IDENTIFICATION AND CHARACTERIZATION OF SWARMING SITES USED BY BATS IN NOVA SCOTIA

by

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ABSTRACT

For insectivorous bats living in temperate areas such as Nova Scotia, underground sites are a critical resource for over-wintering, as well as for swarming in the late summer and early fall, which is when mating occurs. The objectives of this study were to 1) identify additional abandoned mines and caves in Nova Scotia that are important swarming sites, and 2) quantitatively characterize factors which best differentiate between caves and mines that are used for swarming/hibernating, and those that are not. Acoustic and/or trapping surveys of 17 abandoned mines and nine caves in Nova Scotia were conducted in 2010. Five site characteristics were analysed to explain differences between used and unused sites. Surveys indicated that twelve of the 26 sites are used by bats during the swarming period. Results of a logistic regression analysis of nine *a priori* selected models indicated that chamber length was the best predictor of swarming.

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CHAPTER 1: INTRODUCTION

1.1 Background

Worldwide, as landscapes become increasingly altered by human activity, wildlife conservation plays an important role in the protection of natural ecosystems (Groom, Meffe & Caroll 2006). Activities such as urbanization, forest harvesting and mineral extraction can threaten the resources that native wildlife needs to survive. In the 2008 IUCN Red List of Threatened Species, 38% of all species evaluated were listed as threatened with extinction (Vie, Hilton-Taylor, & Stuart 2009). Sadly, this figure has increased every year since 2000. Human activities are largely to blame, with habitat loss representing the number-one cause of extinctions (Pimm & Raven 2000; Vie et al. 2009). With the loss of habitat posing such a large threat, the protection of habitat resources is critical in conservation efforts (Groom et al. 2006; Pimm & Raven 2000; Racey & Entwistle 2003).

In North America, bats (order Chiroptera) are increasingly becoming a conservation priority. This unique group of animals is found on every continent except Antarctica, and make up one quarter of all mammal species (Altringham 1996). The order Chiroptera consists of two sub-orders: Megachiroptera and Microchiroptera. Megachiroptera are referred to as flying foxes or fruit bats, and are found in tropical regions. Microchiropteran bats have a larger global distribution, are generally smaller in size, and locate their prey using echolocation (Altringham 1996), as opposed to olfactory cues and vision which are used by megachiropteran bats (Dumont 2003). In high latitudes, all bats belong to the Microchiroptera. These bats rely on a suite of resources, one of the most critical of which is underground sites, such as caves and abandoned mines.

In temperate locations, the winter months provide a challenge for many mammals, including bats. Bats have had to adapt to survive the cold temperature and absence of food resources of the winter. Bats use one of two methods to deal with these harsh conditions (Kunz & Fenton 2003). The first is migration, which involves physically escaping the winter through a change in location. Migratory bat species travel thousands of kilometres to spend their winters in warmer areas (Fleming & Eby 2003). The second method is hibernation, which is more commonly used by temperate bats (Speakman & Thomas 2003). During hibernation, bats lower their metabolic rates and body temperature to conserve energy (Lyman et al. 1982). Fat resources are accumulated during the fall so that bats can enter hibernation with enough energy stores to survive until the spring (Kunz, Wrazen, & Burnett 1998; Young 1976). Many caves provide ideal conditions for hibernation as they have stable, above-freezing temperatures and high levels of humidity (Brack 2007; Briggler & Prather 2003; Humphries, Speakman, & Thomas 2006; Ingersoll, Navo, & de Valpine 2010). Bats have also taken advantage of underground spaces created by humans. Abandoned mines often create suitable conditions for hibernation, and bats are known to use many such sites (e.g., Altringham 1996; Fenton 1969; Glover & Altringham 2008). Hibernation sites, also referred to as hibernacula, are a critical habitat component and as such are an important consideration in the conservation of bats (Fenton 1997; Racey & Entwistle 2003).

In the context of bat ecology, caves are most well known and well studied as hibernacula (Parsons & Jones 2003). However, underground sites are also extremely important for bats during the autumn swarming period which occurs prior to hibernation. Swarming involves the congregation of flying bats in and around the entrances to underground sites in the late summer and autumn, where they many engage in social behaviours such as chasing (Davis & Hitchcock 1965; Fenton 1969; Ingersoll et al. 2010; Thomas & Fenton 1979). Most of these sites are also used as hibernacula (Fenton 1969; Glover & Altringham 2008; Ingersoll et al. 2010). Groups of swarming bats often contain several species and are dominated by males, especially early in the swarming period (Davis & Hitchcock 1965; Furmankiewicz 2008; Parsons, Jones, Davidson-Watts, et al. 2003; Thomas & Fenton 1979).

Swarming may have several functions. The major purpose of swarming is for courtship and copulation (Fenton 1969; Rivers, Butlin, & Altringham 2005; Thomas & Fenton 1979), which makes these sites extremely important for gene flow (Furmankiewicz & Altringham 2007). This may explain why the sex ratios are male-biased during swarming, as males have more to gain by putting more energy into courtship and mating more frequently (Ingersoll et al. 2010). It has also been suggested that swarming is used to assess and select hibernation sites, or to help familiarize young of the year with these over-wintering sites (Fenton, 1969). Bats can have high fidelity to one swarming site throughout their lives (Parsons & Jones 2003; Rivers, Butlin, & Altringham 2006).

In Nova Scotia, the location of many caves and abandoned mines is known (Moseley 2007b; NSDNR 2009), some of which have records of bat activity (Moseley 2007, Lynne Burns, Unpublished Data). Within the Broders Lab at Saint Mary's University, bat biology at six hibernacula/swarming sites is extensively studied. Another fifteen sites with records of bat activity have been identified in a report (Moseley 2007b). However, the records for some of these sites date back to the 1960s and 1970s and no work has been done since this time. As a result, this report urges further work to determine the importance of many of the sites. This lack knowledge gap is addressed in this thesis. Furthermore, very little is known about which factors affect the use or suitability of sites for swarming and/or hibernating in this region. Both local and landscape variables may be important for site selection by bats (Loeb & O'Keefe 2006; Zimmerman & Glanz 2000), and little is known regarding preferences at both scales in Nova Scotia.

Studies that have investigated internal cave characteristics indicate that consistent, cool temperatures and high levels of humidity are required for hibernation (Brack 2007; Ingersoll et al. 2010; Raesly & Gates 1987). However, only a few studies (Glover & Altringham 2008; Johnson, Wood, & Edwards 2006) have investigated which, if any, external characteristics are important in selecting swarming and hibernation sites. From a practical management standpoint, external factors may be important as they are more accessible to resource managers. The ability to identify important sites from the outside would be helpful to the conservation of swarming and hibernation sites (Johnson et al. 2006).

1.2 Species Information

Seven species of bats have been recorded in Nova Scotia, which include *Myotis lucifugus* (little brown bat), *M. septentrionalis* (northern long-eared bat), *Eptesicus fuscus* (big brown bat, unconfirmed), *Pipistrellus subflavus* (tri-coloured bat), *Lasiurus borealis* (red bat)*,* *L. cinereus* (hoary bat), and *Lasionycteris noctivagans* (silver-haired bat) (Broders, Quinn, & Forbes 2003; Taylor 1997). Of these, *M. lucifugus* and *M. septentrionalis* are the two most abundant species in the province (Broders et al. 2003) and will be the focal species for this study. *Perimyotis subflavus* (tricoloured bat) is also present and frequently observed in Nova Scotia, but is much less understood and has a restricted distribution (Farrow & Broders 2010). Little is known about where this species over winters and swarms in the province.

