosen model is appropriate for the data. A non-significant result of the Pearson  $\chi^2$  goodness of fit test indicates that the model being tested is a good fit to the data because the model-predicted frequencies are not significantly different from the observed frequencies. The residuals of the global model were then imported into ArcGIS 9.1 to test for potential spatial autocorrelation using the Moran's I test. An  $\alpha$  of 0.05 was used in all significance tests.

A lack of independence among experimental units in a set of data should lead to over-dispersion due to positive correlations among individual observations within a group, such as individuals within a social unit or multiple observations at a single site. Over-dispersion is a condition in which the sampling variance of the data exceeds the



theoretical, model-based variance and can occur as a result of small violations of the assumptions of the model, such as independence (Burnham & Anderson 2002). Multiple observations of activity were recorded at each site (six or nine nights), potentially leading to a lack of independence and over-dispersion. The variance inflation factor,  $\hat{c}$ , is a useful approximation of the degree of over-dispersion in a dataset and was estimated from the chi-squared goodness-of-fit statistic of the global model and its degrees of freedom,  $\hat{c} = \chi^2 / df$  (Burnham & Anderson 2002). A value for  $\hat{c}$  of around 1 indicates that there is no evidence of over-dispersion in the data and the fitted model is a good approximation of the data (Burnham & Anderson 2002). The variance inflation factor was calculated for the global model in both years to determine if there are site-specific estimates of eastern pipistrelle activity (i.e. the observations recorded at a site are correlated) and if a more complex model is required to address this lack of independence.

The candidate set of models were ranked using the small sample variant of Akaike's Information Criterion ( $AIC_c$ ) (Burnham & Anderson 2001, Burnham & Anderson 2002). The AIC approach allows for the best model in the candidate set (the model for which AIC is minimized) to be identified and provides a simple, effective and objective means for the selection of an estimated "best approximating model" for data analysis and inference. The difference between the AIC of each model and that of the best approximating model was calculated ( $\Delta_i$ ). The larger the  $\Delta_i$ , the less plausible it is that model  $i$  is the best approximating model in the candidate set (Burnham & Anderson 2001). Akaike weights ( $w_i$ ) were also calculated from the  $AIC_c$  for each model and represent the probability that the  $i$ -th model is actually the best approximating model among the candidate set, given the data (Burnham & Anderson 2002).

To determine which variables are most important, multi-model inference (MMI) was used rather than basing conclusions on only the best approximating model of the candidate set, thus reducing bias (Burnham & Anderson 2001, Burnham & Anderson 2002, 2004). This method is particularly useful when a number of models are nearly as well supported as the best model (Burnham & Anderson 2001). To do this, relative importance weights ( $Nw_i$ , the sum of the normalized Akaike weights for all of the models containing the given variable) were calculated for the variables present in the 95% confidence set of the models (Burnham & Anderson 2002). Model-average parameter estimates ( $\beta_i$ ) with estimated unconditional standard error (Burnham & Anderson 2002) were calculated for quantification of the effects of the variables on activity based on the 95% confidence set of models. The results of modeling were compared between years of this study to assess consistency of the important variables and their parameter estimates. Assessment of the value of a systematic acoustic survey program to monitor the availability of landscape elements associated with eastern pipistrelles will be based on the relative importance ( $Nw_i$ ) and on the strength of the relationships (effect size) between eastern pipistrelle activity and the landscape elements being investigated and on the number of important variables in the best approximating model.

### ***3.2.6 Predictive Map***

The landscape variables determined to influence eastern pipistrelle activity based on the 95% confidence set of models were used to predict the magnitude of eastern pipistrelle activity at a series of systematically selected points located throughout the summer distribution delineated for the population. The weighted average (based on the

number of detector nights) of the model-averaged parameter estimates for the important variables over the two years of this study were calculated. A grid of points was created in ArcGIS 9.1 such that each point was situated 5 km apart and the important landscape variables were quantified in the same manner as the sample sites. The predicted magnitude of eastern pipistrelle activity was determined and represents an estimate of eastern pipistrelle activity on an average temperature night at the sites based on the important landscape variables influencing their activity.

### 3.3 Results

Based on the correlation matrices of the predictor variables, there is no evidence of significant co-linearity between any of the predictor variables in either year of this study (Appendix 5.1). The predictor variables were also investigated for a linear relationship with the response variable, magnitude of activity, and scatter plots suggested that there were no obvious departures from linearity (Appendix 5.2). Therefore, the full set of predictor variables (as described in Table 3.1) was included in the candidate set of models.

Prior to model selection, the goodness-of-fit between the observed data and the fitted values of the global model was estimated. In both 2005 and 2006, the Pearson chi-square goodness-of-fit test was not significant (2005:  $\chi^2 = 158.84$ ,  $df = 178$ ,  $p = 0.85$  and 2006:  $\chi^2 = 314.79$ ,  $df = 358$ ,  $p = 0.95$ ) suggesting that distribution of the model-predicted values for the magnitude of activity is not significantly different from the distribution of the observed levels of activity (Burnham & Anderson 2002). The variance inflation factor,  $\hat{c}$  was 0.89 in 2005 and 0.88 in 2006, indicating that there is no evidence of over-

dispersion in the data due to a lack of independence of the observations. Therefore, it was assumed that there is no biased estimate of site-specific activity levels in the study area, and each night of sampling was considered to be an independent observation.

Given a set of features (in this case sample sites) and an associated attribute (the Pearson residuals of the global generalized linear regression model), the Moran's I test is used to evaluate whether the spatial pattern expressed in a set of data is clustered, dispersed or random. A Moran's Index (MI) value near 1 indicates clustering and a value near -1 indicates dispersion, while a value near 0 indicates a random spatial pattern of observations. The Moran's I test for spatial autocorrelation was not significant in 2005 (MI = -0.011,  $z = -0.974$ ,  $p = 0.33$ ) or 2006 (MI = 0.002,  $z = 1.032$ ,  $p = 0.30$ ), indicating that there is no significant spatial autocorrelation of the residuals of the global model to explain the magnitude of eastern pipistrelle activity in either year of this study

The 95% confidence set of models consisted of nine of the ten candidate models in 2005 and three models in 2006 (Table 3.3). The best approximating model in both years contained the landscape variable non-forested land area (anon). The second best model was also consistent between years and contained the landscape variables non-forested land area (anon) and the area of freshwater resources (awet), but carried considerably less weight than the best approximating model in both years. The remaining seven models of the 95% confidence set in 2005 carried very little support ( $w_i < 0.133$ ). The third model of the 95% confidence set in 2006 had a weight less than 3% ( $w_i = 0.027$ ). Of the variables included in the models comprising the 95% confidence set in both years of this study, only the landscape predictor non-forested area was determined to influence the magnitude of eastern pipistrelle activity recorded at forested river sites in

the summer distribution of the species in southwest Nova Scotia in 2005 and 2006 based on support from the data (2005:  $Nw_i = 0.50$ , 2006:  $Nw_i = 0.82$ ).

The model average parameter estimates (SE) for temperature were 0.091 (0.038) in 2005 and 0.002 (0.027) in 2006 (Table 3.4). This positive relationship with eastern pipistrelle activity is significant in year 1 (standard error does not include zero), but in year two, the standard error of the parameter estimate contains zero, suggesting that average nightly temperature might not have had an influence on eastern pipistrelle activity in the second year of this study (Figure 3.1, a & b). However, the weighted average parameter estimate for temperature over both years of this study is significant and the standard error does not contain zero (Table 3.4, Figure 3.1 c).