Myotis lucifugus and *M. septentrionalis* have many similarities. These two species engage in swarming activities in the autumn and spend their winters in hibernation. In the spring, summer and fall, both species are commonly found in the forests of Nova Scotia (Broders et al. 2003). Fresh water is an important habitat component and bats are frequently found over or near ponds or lakes. Creeks, streams and forested trails are also important, as they are used as commuting corridors (Caceres & Barclay 2000; Fenton & Barclay 1980; Zimmerman & Glanz 2000).

Bats are nocturnal and use echolocation to locate their prey (Kunz & Fenton 2003). The species found in Nova Scotia are insectivores and catch prey in their wing or tail membranes during flight (Altringham 1996). Average body mass varies through the year and range from 5 to 9 grams for *M. lucifugus* and *M. septentrionalis* (Burt & Grossenheider 1976; Caceres & Barclay 2000).

While there are many similarities, *M. lucifugus and M. septentrionalis* also have several important differences. One pertains to roosting patterns and habitat use. *Myotis septentrionalis* is forest-dependant and almost exclusively chooses day-roosts in trees (Menzel 2002; Lacki, Hayes, & Kurta 2007). Foraging also occurs in forests, and while both species can both glean and hawk their prey, *M. septentrionalis* is more specialized in gleaning than is *M. lucifugus* (Faure, Fullard, & Dawson 1993; Ratcliffe & Dawson 2003). *Myotis septentrionalis* may use forest edges or trails to feed and commute, but does not generally venture into open areas (Henderson & Broders 2008). *Myotis lucifugus*, conversely, is less forest-dependant and will readily use human structures such as barns or attics as day-roosts. This species often feeds aerially over water bodies such as ponds, lakes and streams (Fenton & Barclay 1980), and as such, aquatic insects make up a large proportion of their diet (Belwood & Fenton 1976).

During the spring and summer, females of both species form maternity colonies, where they give birth and raise their young (Caceres & Barclay 2000; Fenton & Barclay 1980; Humphrey & Cope 1976; Jong 1985). These groups are generally much larger for *M. lucifugus* and can be composed of tens to hundreds of bats (Caceres & Barclay 2000; Fenton & Barclay 1980). Males of both species tend to roost alone or in small groups during this time and are not involved in the rearing of young (Caceres & Barclay 2000; Fenton & Barclay 1980; Humphrey & Cope 1976; Jong 1985). Due to the reproductive demands of birth and lactation, female bats face greater energetic challenges (Kurta, Bell, & Nagy 1989). This influences roost selection, movement patterns and the use of torpor (Barclay 1991; Willis, Brigham, & Geiser 2006).

While this study focuses only on Nova Scotia's bat species, the applications are much more widespread. *Myotis lucifugus* and *M. septentrionalis* are representative of many other temperate hibernating bat species. Inferences drawn from this study can potentially be applied to other bat species.

1.3 White-Nose Syndrome

It is currently an important time for bat research in North America due to the threat of white-nose syndrome (WNS). White-nose syndrome is associated by the fungus *Geomyces destructans,* and was first discovered in New York State in 2006 (Blehert et al. 2009; United States Fish and Wildlife Service 2011b). Since its discovery, WNS has killed more than a million bats (Frick et al. 2010). The *G. destructans* fungus is cold-loving, and thrives in cave conditions (Blehert et al. 2009). As such, it affects the North American bat population directly during the winter hibernation period. While the cause of death of bats with WNS is still largely unknown, one hypothesis suggests that the presence of *G. destructans* on the muzzles and wing membranes of bats causes them to wake more often than they would naturally during hibernation (Blehert et al. 2009; Frick et al. 2010). Bats must raise their body temperature upon arousal and maintain it during the period during which they are awake. This is energetically costly and causes bats to deplete their energy stores prematurely and according to this explanation, bats ultimately die of starvation (Boyles & Willis 2010). The mortality rates at some caves affected by WNS have been 90-100%, and six species have been affected by the pathogen thus far (United States Fish and Wildlife Service 2011a). One of the most common bat species, *M. lucifugus,* has been the hardest hit, leading researchers to believe that WNS could lead to local extinctions of *M. lucifugus,* as well as other species (Frick et al. 2010).

Since the initially discover of WNS in New York, it has spread throughout the eastern United States and eastern Canada, with the most rapid direction of movement to the southwest. The fungus was first recorded in Canada during the winter of 2010 in Ontario, and has since been recorded to Quebec and New Brunswick (United States Fish and Wildlife Service 2011b). In April of 2011, WNS was confirmed in Nova Scotia on a day-flying bat found in Hants County (NSDNR 2011). Researchers are not aware of any mass die-offs in Nova Scotia at this stage; however, the outlook for the 2011-2012 hibernation season is grim.

This project came about largely in response to the need for baseline data in Nova Scotia. Information regarding the location of swarming and hibernation sites, as well as indices of bat activity at these locations, will be fundamental in assessing the impacts of WNS. This research aims to develop a more comprehensive inventory of swarming sites in Nova Scotia, and to gain an understanding of how bats select these sites in order to gain insight into the fall and winter distribution of these populations.

1.4 Research Goal and Objectives

This thesis aims to contribute to the understanding of bat biology in Nova Scotia by identifying and characterizing underground sites used by bats during the fall swarming season. The goal of the study is to differentiate between caves and mines use for swarming and those that are not to identify priorities for swarming site conservation.

The research objectives of this thesis are twofold:

1) Identify additional abandoned mines and caves in Nova Scotia that are important swarming sites.

2) Quantitatively characterize factors which best differentiate between caves and mines that are used for swarming/hibernating, and those that are not.

CHAPTER 2: SWARMING SITE USE AND SELECTION BY LITTLE BROWN AND NORTHERN LONG-EARED BATS IN NOVA SCOTIA, CANADA

Note: Chapter two is written as a stand-alone manuscript with the intention of publication. For this reason, there is some repetition in the content.

2.1 Abstract

For bats, one of the most critical habitat components is the underground sites used for hibernation and mating. Beginning in late summer, bats congregate and mate at caves and abandoned mines in an activity known as swarming. In Nova Scotia, the location of several such sites are known and documented. However, many abandoned mines and caves exist that have not been surveyed for bats, so it is not possible to reliably determine the ecological significance of these sites. The objectives of this study were to 1) identify abandoned mines and caves that are used by *Myotis lucifugus* (little brown bat) and *M. septentrionalis* (northern long-eared bat) for swarming and hibernation and 2) quantitatively characterize factors which best differentiate between caves and mines that are used for swarming/hibernating, and those that are not. Acoustic and/or trapping surveys were conducted at 17 abandoned mines and nine caves in Nova Scotia that were either previously known to be hibernacula (n=5) or were selected based on their potential to have significant number of bats (n=21), as informed by publically available data. Of bats captured, 55% (n=797) were *M. lucifugus* and 45 % (n=661) were *M. septentrionalis*. Acoustic and/or trapping data suggest that at least 12 of the 26 sites were swarming sites (including 7 newly identified sites). Logistic regression analysis of nine *a priori* selected models was used to determine the extent to which each of five variables (chamber length, entrance size, degree of shelter at entrance, area of forest in surrounding landscape and total stream length in surrounding landscape) differentiate between swarming and non-swarming sites. When ranked by AIC_c, the top model included chamber length and degree of shelter. Of the five explanatory variables, chamber length was the best predictor of whether a site was used for swarming. The swarming sites identified should be monitored for white nose syndrome and targeted for conservation initiatives.

2.2 Introduction

Species require a suite of resources that may vary seasonally, which can pose a challenge to the scientific understanding of habitat needs, and the management decisions that this science informs (Racey & Entwistle 2003). Small, temperate insectivorous mammals, such as bats, face challenges in the winter months due to cold temperatures and a lack of food availability (Fleming & Eby 2003). This creates a potential energy imbalance as animals cannot maintain a high, stable core temperature without food to replenish energy outputs (Speakman & Thomas 2003). Hibernation is a strategy used widely by mammals, including bats (order *Chiroptera*), in temperate locations and involves entering a torpid state throughout the winter months (Lyman et al. 1982; Speakman & Thomas 2003). In Atlantic Canada, the two most common species of bats are hibernators and depend on underground sites, including both caves and abandoned mines (e.g., Caceres & Barclay 2000; Davis & Hitchcock 1965; Fenton & Barclay 1980; Moseley 2007b) throughout the winter months. These locations serve as a refuge from the often sub-zero temperatures and facilitate energy conservation through a decrease in metabolic rate and body temperature (Altringham 1996; King & Murphy 1985). Choosing a suitable over-wintering site that has a stable, above-freezing microclimate is critical to ensure survival (Brack 2007; Briggler & Prather 2003; Humphries, Speakman, & Thomas 2006; Ingersoll, Navo, & de Valpine 2010).

Bats often congregate at caves and abandoned mines during the late summer and early fall in an activity called 'swarming'. During swarming, bats of many species fly in and around the entrances to underground sites (Davis & Hitchcock 1965; Fenton 1969; Hall & Brenner 1968; Ingersoll et al. 2010; Parsons, Jones, Davidson-Watts, et al. 2003;

Thomas & Fenton 1979). Most swarming sites are also used as hibernacula (Fenton 1969; Glover & Altringham 2008; Ingersoll et al. 2010). In contrast to the summer when bats tend to be fairly isolated in either maternity colonies (females), alone or in small groups (males) (Broders & Forbes 2004; Humphrey & Cope 1976), swarming involves the assembly bats from distant locations. A major function of swarming is mating (Fenton 1969; Furmankiewicz & Altringham 2007; Rivers et al. 2005; Thomas & Fenton 1979). However, it has also been suggested that high levels of activity may be partially the result of adults showing their young-of-the-year potential hibernation sites (Fenton 1969). Regardless, these sites merit special attention for conservation purposes (Furmankiewicz & Altringham 2007; Parsons & Jones 2003)..

Currently, the need for bat conservation in North America is critical. White-nose syndrome (WNS), which is associated with the fungus *Geomyces destructans*, has been spreading in the eastern United States and eastern Canada since it was first discovered in 2006 in New York (United States Fish and Wildlife Service 2011b). White-nose syndrome is associated with the death of over a million bats (Frick et al. 2010). In March of 2011, WNS was discovered in Berryton Cave, New Brunswick, which represented the first confirmation of the fungus in Atlantic Canada (New Brunswick Museum, personal communication). Less than a month later, WNS was also confirmed in Nova Scotia (NSDNR 2011). Baseline data regarding critical habitat in the province is essential to our ability to monitor WNS, understand its impacts and implement any potential conservation initiatives.

There are several known swarming and hibernation sites in Nova Scotia. However, there are also hundreds of abandoned mines and natural caves that have not been adequately surveyed for bats. The goal of this study was to get a more complete inventory of sites used by swarming and overwintering bats on the mainland of Nova Scotia, Canada by using publically accessible data to identify potential hibernation sites and surveying these sites during swarming. I assumed that swarming sites would also be hibernation sites. Expanding the current inventory of underground used for swarming will permit these sites to be monitored and protected. Two bat species are commonly found in Nova Scotia: *Myotis lucifugus* (little brown bat) and *M. septentrionalis* (northern long-eared bat). These two species are both forest dependant, insectivorous bats that commonly swarm and hibernate at the same underground sites. Specifically, I had two research objectives:

1) Identify additional abandoned mines and caves in Nova Scotia that are important swarming sites.

2) Quantitatively characterize factors which best differentiate between caves and mines that are used for swarming/hibernating, and those that are not.

2.3 Methods

2.3.1 Study Area

Research took place on mainland Nova Scotia. The province is part of the Acadian forest region, which is a transition zone between the coniferous boreal forest to the north (spruce-fir forest), and the deciduous region to the south (rich tolerant hardwood forest) (Davis & Browne 1996; Loo & Ives 2003). The geological history of Nova Scotia has resulted in a wide range of rock types across the province, which gives rise to diverse habitat types. Caves have formed in areas where limestone or gypsum dominates. Over time, rainwater containing carbonic acid has dissolved these rock types to form cavities that can eventually develop into cave habitats (Davis & Browne 1996).

The natural landscape of Nova Scotia has been heavily affected by human activities, such as forest harvesting and mining, since settlement by Europeans in the 17th century (Loo & Ives 2003). Nova Scotia has a long history of mining that has included the extraction of coal, copper, iron, gypsum, gold and salt resources (Davis & Browne 1996). This practice has resulted in hundreds of abandoned mines across the province, many of which have entrances that have never been sealed off (NSDNR, 2009). Given that bats will readily inhabit abandoned mines (e.g., Caceres & Barclay 2000; Fenton & Barclay 1980; Moseley 2007b), any of these sites that are accessible to bats are potentially important swarming and hibernation sites.

2.3.2 Study Sites

The Nova Scotia Department of Natural Resources (NSDNR) Abandoned Mine Openings database (DP ME10, Version 4, 2009) containing over 7000 mines in the province was queried to select a list of sites that have the greatest potential to be hibernation sites. This database was queried to exclude all sites that had been capped or filled in, had collapsed, flooded, or were not on the mainland. To incorporate natural caves, literature from the Nova Scotia region was consulted (Moseley 2007a, 2007b). Next, consultation took place with experts, including several employees of NSDNR and one local caver, resulting in a reduced list of approximately 30 underground sites. Each potential study site was visited with someone who knew the location well prior to data collection to determine the feasibility of the location as a study site based on accessibility and safety concerns.

2.3.3 Data Collection Methods

Although variable by latitude, swarming occurs between the beginning of August and the end of October in the northern hemisphere (Parsons, Jones, Davidson-Watts, et al. 2003). To avoid the early and late stages of swarming where activity can be lower (Parsons, Jones, & Greenaway 2003), data were collected only between August 15th and September 21st.

Surveys were conducted in two stages. First, acoustic detectors (Anabat II, Titley Electronics, Ballina, Australia) were deployed at the cave or mine entrance and left for a minimum of three rain-free nights. This technique is commonly used in bat research (Broders 2003; Fenton 2003; Parsons & Szewczak 2009) as it enables researchers to monitor bats passively (Parsons, Jones, & Greenaway 2003). If acoustic results showed activity levels that did not exceed what was expected on a typical summer night, I considered there to be no evidence of swarming and no further surveying was conducted. Conversely, if data did indicate elevated levels of activity, a trapping survey was conducted by deploying a harp trap (Austbat Research Equipment, Lower Plenty, Victoria, Australia) directly in front of or next to the cave or mine entrance. Each site was trapped for a minimum of four hours beginning at sunset on two nights, with one exception. Trapping surveys were not conducted if the forecast indicated that rain would exceed 15 mm per 24-hr period (Berkova & Zukal 2010; Parsons, Jones, & Greenaway

2003). During trapping surveys, date, trapping hours and weather conditions were recorded. For each bat that was caught, sex and species were identified.

At each study site, values for five site characteristics were collected that described internal, entrance and external cave/mine characteristics. These variables were chosen based on features that have been identified previously as important characteristics of swarming and/or hibernation sites in the literature (Glover & Altringham 2008; Johnson et al. 2006; Raesly & Gates 1987) and include:

1) *Chamber length (m)*: Estimate of the sum of all chamber lengths within the cave or mine. Estimates were derived from the NSDNR Abandoned Mine Openings database (NSDNR 2009), other published reports (e.g. Moseley, 2007) or from the best estimates available (e.g., from a local caver). It is not known if sites have collapsed, filled with water, or have been otherwise altered in ways that would change chamber length since the estimate was made.

2) *Entrance opening size (m^2)*: area of entrance opening.