The model averaged parameter estimates (SE) for non-forested area were -0.025 (0.006) and -0.033 (0.007) for 2005 and 2006 respectively (Table 3.4). The consistent and negative estimated effect sizes in both years indicate a decrease in the magnitude of eastern pipistrelle activity as the area of non-forested land-use increased in commuting distance of foraging sites (Figure 3.1, a & b). Of the 78 km<sup>2</sup> buffers identified around each sample site, open area ranged from 1.3 to 58% of the total area for sites sampled in 2005 and 4.0 to 56% for sites sampled in 2006. The weighted average of these two values (based on the number of detector nights in each year) was used for the models of predicted eastern pipistrelle activity (Figure 3.2 c).

Eastern pipistrelle activity is expected to be greatest on warm nights at sites where there are fewer non-forested areas within 5 km of the site (Figure 3.3). The distribution of predicted eastern pipistrelle activity at systematically selected points within the summer distribution delineated for the population in Chapter 2 were estimated (Figure

3.4). The values of the predicted magnitude of activity based on the model containing temperature and non-forested area, range from approximately 0.1 to 0.8, whereas actual values for the magnitude of activity were as high as 4 (Pearson  $r^2 = 0.334$ ). This suggests that, although there is a quantitative link between the magnitude of eastern pipistrelle activity and non-forested area that was validated by two separate years of data, this link is not strong and non-forested area predicts actual activity levels relatively weakly.

### 3.4 Discussion

In forested landscapes, the distributional patterns of species are influenced by a complex interaction of factors from the spatial scale of individual trees to stand and landscape level interactions, which are all governed by the ecology of individual species relating to resource requirements, temporal factors, and climate. Landscape models are often used in ecology to predict the presence or absence of species based on the landscape level interactions of their distributional patterns. The use of acoustic detectors to record the echolocation calls of bats provides the opportunity for greater resolution than presence and absence alone through the use of an index of ultrasonic activity. Because of the considerable mobility of bats, I anticipated that the magnitude of eastern pipistrelle ultrasonic activity would be influenced by landscape attributes in commuting distance of riparian foraging sites in southwest Nova Scotia. The results of generalized linear regression models indicate that activity of the eastern pipistrelle in the region is influenced by average nightly temperature and non-forested area at the landscape-level.

Bat activity tends to vary with temperature (Hayes 1997, Kusch *et al.* 2004, Vaughan *et al.* 1997) and the results of this research provide additional evidence for a

positive relationship between bat activity and average nightly temperature. This observed relationship was expected for at least two reasons. Overall insect abundance on a given night has been shown to vary with temperature with a greater abundance of insect prey on relatively warm nights (Grindal & Brigham 1999, Taylor 1963). This relationship however is often non-linear with distinct upper and lower temperature thresholds associated with dramatic decreases in flight activity by insects (Hayes 1997, Taylor 1963). As a result of this relationship, bat activity may also be related to temperature in a non-linear fashion. Hayes (1997) demonstrated a non-linear relationship between minimum nightly temperature and bat activity such that activity decreased dramatically when minimum temperatures dropped below 0 to 4°C. Average nightly temperatures in this study, however, did not drop below 10°C, providing a possible explanation for the lack of a lower temperature threshold in bat activity.

A positive relationship between bat activity and average nightly temperature was also expected for reasons related to thermoregulation. Maintaining high body temperature during exposure to cool temperatures is energetically costly for bats (Willis et al. 2006). Foraging bouts usually account for the largest proportion of an individual's daily energy budget (Kurta et al. 1989) and on cool nights with little active prey, the energy costs of foraging may be too great for the given prey rewards. As a result, individuals are expected to limit their foraging activity on cool nights.

Interestingly, temperature had a positive effect on eastern pipistrelle activity in 2005, but this relationship was not evident in 2006. The average temperature over the duration of the study was consistent between the two years (2005 mean temperature = 17.21°C and 2006 mean temperature = 17.51°C). This is also consistent with expected

average summer temperatures for the region based on the literature (Davis & Browne 1996, p.47). In 2005 however, the frequency distribution of nightly temperatures was slightly skewed towards cooler nights while in 2006 they are slightly skewed to warmer nights. This may suggest that in 2005, individuals experienced a greater number of cooler nights when foraging activity is more energetically costly than warm nights, so that on the warm nights, they were highly active thus leading to the detection of a positive relationships between temperature and foraging activity. In 2006, there were a greater number of warm nights and therefore the foraging activity of individuals was not as constrained as in the previous summer. Despite the inconsistency in the relationship between bat activity and temperature between the years of this study, due to the relationship detected in 2005 and the abundance of support in the literature for an association between the bat activity and temperature, it is recommended that temperature be accounted for when modeling activity patterns of bats with spatial characteristics.

The landscape-level attribute most closely associated with eastern pipistrelle activity was the area of non-forested land use, which does not include open areas over water and this was the only landscape variable found to be an important factor influencing their distribution based on the analysis. This landscape attribute had, as predicted, a negative relationship with eastern pipistrelle activity suggesting that eastern pipistrelles are less active in landscapes where forests are cleared for agriculture, urban areas, roads and clear cuts. This result is consistent with large-scale studies in agricultural landscapes, which have found that commuting and foraging bats often avoid flying across large open habitats but frequently follow linear landscape elements such as tree corridors, hedgerows and windbreaks (Limpens *et al.* 1989, Limpens & Kapteyn



1991, Verboom & Huitema 1997, Verboom & Spoelstra 1999, Walsh & Harris 1996b).

To bats, these linear landscape elements may function as navigational references, sources of insect prey, shelter from wind, and protection from predators (Limpens & Kapteyn 1991).

At localized scales, bats have been shown to use small gaps and openings in intact forest (Law & Chidel 2002, Patriquin & Barclay 2003, Tibbels & Kurta 2003), possibly a result of greater insect availability, proximity to roosts, or decreased structural complexity. Loeb and O'Keefe (2006) modeled the presence and absence of bat species in South Carolina in relation to landscape context and they found that the eastern pipistrelle was more likely to be recorded at sites with sparse vegetation, such as small gaps and openings within forest stands and early successional forest stands. At the landscape scale in southwest Nova Scotia however, my results suggest that the eastern pipistrelle is an example of a forest associated species that responds negatively to an increase in non-forested areas across landscapes, such as clear cuts and agricultural fields. Since the eastern pipistrelle is dependent on forest for roosting and is known to forage predominantly over water, these non-forested areas likely do not provide resources of any value to this species.

The distribution of predicted eastern pipistrelle foraging activity in southwest Nova Scotia based on non-forested area shows areas of high predicted activity in areas of the region where non-forested land use is minimized. One possible limitation to the utility of this predictive map is that the sites of predicted activity were systematically chosen and are not necessarily located on rivers, whereas echolocation sampling to develop the model only took place at river sites. Inferences on the regional activity

patterns of the species may have to be limited to sites that are at or in close proximity to rivers without canopy cover in the region.

Roosting requirements represent a critical component of the ecology of bats (Kunz 1982), and therefore roost habitat may be limiting for many bat species. Forests and other woodland habitats have been shown to positively affect foraging activity (Vaughan et al. 1997; Walsh & Harris 1996b) and roost availability (Altringham 1996) for many bat species. At the landscape scale, studies have found that vegetation structure can adequately predict the distribution of some bat species (Crampton & Barclay 1998, Jaberg & Guisan 2001, Miles *et al.* 2006). It was expected that activity patterns of the eastern pipistrelle would be related to the overall abundance of suitable roosting areas and their proximity to foraging areas at the landscape scale. Contrary to these expectations, the results of this study fail to provide evidence that the magnitude of eastern pipistrelle activity in southwest Nova Scotia is influenced by broad vegetation types at the landscape scale, including the area of spruce and balsam fir dominated stands, which represent expected roosting habitat for this species in the region. Nor is there evidence that foraging habitat, as it was inferred through the use of the area of lakes, rivers and wetlands, is a limiting factor influencing their activity patterns in the region.

Surface water is abundant throughout southwest Nova Scotia, which supports an extensive network of lakes, large rivers and wetlands (Davis & Browne 1996, p.47). Additionally, sampling took place only at river sites such that within the 5 km buffers around the each site it was known that there was at least some available foraging habitat.

These factors likely explain the lack of a relationship detected between eastern pipistrelle activity and the area of lakes, rivers and wetlands in the region.

The results of this research fail to provide evidence that selection for roosting areas in close proximity to foraging areas by eastern pipistrelles occurs at the landscape scale in southwest Nova Scotia. Though evidence has been provided in the literature supporting relationships between bat activity and forest characteristics at the landscape scale, other research suggests that bat activity is a function of features at more localized scales, including individual forest stands (Erickson & West 2003, Ford *et al.* 2005). Therefore, the eastern pipistrelle may be selecting localized forest resource characteristics that are not captured at the landscape scale and that are constrained by factors that are more appropriate for roosting studies at the level of the forest stand. The negative relationship between their activity and non-forested land areas does, however, imply a positive relationship with total forested areas. Therefore, there is evidence that the eastern pipistrelle is associated with forests, which provide the critical roosting habitat on which they depend, at the landscape scale.

It was assumed that forest type can be used to approximate the amount of suitable roosting habitat for the eastern pipistrelle in the region and this may not have been appropriate. All of our current knowledge regarding the roosting ecology of the eastern pipistrelle in Nova Scotia is based on one detailed study of roosting behaviour at one location in Kejimikujik National Park (Quinn & Broders, unpublished data). In this study, the roost areas of several colonies of reproductive females were investigated during the summers of 2003 and 2004 and it was concluded that colonies roost in clumps of *Usnea* lichen usually found in spruce and balsam fir species. It was also demonstrated that at

this location, *Usnea* is four times more likely to be found in spruce and balsam fir species than other tree species (Quinn & Broders, unpublished data). It is not known, however, whether this relationship between *Usnea* and these tree species could be location-specific. Detailed studies on the roost requirements of individuals of this population at additional locations within their summer distribution and a greater understanding of the factors that influence the distribution and abundance of *Usnea* lichen would benefit conservation efforts for this isolated population of bats. The results of echolocation monitoring, as well as the predictive map of eastern pipistrelle activity in the region developed in this study, should assist in the identification of areas appropriate for additional studies of their roosting ecology.

Based on this large-scale investigation of the activity patterns of the eastern pipistrelle in southwest Nova Scotia, I conclude that either 1) this species does not represent an appropriate indicator species of the abundance of critical forest components at the landscape scale, contrary to what was expected; 2) that the spatial land-use data used to generate the landscape attributes did not provide the resolution necessary to determine the critical forest components required for the species. For example, patches that are identified as homogeneous based on photo interpretation may possess small-scale heterogeneity that could potentially provide bats with local foraging or roosting resources; or 3) that the sample size of this study was too small to detect a relationship between eastern pipistrelle activity and landscape attributes. I have shown, however, that their activity is negatively impacted by an increase in non-forested areas at the landscape level, suggesting that this forest-associated species is sensitive to large-scale habitat

disturbance leading to a decrease in forested area, such as clear cuts created by timber harvesting.

Colville and Prakash (2005) used remote sensing to investigate land cover change in southwest Nova Scotia over the period from 1991 to 2005. They determined that the rate of forest loss in the region has increased between 1997-2005 compared to 1991-1997 and that forest losses from 2000-2005 greatly exceeded forest re-growth. If these trends continue, forestry practices have the potential to further affect the region's forested landscapes, likely resulting in negative impacts on the eastern pipistrelle and other forest-associated species in southwest Nova Scotia. As forest stands are cut, thus eliminating potential roosting habitat for bats, bats may have to travel greater distances between appropriate roosting and foraging areas.

#### ***3.4.1 Management Implications***

In terms of the impact of forest loss on bat populations, it appears that timber harvest activities, which are the dominant force shaping the landscape in southwest Nova Scotia (Colville & Prakash 2005), negatively impact foraging activity of the eastern pipistrelle. Management policies in the region should consider the overall area and connectivity of forested landscape for the eastern pipistrelle and other forest associated species with similar resource requirements. Structural diversity is an important component of mature and old growth forest, compared to relatively homogeneous even-aged young forests (Neitlich & McCune 1997) and species diversity and frequency of forest-dependent species could be enhanced by improving the impacts of current forestry methods on the structural diversity of the region's forests. Management techniques such

as structural retention of remnant trees, long rotations, and the creation of reserves could potentially reduce the impacts of disturbance created by forestry practices on animal populations at large scales (Price & Hochachka 2001). Individual remnant trees or groups of trees left standing following forestry activities are immediately available for use as wildlife trees by a range of organisms and may also enhance the growth of lichens (Neitlich & McCune 1997, Peck & McCune 1997, Price & Hochachka 2001). Cameron (2002) has also suggested that the retention of remnant live and dead trees in Nova Scotia is useful for the development of diverse lichen communities by providing a source of propagules for future lichen growth (Peck & McCune 1997). Groups of remnant live and dead trees and reserve areas sufficient in size to provide roosting areas for colonies of reproductive eastern pipistrelle will provide habitat for a range of other species that share similar habitat requirements for mature forest with abundant *Usnea* growth.

Additionally, activity levels of the eastern pipistrelle should be monitored at a series of the sites monitored in this project at regular intervals (e.g. five years) to assess long-term trends in their activity patterns. If there is a general decrease in their overall activity in the region compared to the baseline activity levels presented in this paper, then this would suggest a loss of critical forest components for this species, likely a result of an increase in non-forested areas in the region.

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### 3.6 Tables & Figures

**Table 3.1.** Potentially important factors influencing the magnitude of eastern pipistrelle activity at forested river sites in southwest Nova Scotia, 2005-2006. The landscape attributes are areas within a 5 km buffer (estimated commuting distance) of each sample site.

Variable	Abbr.	Description
Temperature	temp	Average of hourly temperature readings from 19:00 to 06:00 (°C)
River Width	rwth	Average of three river width measurements/estimates at the site, 25 m upstream and 25 m downstream from each site (m)
Area of shade-tolerant hardwood	aihw	Area of forest dominated by shade-tolerant hardwood species (> 50% composition; including red oak, yellow birch and sugar maple) with a height greater than 11 m (km <sup>2</sup> )
Area of shade-intolerant hardwood	athw	Area of forest dominated by shade-intolerant hardwood species (> 50% composition; including red maple and white birch) with a height greater than 11 m (km <sup>2</sup> )
Area of spruce and balsam fir	aspb	Area of forest dominated by spruce and fir species (> 50% composition) with a height greater than 11 m (km <sup>2</sup> )
Area of other softwood	aosw	Area of forest dominated by softwood species other than spruce and balsam fir (> 50% composition; including pine, larch and eastern hemlock) with a height greater than 11 m (km <sup>2</sup> )
Area of lakes, rivers and wetlands	awet	Area of lakes, rivers and wetlands (km <sup>2</sup> )
Non-forested land area	anon	Area of open, non-forested land use including clear cuts, fields, agriculture and urban areas and not including lakes, rivers and wetlands (km <sup>2</sup> )



**Table 3.2.** Candidate set of *a priori* generalized linear regression models to explain the magnitude of eastern pipistrelle activity at forested river sites in southwest Nova Scotia.