3) *Degree of shelter at entrance (%):* Shelter refers to the exposure to weather elements such as wind and rain. Two factors that affect degree of shelter are canopy cover and rock faces (Glover & Altringham 2008). A spherical densiometer (model A, Forest Densiometers, Canada) was used to measure canopy cover at the entrance to the mine/cave. Readings were taken at each of the four cardinal directions at the mine/cave opening and were averaged to determine percent canopy cover. To take into account protection from cliffs, it was assumed that mines/caves at the base of a rock face that was $\geq$ 5 m would be more sheltered from wind and rain than would other sites. For such sites, the canopy

cover for two of the four cardinal directions was set at 100%. This modification was expected to simulate the degree of shelter created by the cliff. As such, for these sites, the shelter variable was always ≥ 50%. For sites where no cliff was present, or the cliff was < 5 m high, canopy cover is equal to degree of shelter. In this case, degree of shelter ranges from 0 to 100%, where 0% represents an extremely exposed site, and 100% represents an extremely sheltered site.

4) *Total forested area in landscape (ha):* the total forest area in the surrounding 1257 ha (2000 m radius buffer), as determined by spatial analysis. A 2000 m buffer was selected based on the estimated maximum distance that either *M. lucifugus* or *M. septentrionals* will move on a summer night (Broders et al. 2006). While this work took place during the autumn, the goal of the buffer was to represent the distance that bats may travel in relation to habitat resources, and the 2000 m value was the best estimate available. Forested area was determined using spatial analysis (ArcGIS version 9.3, ESRI, California, USA) of the NSDNR Forest Resource Inventory (FRI) database. Area categorized as 'forest' in the FRI database was compared to 2010 LANDSAT imagery to ensure accuracy and to account for recent changes caused by forest harvesting. Areas shown to be recently cut in the satellite imagery were digitized and removed from the forest categorization.

5) *Total stream, river and creek lengths in landscape (m):* total length of streams, rivers, and creeks present in the surrounding 1257 ha (2000 m buffer). This was determined using spatial analysis (ArcGIS version 9.3, ESRI, California, USA) of the NSDNR water line layer. This layer contains only lines, no polygons.

2.3.4 Data Analysis Methods

To address objective one, both acoustic and trapping surveys were used to determine the dichotomy between swarming and non-swarming sites, and the single night of highest activity (# of bats caught per hour) was used when analysing trapping data. Sites that had no activity or low activity (specified as < 100 echolocation sequences recorded per night or < 6 bats caught per hour), were classified as *non-swarming* sites. This swarming/non-swarming dichotomy was determined by examining where natural breaks occurred in both the acoustic and trapping data. Conversely, sites with activity levels above the designated threshold were classified as swarming sites. For all analysis, *M. lucifugus* and *M. septentrionalis* captures were combined and analysed as one group. These species swarm together at the same sites (Brack 2007; Johnson et al. 2006; Raesly & Gates 1987), suggesting that their site preferences may be similar.

Logistic regression models were used to differentiate between the swarming and non-swarming sites. Nine *a priori* candidate models were chosen based on current knowledge of the biology of *M. lucifugus* and *M. septentrionalis*. Each of the five explanatory variables occurred individually in a model, and chamber length appears once in combination with every other variable. Past studies show strong support for chamber length as a determinant of bat presence during both swarming and hibernation (Glover & Altringham 2008; Raesly & Gates 1987). While it was expected to be an important predictor in the candidate models, the aim of including chamber length was to quantify the magnitude of effect size on the occurrence of swarming.

All statistical analysis was completed with the software R (version 2.11.1) (R Development Core Team 2010). A correlation matrix was constructed to ensure that there was no co-linearity among the five variables. A binomial family generalized linear model was used with a logit link. Akaike information criterion (AIC) values for a small sample size (AICc) were used to rank the goodness of fit of each model (Burnham & Anderson 2002). These values were then used to calculate Akaike weights (w_i). A weighted average of coefficient estimates and standard error of estimates across the models was calculated (Burnham & Anderson 2002). These model-averaged results were used to calculate the odds ratio for the all variables where the average standard error of coefficient estimates did not overlap zero (Hosmer & Lemeshow 2000).

2.4 Results

2.4.1 Swarming Site Inventory

The site selection process resulted in the identification of 21 previously unstudied underground sites on mainland Nova Scotia. Five swarming/hibernation sites that were known prior to this study were also included for objective 2, resulting in a final list of 26 study sites that include 17 abandoned mines and nine natural caves (Figure 1, Table 1).

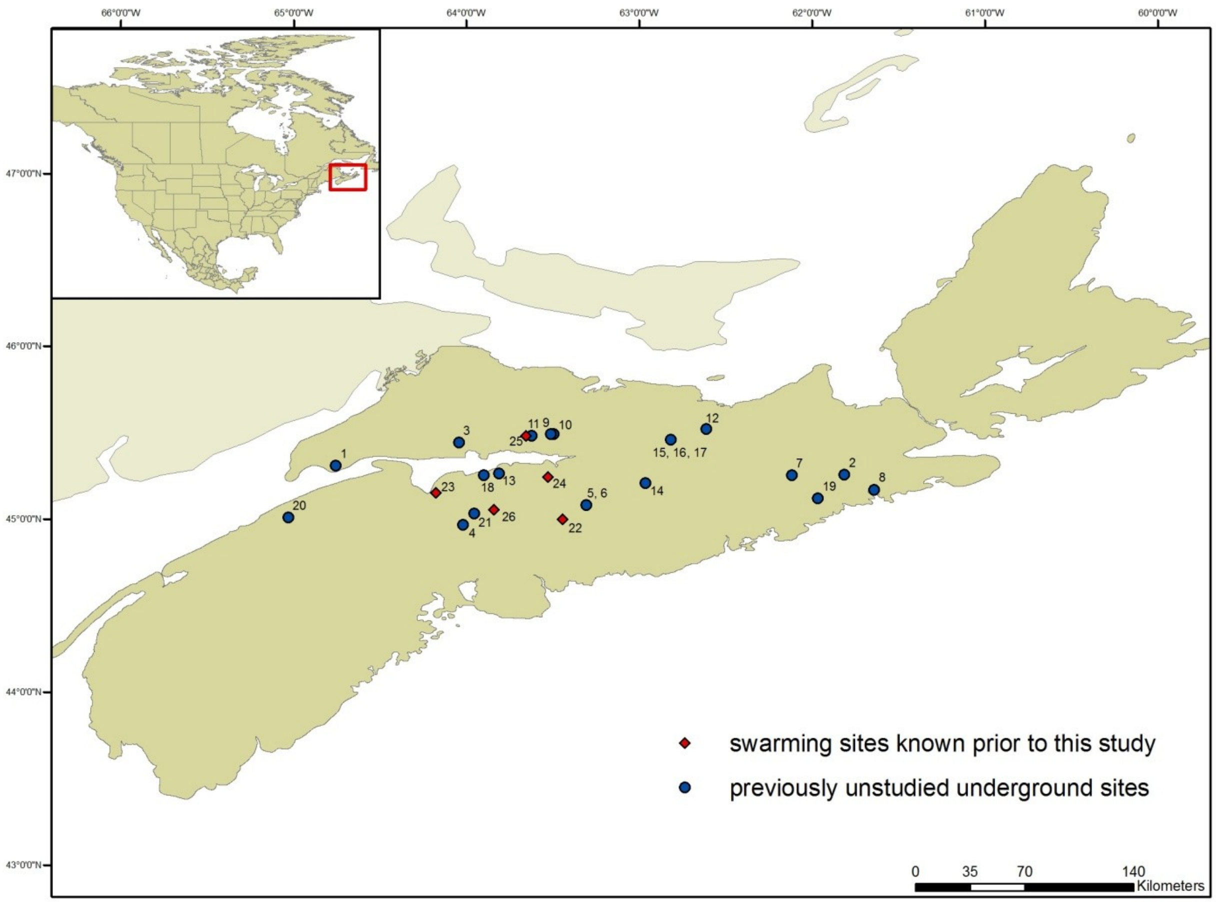

Figure 1 Location of study sites (nine natural caves and 17 abandoned mines) on mainland Nova Scotia that were surveyed for bat activity. Blue circles represent study sites surveyed for the first time in this study. Red diamonds represent swarming sites/hibernacula known prior to this study. Numbers correspond with descriptions of sites in table 1.

Table 1 List and description of the 26 underground study sites surveyed for bat activity. Sites 1 to 21 were previously unstudied; sites 22 to 26 are swarming/hibernation sites known prior to this study. Numbers correspond with the location of each site shown in figure 1.

STUDY SITE NAME		COUNTY	DESCRIPTION
1	Cape D'Or Shaft	Cumberland	Abandoned copper mine shaft
2	Country Harbour Shafts	Guysborough	Abandoned gold mine shafts
3	Five Islands Adit	Colchester	Abandoned barite mine shaft
4	Frenchmans Cave	Hants	Gypsum cave
5	Gay's River Adit 3	Colchester	Abandoned gold mine adit
6	Gay's River Adit 4	Colchester	Abandoned gold mine adit
7	Glenelg Adit	Guysborough	Abandoned lead mine adit
8	Isaacs Harbour Shaft	Guysborough	Abandoned gold mine shaft
9	Reid Road Adit	Colchester	Abandoned iron mine adit
10	Slack Brook Adit	Colchester	Abandoned iron mine adit
11	Upper Road Adit	Colchester	Abandoned iron mine adit
12	McLellan's Brook Cave	Pictou	Limestone cave
13	Minasville Cave	Hants	Gypsum cave
14	Natural Bridge Cave	Colchester	Gypsum cave
15	New Lairg Adit 1	Pictou	Abandoned copper mine adit
16	New Lairg Adit 2	Pictou	Abandoned copper mine adit
17	New Lairg Adit 3	Pictou	Abandoned copper mine adit
18	Peddler's Cave	Hants	Abandoned mine adit in limestone
19	Sherbrooke Adit	Guysborough	Abandoned gold mine adit
20	Vault Cave	Kings	Tectonic rift cave in Triassic basalt
21	Woodville Cave	Hants	Gypsum cave
22	Cave of the bats	Halifax	Gypsum cave
23	Cheverie Cave	Hants	Gypsum cave
24	Hayes Cave	Hants	Gypsum cave
25	Lear Shaft	Colchester	Abandoned iron mine shaft
26	Rawdon Mine	Hants	Abandoned gold min adit

During the trapping surveys of all 26 underground sites, three species of bats were captured; *M. lucifugus* (797), *M. septentrionalis* (661) and *P. subflavus* (4). Due to the low prevalence of *P. subflavus*, these individuals were not included in the analysis. The proportions of captures of *M. lucifugus* and *M. septentrionalis* varied greatly between sites.

Of the 21 previously unstudied sites surveyed during the fall of 2010, seven had recorded >100 echolocation sequences per night and/or >6 bats caught per hour, and were thus designated as swarming sites. These sites included four natural caves and three abandoned mine adits. Vault Cave in Kings Country showed the highest level of bat activity with 249 bats caught (an average of 49.8 captures per hour). This site had such high activity levels on the first night of trapping that it was categorized as a swarming site and a second night of trapping was deemed unnecessary. The lowest number of captures at a location designated as a swarming site occurred at Reid Road adit, where nine bats were caught. However, trapping did not take place until late in the season (September 18) which may have contributed to low capture numbers. The acoustic data retrieved earlier in the season at Reid Road adit showed a high amount of activity (206 echolocation sequences/night), which justified the swarming site categorization.

The Natural Bridge Cave study site was not categorized as either *swarming* or *non-swarming*, and was thus excluded from further analysis. The acoustic detector malfunctioned at this site and only one night of trapping occurred, which resulted in insufficient data to confidently categorize bat activity.

The results of trapping surveys at certain sites, such as Vault Cave, Minasville Cave and Rawdon Mine, showed activity levels that were highly biased towards one of the two species. This bias did not always appear during both nights of trapping for a single site, which was the case for Minasville Cave and Rawdon Mine (Appendix A). Results shown are for the single night of data collection where the highest number of bats was caught for each particular site (Table 2).

Table 2 Trapping results for sites categorized as swarming site. The average number of bats captured per hour, for a minimum of four hours after sunset, is specified to standardize results among the sites.

		Capture Numbers		
Study Site	**Trap date**	**Total # *M. lucifugus***	**Total # *M. sepentrionalis***	**Total /hour**
Cave of the Bats	15-Aug	35	27	8.4
	09-Sep	1	36	6.4
Cheverie Cave	20-Aug	22	3	8.6
	07-Sep	9	9	3.6
Frenchmans Cave	29-Aug	4	33	6.4
	19-Sep	0	1	0.3
Glenelg Mine	06-Sep	31	29	12.6
	10-Sep	37	31	16.7
Hayes Cave	16-Aug	20	0	8.6
	21-Sep	47	2	11.4
Lear Shaft	19-Aug	88	49	17.3
	23-Sep	5	4	2.4
Minasville Cave	01-Sep	60	123	30.5
	16-Sep	61	44	14.3
Rawdon Mine	14-Aug	45	48	14.4
	18-Aug	42	84	18.4
Reid Road Adit	18-Sep	6	3	2.3
	21-Sep	0	0	0
Upper Road Adit	02-Sep	19	19	8
	12-Sep	6	1	1.8
Vault Cave	16-Sep	194	55	49.8
Woodville Cave	18-Aug	55	34	14.4
	14-Sep	5	0	1.3

2.4.2 Predictors of Activity: Site Characteristics

There were five models included in the ≥95% confidence set of models, each of which contained the chamber length variable. The top ranked model includes chamber length and degree of shelter at the entrance (Table 3). The next best model contained the terms chamber length and stream length in surrounding landscape, followed by chamber length on its own. For each of these variables, the directionality of the effect is consistent among the models and the standard error of the averaged coefficient estimate does not overlap zero (Table 4), suggesting that chamber length, degree of shelter and stream length in surrounding landscape may be important variables in predicting the occurrence of swarming.

Table 3 AICc values for the nine *a priori* models are shown. For the models that comprise ≥95% of the total Akaike weights ($\sum w_i$), delta AIC (Δ_i) values, weights (w_i) and sum of weights are also shown.

	Variables in Logistic Model	AICc	Δ_i	w_i	$\sum w_i$
1	chamber length, degree of shelter	23.630	0	0.337	0.337
2	chamber length, stream length	24.105	0.475	0.266	0.602
3	chamber length	24.690	1.060	0.198	0.801
4	chamber length, forest area	26.144	2.514	0.096	0.896
5	chamber length, entrance size	26.148	2.518	0.096	0.992
6	stream length	32.521	-	-	-
7	degree of shelter	33.451	-	-	-
8	forested area	35.811	-	-	-
9	entrance size	36.013	-	-	-

Table 4 Model-averaged coefficient estimates (β), standard error and odds ratios for the top three explanatory variables. Odds ratio refers to an increase in 50 m for chamber length, an increase of 10% for degree of shelter and an increase of 10 km for stream length. The 95% confidence interval (CI) is shown in brackets.