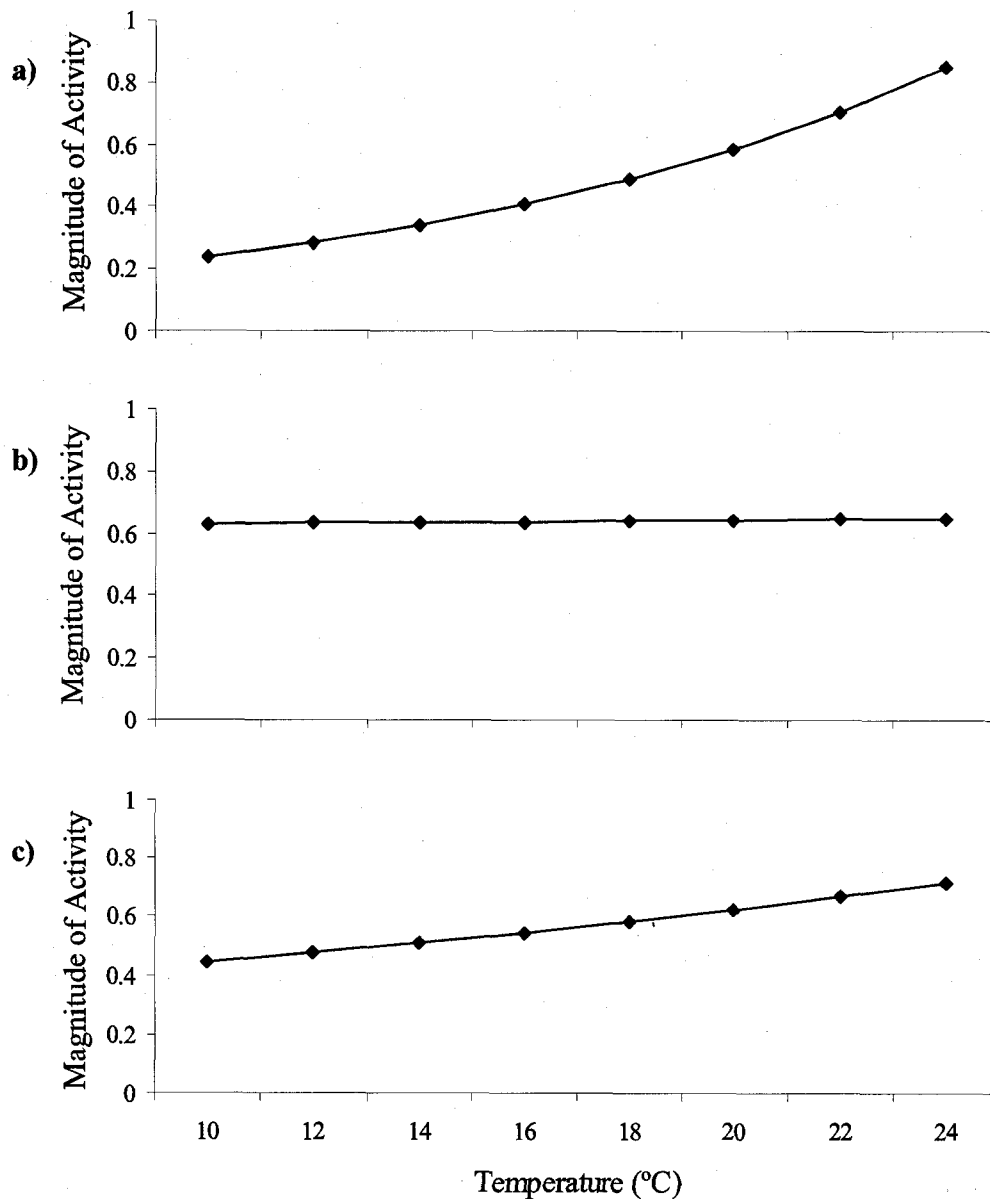
Model	Terms	Hypothesis
1	temp + aihw + athw + aosw + aspb	Forest Components
2	temp + aihw + athw	Hardwood Forest
3	temp + aosw + aspb	Softwood Forest
4	temp + rwth + awet	Foraging Areas
5	temp + anon + awet	Non-forested Areas
6	temp + aspb + awet	Roosting and Foraging Areas
7	temp + aspb	Roosting Areas
8	temp + anon	Non-forested Land Areas
9	temp + rwth	River Width
10	temp	Average Nightly Temperature

**Table 3.3.** The small sample variant of AIC ( $AIC_c$ ) and Akaike weights ( $w_i$ ) for the models making up the 95% confidence set of Poisson family (link = log) generalized linear regression models to explain the magnitude of eastern pipistrelle activity at forested river sites monitored from June to August, 2005 and 2006 in southwest Nova Scotia.

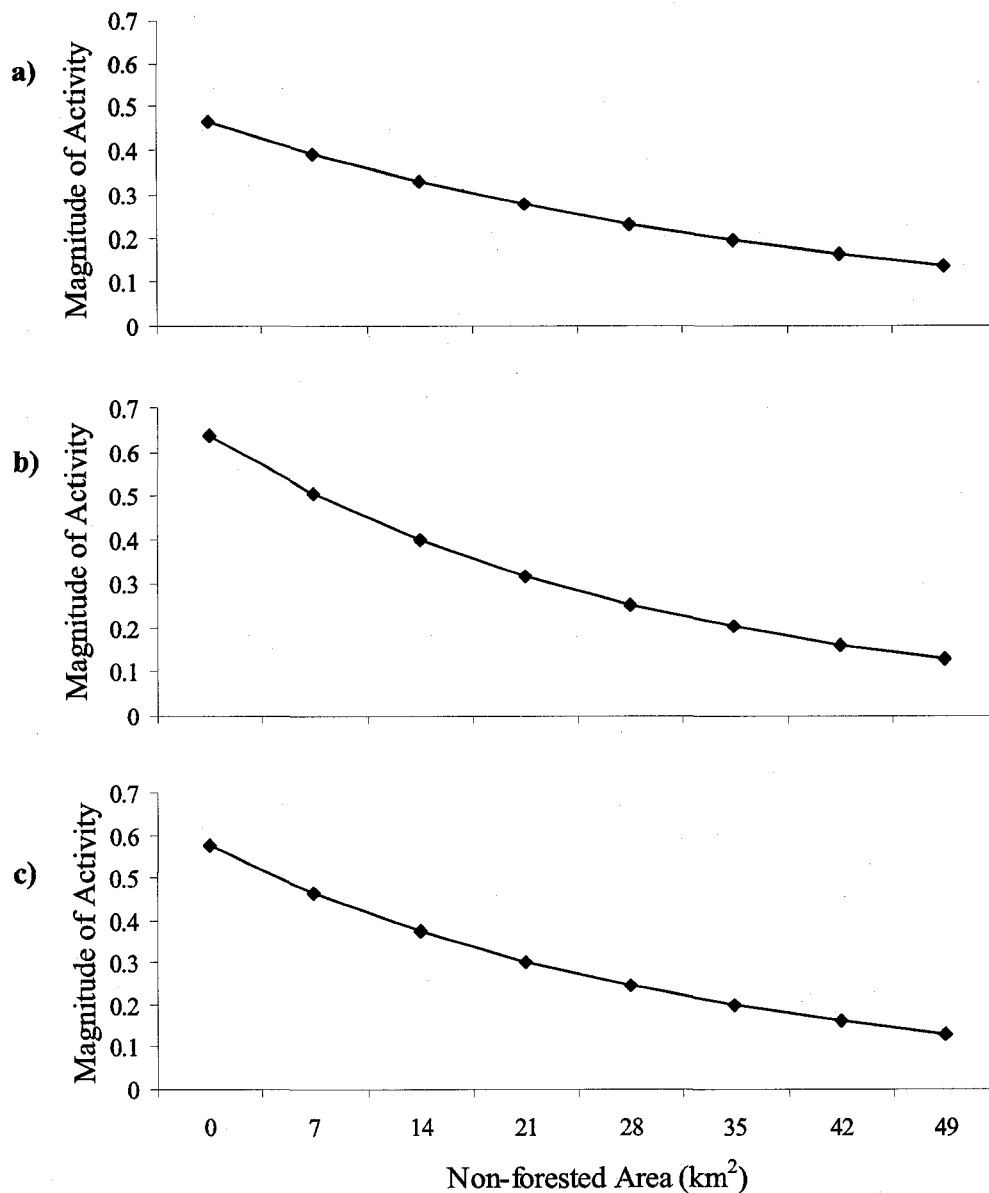
Model	Terms	2005		2006	
		$AIC_c$	$w_i$	$AIC_c$	$w_i$
8	temp + anon	167.25	0.354	326.71	0.670
5	temp + anon + awet	169.20	0.133	328.46	0.279
10	temp	169.62	0.108	-	-
2	temp + aihw + athw	169.74	0.102	-	-
1	temp + aihw + athw + aosw + aspb	170.55	0.068	-	-
3	temp + aosw + aspb	170.65	0.065	-	-
7	temp + aspb	170.95	0.056	-	-
9	temp + rwth	170.96	0.055	333.15	0.027
6	temp + aspb + awet	172.09	0.031	-	-

**Table 3.4.** Model-averaged parameter estimates ( $\beta_i$ ) with associated unconditional standard error (SE) for the intercept, temperature and non-forested land area to explain the magnitude of eastern pipistrelle activity at forested river sites in southwest Nova Scotia monitored in 2005, 2006 and the weighted average of the two years based on the number of observations.

Variable	$\beta$ (SE) for 2005	$\beta$ (SE) for 2006	Weighted Average $\beta$ (SE)
intercept	-2.358 (0.960)	-0.483 (0.578)	-1.118 (0.708)
temperature (temp)	0.091 (0.038)	0.002 (0.027)	0.032 (0.022)
non-forested area (anon)	-0.025 (0.006)	-0.033 (0.007)	-0.030 (0.007)

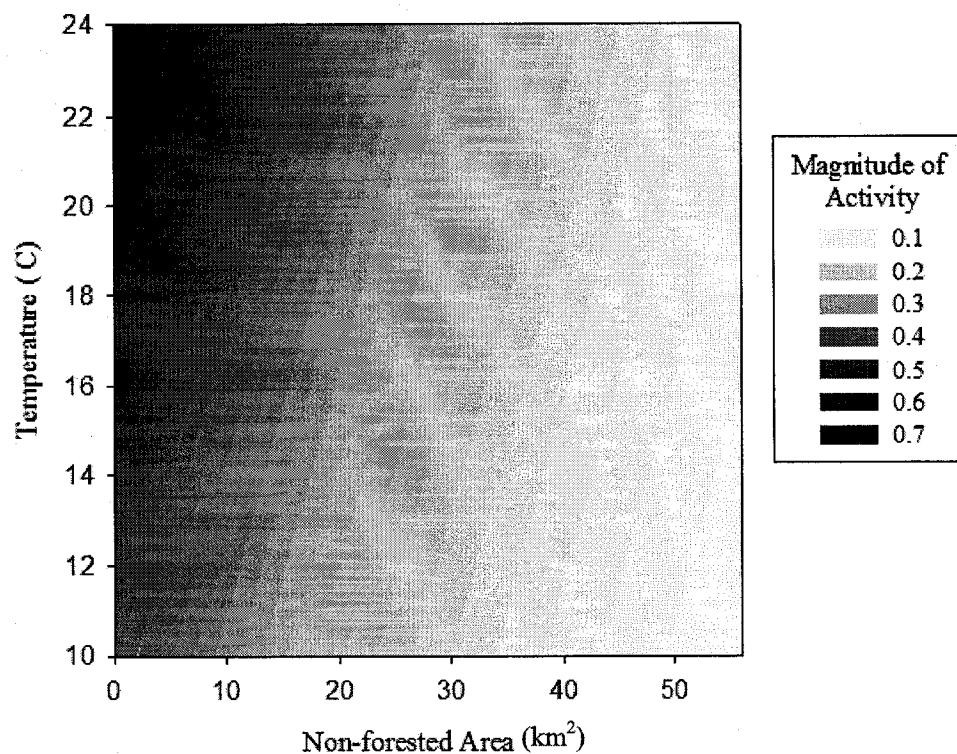


**Figure 3.1.** Predicted magnitude of eastern pipistrelle activity per night (0.0 = no echolocation calls, 1.0 = 200 calls) as a function of average nightly temperature at river sites in southwest Nova Scotia in a) 2005, b) 2006, and c) the weighted average of the two years based on the Poisson family (link = log) generalized linear regression model ( $\text{Activity} = e^{(\beta_0 + \beta_1 (\text{Temperature}))}$ ) through the minimum and maximum values of temperature (°C) recorded during the study.