	Explanatory Variable	**Estimate (β)**	**Standard Error**	**Odds Ratio (CI)**
1	Chamber length	0.027	0.015	3.786 (16.208, 0.885)
2	Degree of shelter	-0.061	0.041	0.542 (1.208, 0.244)
3	Stream length	7.655e-05	5.863e-05	2.150 (6.784, 0.681)

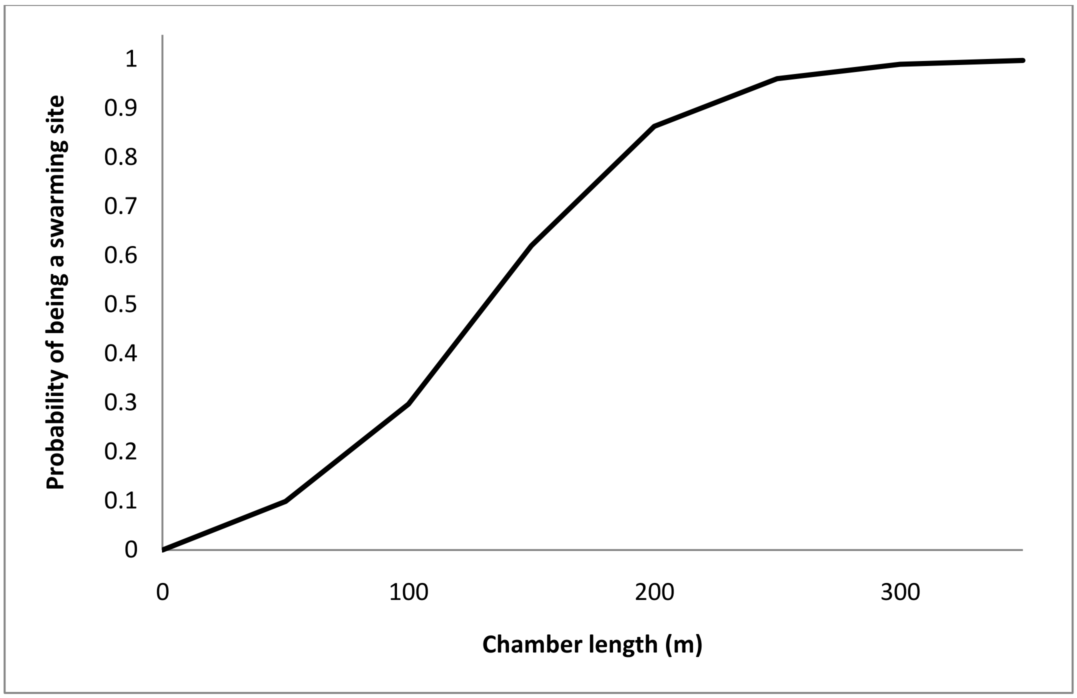

Figure 2 Model averaged predicted logistic curve showing the probability of being a swarming as predicted by chamber length.

As chamber length increases, so too does the probability of a site being used for swarming (Table 4, Figure 2). According to the model-averaged results, at a chamber length of more than 250 m, there is a 99% chance that the site will be used for swarming.

2.5 Discussion

It is well known that bats will readily inhabit abandoned mines (e.g., Altringham 1996; Caceres & Barclay 2000; Davis & Hitchcock 1965; Fenton & Barclay 1980; Moseley 2007b), and there are many cases of mines that are important swarming and hibernation sites, such as the Rawdon gold mine and Lear shaft in Nova Scotia. Of the 21 previously unstudied sites, four of the six natural caves and three of the 15 abandoned mines were found to be significant swarming sites for bats. The evidence with regards to bat use of abandoned mines suggests that the greater selection of natural caves for swarming in this dataset is not due to the fact that bats prefer natural caves, but is rather attributed to the preferable characteristics of these sites, such as long chamber lengths.

Results indicate that it may be possible to differentiate between underground sites that are used for swarming and those that are not based on site characteristics. Of the five characteristics measured in this study, chamber length was the best variable for predicting the occurrence of swarming. This result is consistent with the literature (Briggler & Prather 2003; Glover & Altringham 2008; Raesly & Gates 1987). The effect size of this variable is large, with an odds ratios that indicates when chamber length increases by 50 the odds of being a swarming site increases by 3.79 times until a length of 250 m is reached. Chamber length is the only variable that represents an internal site characteristic, which could suggest that internal features are especially important to bats. This may be due to the strong link between swarming and hibernation sites (Fenton 1969; Glover & Altringham 2008; Ingersoll et al. 2010). If bats are hibernating where they swarm, it is logical that they would select swarming sites that have conditions conducive to hibernation. Chamber length may influence microclimate in hibernacula as the deeper parts of longer caves are better buffered from external conditions (Briggler & Prather 2003). No internal microclimate variables were measured for this study, but it is likely that because cave temperature and humidity are critical factors for hibernation, they are also important in swarming site selection (Altringham 1996; Brack 2007; Briggler & Prather 2003; Humphries et al. 2006; Ingersoll et al. 2010).

The degree of shelter at the cave/mine entrance also appeared in the best explanatory model. In my sample of caves and mines, bats tended to swarm at sites that had more exposed entrances. This could be because there is less clutter and more room to allow for the flight of large groups of bats and social behaviours such as chasing (Fenton 1969). This result does not support Glover and Altringham (2008), who found that bats preferred sheltered sites. This could be attributed to the differences in the way that degree of shelter was measured. Glover and Altringham (2008) used categorical data to quantify shelter, whereas I used continuous data. Another possibility is that the difference could reflect the fact that the range of shelter data was quite small in this study. Degree-of-shelter data ranged from 51 to 99%. As such, all sites were relatively sheltered, and 21 of the 26 sites were over 75% sheltered (Appendix B).

The last variable that appears in the top three models is total length of rivers, creeks and streams in the surrounding landscape. The directionality here was positive, as expected. Bats use rivers, creeks and streams for both foraging and commuting (Broders et al. 2006; Brooks 2009; Krusic et al. 1996), which may be related to why they would select swarming sites that are near these features. This result suggests that larger scale, landscape type variables that represent proximity to summer habitat may be important in swarming site selection.

The results of the trapping surveys indicate that in some cases, the number of individuals of each species caught was fairly even, while in other instances captures were heavily skewed towards one species. Species abundances can change from night to night at a single site, and have been shown to vary throughout the swarming period (K. Parsons, Jones, Davidson-Watts & Greenaway, 2003). As such, it is not possible to draw any conclusions regarding the possibility of differences in selection for swarming sites between *M. lucifugus* and *M. septentrionalis* based on this dataset since it includes only two night of trapping at each site. However, at all swarming sites, including the seven previously unstudied and the five known sites, both *M. lucifugus* and *M. septentrionalis* were captured, which supports the hypothesis that preferences are similar between the two species.

The research objectives explored in this thesis address a complex ecological system, where it is difficult to isolate the impacts of one variable and obtain definitive results with respect to predictor variables. Despite this, the results of the logistic regressions remain informative. Chamber length appeared in every model that made up the top 95% of Akaike weights, and along with degree of shelter and total stream length in surrounding landscape, had coefficient estimates that were consistent across all models and standard errors that did not overlap zero, indicating that these variables all influence the occurrence of swarming. However, it is likely that other factors not included in this study also influence swarming behaviour. A larger sample size would be useful in future work to allow for the inclusion of more variables and to provide greater power in describing the effect size of these variables.

The results of this study have important management and conservation implications. The swarming sites identified in this study should become conservation priorities due to the strong fidelity that bats have to these sites and the important role that they play in maintaining genetic diversity (Furmankiewicz & Altringham 2007; Parsons & Jones 2003; Rivers et al. 2005). As *M. lucifugus* and *M. septentrionalis* often swarm and hibernate at the same locations, the protection of the identified sites will help to conserve both species. Bats are highly vulnerable to disturbance during the hibernation period, and resource managers should focus on their protection during this time (Johnson, Brack, & Rolley 1998). Gating the entrances to abandoned mines or caves is a management initiative that can effectively reduce disturbance during hibernation by allowing the passage of bats but prevent people from entering the cave or mine (Pugh & Altringham 2005; Spanjer & Fenton 2005).