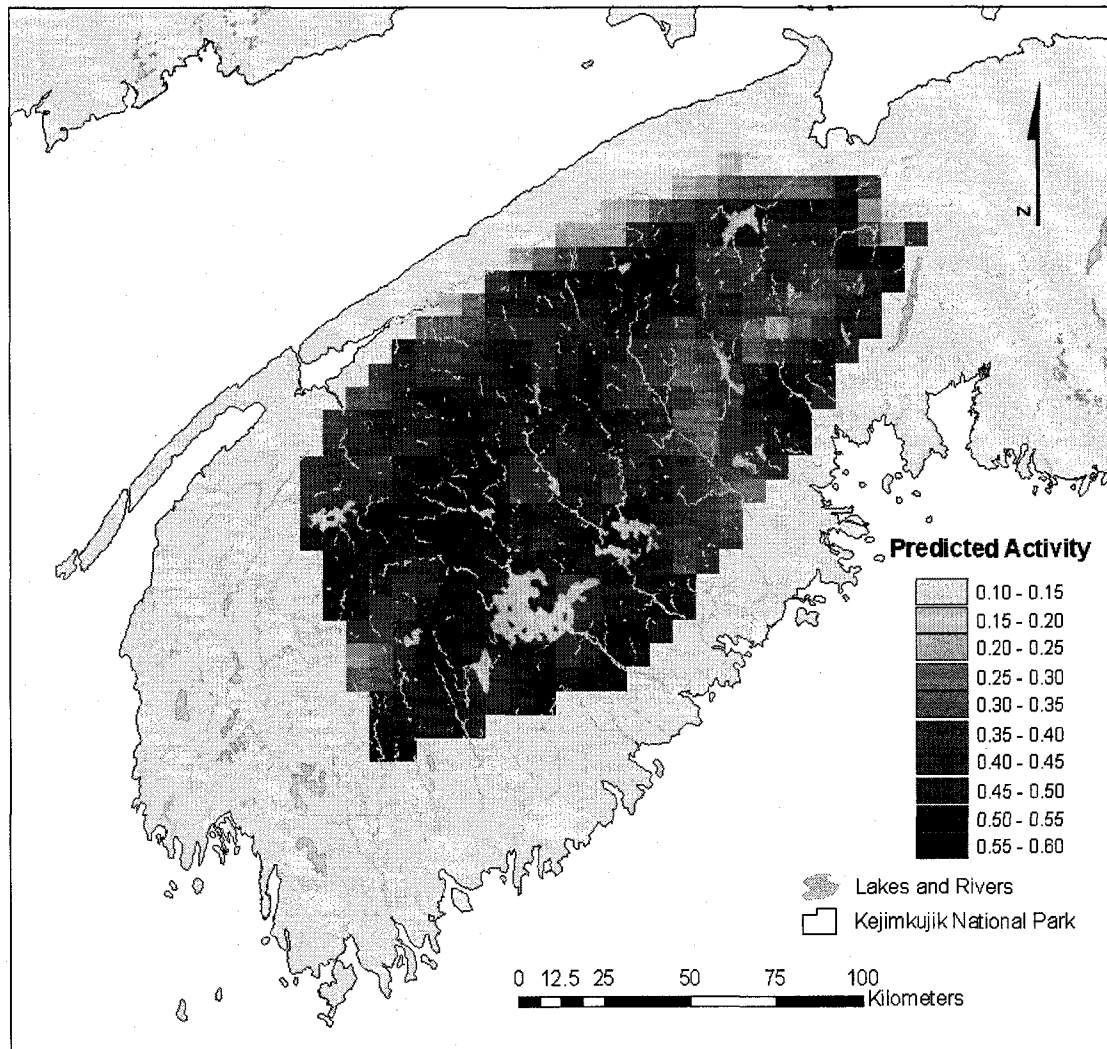


**Figure 3.2.** Predicted magnitude of eastern pipistrelle activity per night (0.0 = no echolocation calls, 1.0 = 200 calls) as a function of non-forested land area in commuting distance of river sites in southwest Nova Scotia in **a)** 2005, **b)** 2006, and **c)** the weighted average of the two years based on the Poisson family (link = log) generalized linear regression model ( $\text{Activity} = e^{(\beta_0 + \beta_1 (\text{Temperature}) + \beta_2 (\text{Non-forested Area}))}$ ) through the minimum

and maximum values of non-forested land area ( $\text{km}^2$ ) using the average temperature recorded during the study of  $17.5\text{ }(^{\circ}\text{C})$ .



**Figure 3.3.** The predicted magnitude of eastern pipistrelle activity per night (0.0 = no echolocation calls, 1.0 = 200 calls) at river sites in southwest Nova Scotia based on the weighted average of the parameter estimates and the Poisson family (link = log) generalized linear regression model ( $\text{Activity} = e^{(\beta_0 + \beta_1 (\text{Temperature}) + \beta_2 (\text{Non-forested Area}))}$ ) through the minimum and maximum values of temperature (°C) and non-forested land area (km<sup>2</sup>).



**Figure 3.4.** The predicted magnitude of eastern pipistrelle activity per night (0.0 = no echolocation calls, 1.0 = 200 calls) at a series of systematically generated points (5 km intervals) in southwest Nova Scotia based on the weighted average of the parameter estimates and of the Poisson family (link = log) generalized linear regression model ( $\text{Activity} = e^{(\beta_0 + \beta_1 (\text{Temperature}) + \beta_2 (\text{Non-forested Area}))}$ ) and the values of non-forested area (hectares) at these points and the average temperature of 17.5 (°C).



## **CHAPTER 4:**

### **Distribution of the eastern pipistrelle (*Perimyotis subflavus*) in southwest Nova Scotia relative to landscape factors: A Synthesis**

## 4.1 Synthesis

The presence of the eastern pipistrelle (*Perimyotis subflavus*) in Nova Scotia has been recognized for several decades (Bleakney 1965); however, throughout most of this time they were believed to be uncommon to rare (Davis & Browne 1996a, p.252). Until recently, very little was known about the population outside of a few sporadic sightings at hibernacula during fall and spring counts (Bleakney 1965, Taylor 1997). Since the discovery of a significant concentration of eastern pipistrelles at Kejimikujik National Park in 2001, research relating to the population has focused on 1) investigating the local roosting ecology of members of the population, revealing unique roosting behaviour exhibited by colonies of females (Quinn & Broders, unpublished data); 2) gaining a basic understanding of bat species distributions through the use of a spatially extensive ultrasonic survey of mainland Nova Scotia in 2003, suggesting that eastern pipistrelles are restricted to southwest Nova Scotia during the summer (Rockwell 2005); and 3) monitoring the timing of arrival and activity of bat species at local hibernacula. Many questions remained in our understanding of the dynamics of this population. There was a need for a more detailed assessment of their summer distribution in the region to help determine the significance of the population and a better understanding of their large scale resource requirements.

The goal of this thesis was to provide additional insights into the distribution and local ecology of this peripheral population of eastern pipistrelles. More specifically, I was interested in determining the summer distribution of the population and characterizing their spatial patterns of activity within this geographic area through the use of an index of their echolocation activity. I was also interested in investigating the

relationship between the magnitude of activity and landscape factors to determine if their activity at river sites is related to the composition of the surrounding landscape.

Through the use of remotely placed ultrasonic detectors I monitored the activity of eastern pipistrelles at 90 sites over two years. The results of this monitoring provide baseline data on the spatial activity patterns of the population and have allowed me to delineate the population's regional distribution. The eastern pipistrelle occurs within a minimum area of 10 020 km<sup>2</sup> mostly in the interior of southwest Nova Scotia, though no sites were sampled on North Mountain so they could be present along the Fundy Coast. I have also identified additional sites of high eastern pipistrelle activity levels that are comparable to the levels previously recorded at Kejimikujik National Park prior to this research.

Their general distribution suggests that at broad scales they may be influenced by average summer temperatures because they are absent from cooler areas along the coast and in the far southwest and their activity levels are greatest in areas recognized as some of the warmest in the region (Davis & Browne 1996a, p.47). Isolation of this southern affiliated population to warm areas of southwest Nova Scotia is characteristic of greater than 60 other southern affiliated species of aquatic and terrestrial flora and fauna (Davis & Browne 1996b, p.262). This trend is likely explained by post-glacial warming and cooling following the most recent glaciation event (Davis & Browne 1996a, p.57-59). These results provide additional support for the contention that the population is isolated at the periphery of the species range. Therefore, it may be important to the maintenance of the species' genetic diversity and ability to adapt to environmental change, and as a source of future speciation events (Lesica & Allendorf 1995).