In the context of WNS, the conservation of bats in North America has become critical. While *M. lucifugus* has been most heavily hit by the fungal pathogen (Frick et al. 2010), both species are susceptible (United States Fish and Wildlife Service 2011b). Known hibernation, including the potential hibernation sites identified in this study, should be monitored throughout winter to document the spread of WNS and to study its impact on hibernating populations.

As the species in this study are representative of temperate insectivorous bats generally, the knowledge of swarming site use and selection gained in this study should be applied to a much broader group of bat species. Future work in this area should also include winter surveys of the seven newly identified swarming sites to determine which are also being used for hibernation. Verifying that they also serve as over-wintering sites would increase the importance of conservation at these locations.

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CHAPTER 3: DISCUSSION

3.1 Recommendations for Management

Bat conservation should be a priority in nature-conservation programs for several reasons. Like all wildlife species, *M. lucifugus* and *M. septentrionalis* have intrinsic value as native species that play an important role in Nova Scotia's ecosystems (Burt & Grossenheider 1976). Bats also have considerable economic value. A recent study based on 2007 data suggested that the value of bats as insect eaters to the North American agricultural industry is approximately $22.9 billion US/year (Boyles et al. 2011). This figure alone should motivate both government and industry to contribute to bat conservation efforts in Canada.

In Nova Scotia, the most important recommendation for resource managers regarding bat conservation is that all known hibernacula be protected to ensure that they continue to be suitable and available for bats. Despite being abandoned, changes can still occur at old mines. Decisions may be made to close mines permanently, or to re-open a mine for further mineral extractions. Before any such actions take place, surveying for bats should occur (Hayes, Schorr, & Navo 2011).

During the hibernation period, bats are sensitive to disturbance and can be easily awoken by human visitors, causing a decline in vital energy reserves (Thomas 1995). People should be prevented from entering hibernacula, which may require that managers gate the entrances to these sites. Gates give bats ready access to the site, but prevent people from entering, thus effectively minimizing human disturbance (Pugh & Altringham 2005; Spanjer & Fenton 2005). Of the 12 sites identified in this study as used by bats, only two (Lear shaft and Glenelg adit) are gated. One other hibernaculum in

Nova Scotia, Lake Charlotte adit, is also gated. Managers should increase the number of gated sites by targeting the sites most frequently visited by people, such as Hayes Cave. These gates should then be monitored to ensure that they are working and are not vandalized.

Another way to keep people out of caves is through public education. Resource managers should be taking part in public outreach to educate people about the importance of bats. The public should be advised on how to ensure the well being of bats, which includes staying out of caves in the winter time. Recreational cavers should be of particular interest for outreach programs.

Of the five site characteristics analysed in this study, four represent external characteristics, with chamber length providing the only internal measurement. Abandoned mines and caves can be unstable and dangerous, and as such no internal data collection occurred so as to protect the safety of the research team. Regardless, from a management perspective, knowledge of external site characteristics preferred by bats may be very useful. Resource managers are unlikely to enter underground sites due to safety concerns. The identification of external variables that are preferred by bats allows managers to predict which sites are used without entering the cave or mine (Johnson et al. 2006). This study has shown that external features such as degree of shelter at the entrance or total length of streams, rivers or creeks in the surrounding landscape may be important. These factors, along with knowledge of chamber length, may help to predict which underground sites are used by swarming and hibernating bats. Future work should follow up on this idea to provide managers with more information on the extent to which external features should be preserved to protect bat habitat.

In the context of WNS, certain additional management efforts should be taken. Although there is no known method to prevent WNS, nor is there a cure, there are still measures that managers can take to help the situation and to learn from it. Managers should monitor the spread of WNS, as it provides a learning opportunity regarding the movement of bats across the landscape. White-nose syndrome hits during the hibernation period (Blehert et al. 2009; Frick et al. 2010) and hibernacula should be targeted for this work. This thesis has identified seven underground sites that are used by bats, and each of these, along with the previously known hibernacula, should be monitored for the presence of WNS. Fortunately, this work has begun in Nova Scotia, and site visits are being conducted by the researchers during the winter and spring, when bats are using these sites. In the future, if any management initiatives are identified that reduce the impacts of WNS, or help to rebuild the bat population, these 26 sites should be targeted.

Monitoring should also occur during the summer. Maternity colonies of *M. lucifugus* are often faithful to a particular roost from year to year (Humphrey & Cope 1976). A decline in numbers at a specific colony or the failure to return in the spring may indicate a problem, such as the presence of WNS, within the colony. Monitoring health indicators, such as wing condition, can also be used to assess the presence of WNS (Meteyer et al. 2009; Reichard & Kunz 2009). Monitoring the spread of infection regionally may help to identify which populations continentally are being hit the hardest, which may aid in the understanding of resistance or resilience to the fungus.

3.2 Recommendations for Future Research

We are far from having a comprehensive understanding of bat populations within Nova Scotia. It is essential for bat research to increase in priority as WNS begins to affect animals in the Atlantic provinces.

No underground surveys were conducted at any caves or mines. As such, we do not know which of the seven newly identified swarming sites also function as hibernation sites. Future research should involve internal surveys during the winter at any sites that are deemed safe to do so. Hibernation counts would help to determine which sites should be priorities for conservation initiatives, such as gating. The data would also be helpful in monitoring population declines caused by WNS.

This study helped to expand the inventory of sites used by bats in Nova Scotia. However, our knowledge of these locations is still far from complete. The search for swarming and hibernation sites should continue across Nova Scotia and the Atlantic Provinces. Nothing is known about the ecology of bats on the island of Cape Breton and it should therefore be the focus of future work.

Little is known about the tri-coloured bat, *Perimyotis subflavus*, in Nova Scotia, especially in regard to where it over-winters. In this project, only four *P. subflavus* individuals were caught, and thus it was not possible to draw any conclusions with respect to this species. Future work could focus specifically on this species in an effort to identify which sites it uses and if these preferred sites differ from those used by *M. lucifugus* and *M. septentrionalis.*

3.3 Ethical Considerations

The nature of field biology dictates that the subject animal must sometimes be observed in close proximity, trapped or otherwise disturbed in the course of conducting research (Farnsworth & Rosovsky 1993; Swart 2004). It is the role of the researcher to minimize the level of disturbance that is imposed on the individual, population or community under study. As such, ethical considerations should be of foremost importance in any research involving animals (Minteer & Collins 2005, 2008). All research that involves the trapping and handling of wild animals is innately stressful for the animals, and must be executed carefully (Swart 2004).

Throughout this research project, every effort was made to reduce stress to the bats during the trapping process. After being captured, bats were released as quickly as possible after being processed at the same location that they were trapped. If waiting to be processed, bats were placed in individual cloth bags that were put in a quiet, dark location. The research project and procedures were approved by the Saint Mary's Animal Care Committee, and subsequently the Dalhousie Animal Care Committee prior to commencing any field work.

To minimize disturbance to the focal species, passive monitoring techniques should be used whenever possible. For this reason, acoustic detectors were used in the first round of surveying. This stage not only saved time in the field, but it also eliminated the need to trap bats at sites where activity levels did not indicate swarming, thereby reducing the impact on bats at these locations.

Conducting field research requires that important decisions regarding ethics are made, and as such all researchers are morally obligated to think critically about the ethical implications of their research (Minteer & Collins 2005). Unavoidably, tradeoffs exist between conducting research and causing disturbance to the focal species (Parris et al. 2010). I believe that trapping and handling wild bats is defensible in conducting research that will contribute to conservation efforts, particularly in the face of WNS.