The results of an information-theoretic modeling approach to investigate the relationship between the magnitude of eastern pipistrelle activity and landscape factors failed to provide evidence that eastern pipistrelles select roosting areas that are in close proximity to foraging areas at the landscape scale in southwest Nova Scotia. Based upon radio telemetry studies in summer 2003-04, we know that female eastern pipistrelles roost almost exclusively in old man's beard lichen (*Usnea* spp.) usually in spruce tree species (Quinn & Broders, unpublished data). The results of this study however are based almost entirely on the behaviour of female members of the population and the roosting ecology of male eastern pipistrelles in the region remains unclear.

It was expected that activity levels of the eastern pipistrelle would be associated with the area of spruce and balsam fir dominated forest stands within commuting distance of sample sites. An association between their activity and expected roosting habitat was not detected, suggesting that they are either selecting sites based on smaller-scale characteristics not captured at the landscape scale and that are more appropriate for studies of their roosting ecology at the level of the forest stand, or that they are selecting areas at the landscape scale that are not appropriately captured by the resolution of the forest inventory data used in this analysis.

As predicted, their activity levels did have a negative relationship with non-forested land area, suggesting that eastern pipistrelles are less active in landscapes where forests are cleared for agriculture, settlements and timber production. This finding is consistent with large-scale studies conducted in agricultural landscapes (Limpens & Kapteyn 1991, Verboom & Huitema 1997). Therefore this forest dependent species may be negatively impacted by escalating forestry practices in the region which can eliminate

potential roosting habitat for bats, such that they must travel greater distances between appropriate roosting and foraging areas.

There are two important limitations to the conclusions that can be drawn from the results of this research that I would like to address before I conclude this thesis. They are related to the use of ultrasonic monitoring to investigate activity patterns of bat species. The first is that individuals cannot be differentiated using ultrasonic techniques and therefore estimates of population size cannot be drawn from activity levels alone. The echolocation data presented in this paper represent an index of activity alone and can not be used as estimates of population size. Second, males and females cannot be differentiated based on the structure of their echolocation calls. Very little is known about the roosting ecology of male eastern pipistrelles in the Nova Scotia population, but males and females of many bat species often adopt ecologically distinct behavioural strategies due to differences in the costs of reproduction. In New Brunswick, for example, Broders (2006) investigated the habitat use and distribution of two vespertilionid bat species and found that they are best represented by four ecologically distinct groups based on species and gender, suggesting that accurate assessment of bat habitat use requires an understanding of the differences in the spatial and temporal aspects of habitat selection between genders. This factor may also help to explain the lack of distinct vegetation associations at the landscape scale because of the potential differences in resource requirements between males and females.

## **4.2 Future Research Directions**

Important aspects of the distribution and activity patterns of this peripheral population of eastern pipistrelles as they relate to landscape context in southwest Nova Scotia have been revealed through this research; however many aspects of their ecology remain unknown. Thorough understanding of their local resource requirements is important because we do not yet have a good understanding of the significance of the population, though all of the current data suggests that they are isolated at the northern periphery of their range. Here I outline a series of research directions that I perceive as most critical to improve our knowledge of the ecology and conservation value of this population.

1. The landscape scale assumptions of this research were based on local scale roost-site selection by colonies of females captured at one location within their summer distribution. A better understanding of their roost-site selection and roost area requirements at additional locations would be beneficial to improve understanding of their roost site selection at the landscape-scale.
2. An analysis of the genetic divergence of this population of eastern pipistrelles from other populations located throughout their range will give some insight into the amount of movement, if any, that occurs between the Nova Scotia population and populations further south. This will help us to assess the significance of this population.
3. Studies conducted at Kejimikujik National Park revealed that individuals captured on a given night travel up to five kilometers to their roost sites in the same night (Quinn & Broders, unpublished data). It may be, however, that they typically travel much

shorter distances. Additionally, it is unknown how site factors such as forest type (species composition), age and density influence foraging activity at river sites. An in-depth examination of foraging area selection and the spatial extent of movement of foraging eastern pipistrelles would help address these questions.

4. Finally, a critical aspect of the ecology of this species relating to its viability in the region and that represents the largest gap in our understanding of the dynamics of this population is regarding their winter ecology. Disturbance at hibernacula could represent a serious threat to the eastern pipistrelle population in Nova Scotia. Several known hibernacula in the region have been monitored since 2003 and, although eastern pipistrelles have been captured, sufficient numbers to account for the region's summer population have not been recorded. Therefore, we do not know where they are hibernating or whether most individuals in the population are using a single hibernacula or several. Determination of where they are hibernating, the timing of their arrival at hibernacula and what potential threats to those sites exist is vital to understanding their ecology in the region. As a result, the vulnerability of the population to disturbance during the winter is unclear.

### 4.3 Literature Cited

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## 5.0 Appendices

### 5.1 Pearson Correlation Coefficients of the Predictor Variables

The matrices of Pearson correlation coefficients (Systat 12, Systat Software Inc.) of eastern pipistrelle activity and the predictor variables (Table 3.1) recorded at river sites in southwest Nova Scotia from June to August 2005 and 2006.

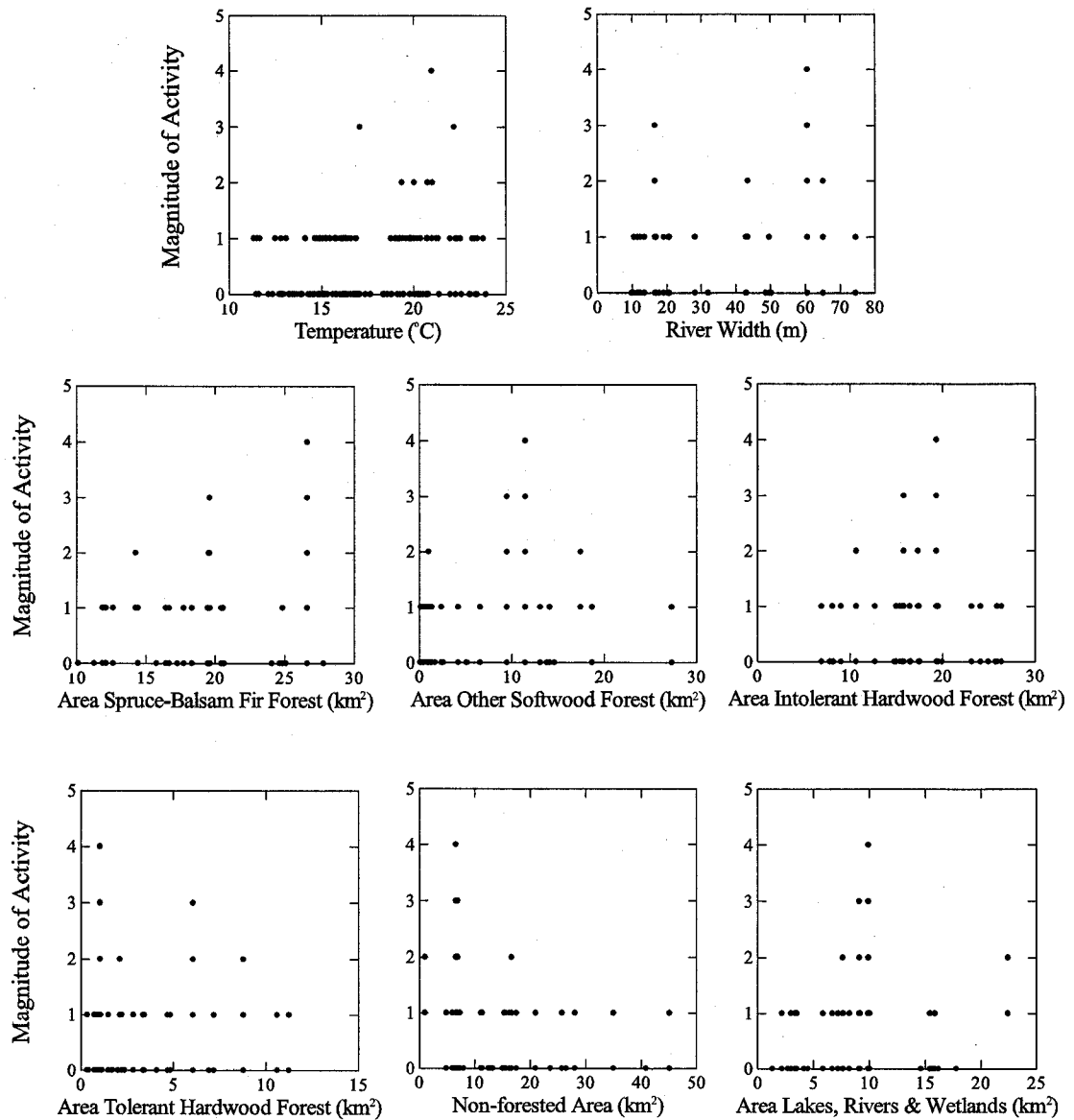
**Table 5.1.1.** Data recorded at sites sampled in 2005.

	act	temp	rwth	aihw	anon	aosw	aspb	athw	awet
act	1.00								
temp	0.22	1.00							
rwth	0.12	0.31	1.00						
aihw	0.01	-0.32	-0.21	1.00					
anon	-0.19	-0.22	-0.31	-0.20	1.00				
aosw	0.21	0.39	0.40	-0.30	-0.62	1.00			
aspb	-0.01	0.19	0.05	-0.16	-0.28	-0.04	1.00		
athw	0.11	0.01	0.19	-0.04	-0.25	0.10	-0.21	1.00	
awet	0.11	0.11	0.22	-0.10	-0.60	0.41	0.00	-0.05	1.00

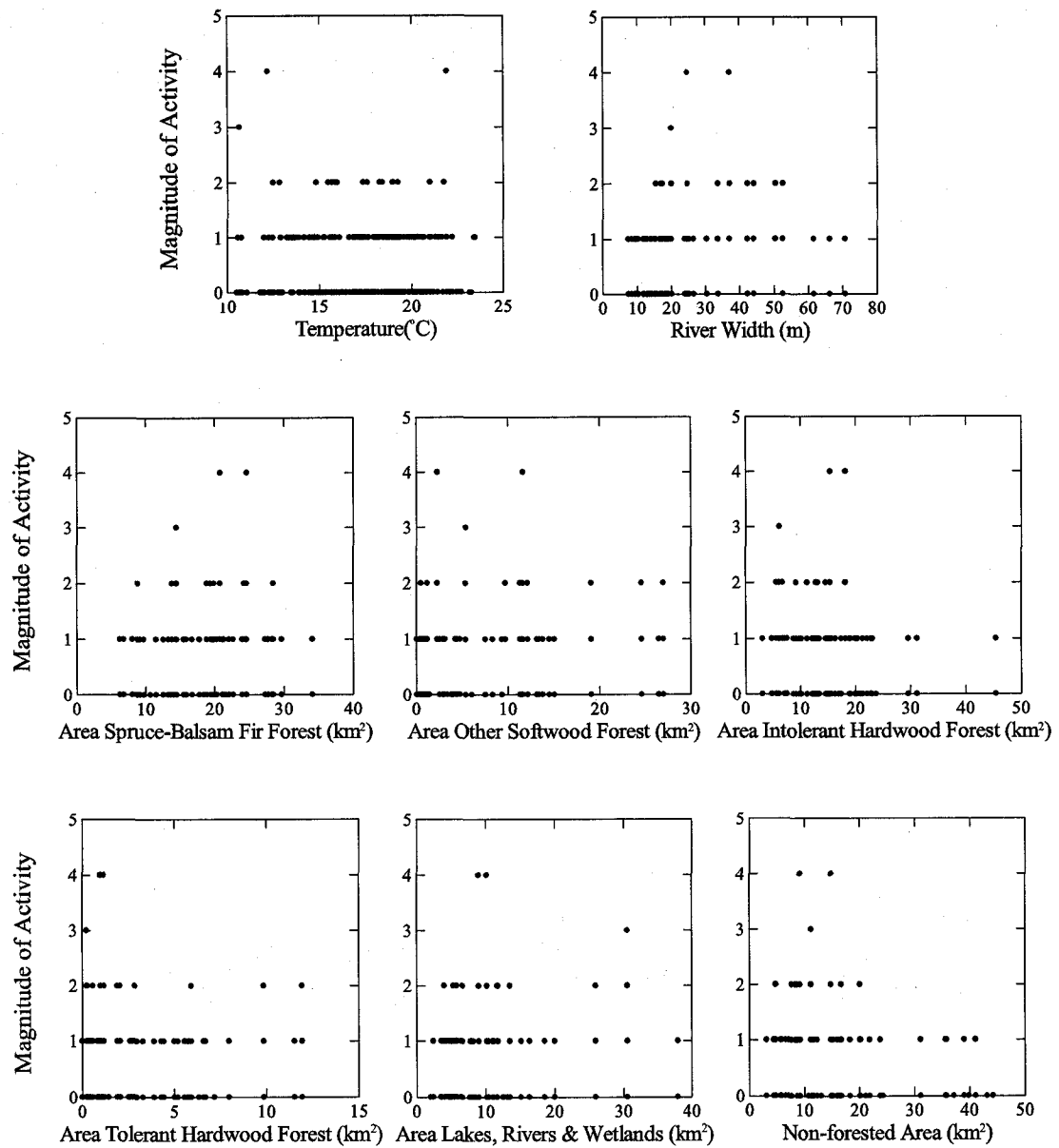
**Table 5.1.2.** Data recorded at sites sampled in 2005.

	act	temp	rwth	aihw	anon	aosw	aspb	athw	awet
act	1.00								
temp	-0.02	1.00							
rwth	0.19	-0.06	1.00						
aihw	-0.08	0.04	-0.20	1.00					
anon	-0.21	0.13	-0.35	0.02	1.00				
aosw	0.16	-0.13	0.57	-0.36	-0.51	1.00			
aspb	0.11	-0.08	0.16	-0.24	-0.55	0.22	1.00		
athw	0.02	0.00	0.13	-0.07	-0.10	0.07	-0.11	1.00	
awet	0.07	-0.04	0.09	-0.34	-0.44	0.17	-0.03	-0.23	1.00

## 5.2 Scatterplots of Eastern Pipistrelle Activity with the Predictor Variables



**Figure 5.2.1.** Scatterplots of the magnitude of eastern pipistrelle activity (0.0 = no echolocation calls, 1.0 = 200 calls) recorded at river sites in southwest Nova Scotia from June to August 2005 with each of the predictor variables investigated using Poisson family (link = log) generalized linear regression models.



**Figure 5.2.2.** Scatterplots of the magnitude of eastern pipistrelle activity (0.0 = no echolocation calls, 1.0 = 200 calls) recorded at river sites in southwest Nova Scotia from June to August 2006 with each of the predictor variables investigated using Poisson family (link = log) generalized linear regression models.