3.4 Conclusions

As the only mammal capable of flight, bats are a unique order of animals (Altringham 1996). In Nova Scotia, *Myotis lucifugus* and *Myotis septentrionalis* are native species and are commonplace in rural and wilderness areas. As threats to these species increase, so too does the need for research and conservation efforts. It is the responsibility of ecologists and resource management to make the protection of bats a priority under the current context of WNS, which involves the protection of critical habitat resources, such as swarming and hibernation sites. This thesis is a response to the need for baseline data in Nova Scotia, and was undertaken with the goal of aiding in conservation efforts.

The objectives of this research were twofold; 1) identify additional abandoned mines and caves in Nova Scotia that are important swarming sites, and 2) quantitatively characterize factors which best differentiate between caves and mines that are used for swarming/hibernating, and those that are not. Twenty-six underground study sites were chosen across mainland Nova Scotia. Of these, twelve were found to have high levels of bat activity through acoustic and trapping surveys, and were thus designated as swarming sites. Of the five site characteristics that were measured, chamber length was the most important explanatory variable. Bats often swarm at the same location that they hibernate, thus it is likely that many of the sites identified in this study are also used for overwintering.

As the IUCN list of endangered species continues to grow from year to year, it is clear that action is required to protect our native wildlife. The fact that the top threat to species is the loss of suitable habitat (Pimm & Raven 2000; Vie et al. 2009) indicates that the protection of habitat resources is essential in wildlife conservation. To do this effectively, managers must know which resources are required. Bats have important intrinsic, ecosystem, and economic values, but face an uncertain future in North America. In Nova Scotia, bats depend on underground sites, particularly those characterized by chamber lengths of > 100 m. Protecting the future of bats will require protecting the habitat that these animals depend on.

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APPENDIX A:

Total capture numbers by species for all sites where trapping took place

Appendix A: Results for all trapping surveys that took place during late summer and early fall, 2010. A harp trap was used, and trapping was executed for a minimum of four hours beginning at sunset. Trapping only occurred on nights without rain. Prior to trapping, acoustic surveys were conducted at all study sites, and trapping was deemed unnecessary at sites where ≥ 30 files of echolocation sequences were recorded per night. Three species were captured, with *Myotis lucifugus* and *Myotis septentrionalis* making up >95% of all captures. At some of the five known swarming sites, trapping occurred more than twice during the swarming period, but only the two nights with highest captures are included in this appendix. The single night of trapping with the highest total captures per hour was used in the analysis.

	M. lucifugus			***M. septentrionalis***			***P. subflavus***			**Grand**	**Total captures**
	female	**male**	**total**	**female**	**male**	**total**	**female**	**male**	**total**	**Total**	**per hour**
Cape D'Or											
27-Aug-10		1	1		3	3				4	1.00
Cave of the Bats											
15-Aug-10	8	27	35	7	20	27		2	2	64	8.68
09-Sep-10	0	1	1	16	20	36				37	6.38
Cheverie Cave											
20-Aug-10	13	9	22	1	2	3				25	8.57
07-Sep-10	3	6	9	5	4	9				18	3.60
Frenchman's Cave											
29-Aug-10	2	2	4	12	21	33				37	6.43
7-Sep-10		2	2					1	1	3	0.71
19-Sep-10				1		1				1	0.25

	M. lucifugus			*M. septentrionalis*			*P. subflavus*			Grand	Total captures
	female	**male**	**total**	**female**	**male**	**total**	**female**	**male**	**total**	**Total**	**per hour**
Gays River Adits											
20-Aug-10				4	8	12				12	3.00
Glenelg Adit											
6-Sep-10	13	18	31	10	19	29				60	12.63
10-Sep-10	9	28	37	12	19	31				68	16.65
Hayes Cave											
16-Aug-10	13	7	20	0	0	0				20	8.57
21-Sep-10	24	23	47	0	2	2				49	11.44
Lear Shaft											
19-Aug-10	48	40	88	19	30	49				137	17.31
23-Sep-10	2	3	5	1	3	4				9	2.35
Minasville Cave											
16-Sep-10	32	29	61	15	29	44				105	14.32
1-Sep-10	30	30	60	61	62	123				183	30.50
Natural Bridge Cave											
21-Aug-10		2	2	1	5	6				8	2.00
Peddlers Cave											
28-Aug-10					5	5				5	1.20
Rawdon Mine											
14-Aug-10	12	33	45	11	37	48		1	1	94	14.35
18-Aug-10	22	20	42	26	58	84				126	18.44

	M. lucifugus			*M. septentrionalis*			*P. subflavus*			Grand	Total captures
	female	male	total	female	male	total	female	male	total	Total	per hour
Reid Road Adit											
18-Sep-10	1	5	6	2	1	3				9	2.25
Upper Road Adit											
2-Sep-10	3	16	19	5	14	19				38	8.00
12-Sep-10	3	3	6	1		1				7	1.75
Vault Cave											
16-Sep-10	80	114	194	22	33	55				249	49.80
Woodville Cave											
18-Aug-10	18	37	55	10	24	34				89	14.43
14-Sep-10	1	4	5							5	1.25
TOTAL	337	460	797	242	419	661	0	4	4	1462	

APPENDIX B:

Site characteristic measurements for all study sites

Appendix B: Measurements taken at each study site of the five site characteristics used as explanatory variables in nine *a priori* models. A logistic regression was run on each model to determine which characteristics affected swarming activity, and models were ranked using the AIC_c value. Entrance area and degree of shelter at entrance were measured at the site and chamber length values were retrieved from the NSDNR abandoned mines database (NSDNR 2009), from other published reports and best estimates. Total river length and total forested area were both determined through GIS analysis using the NSDNR water lines and forest resource inventory layers.

Site	**Entrance area (m^2)**	**Degree of shelter at entrance (%)**	**Chamber length (m)**	**Total river length in surrounding 2000 m buffer (m)**	**Total forested area in surrounding 2000 m buffer (ha)**
Cape D'Or Shaft	40	94.47	112	17,616.68	575.99
Cave of the Bats	5.71	68.54	70	52,623.21	532.87
Cheverie Cave	1.19	50.85	100	21,941.19	427.44
Country Harbour	5.5	96.98	22	32,225.02	939.34
Five Islands Adit	0.62	98.57	45	24,157.41	1100.10
Frenchmans Cave	5.13	83.23	110	50,773.54	763.26
Gays River Adit 3	1.53	98.18	55	19,788.87	911.91
Gays River Adit 4	1.46	97.14	15	19,788.87	911.91
Glenelg Adit	2.43	77.51	220	45,281.26	886.35
Hayes Cave	2.52	59.96	365	39,021.19	955.49
Isaacs Harbour Shaft	12	92.72	67	33,296.76	640.64
Lear Shaft	0.81	98.57	365	17,683.95	966.37
McLellans Brook Cave	1.15	82.57	85	26,240.08	894.94
Minasville Cave	0.61	71.14	80	27,914.54	991.17

Site	Entrance area (m^2)	Degree of shelter at entrance (%)	Chamber length (m)	Total river length in surrounding 2000m buffer (m)	Total forested area in surrounding 2000 m buffer (ha)
Natural Bridge Cave	8.39	86.09	15	32,504.36	822.52
New Lairg Adit 1	0.026	51.25	18	17,240.25	779.82
New Lairg Adit 2	2.11	79.98	24	17,240.25	779.82
New Lairg Adit 3	0.12	85.31	40	17,240.25	779.82
Peddler's Cave	0.4	92.98	23	13,778.76	1,047.83
Rawdon Mine	2.72	90.9	280	17,795.45	695.28
Reid Road Adit	48.5	84.79	60	21,188.14	909.54
Sherbrooke Adit	3.7	91.23	45	40,649.21	765.44
Slack Brook Adit	0.21	98.96	35	21,815.37	888.67
Upper Road Adit	2.33	98.57	230	25,572.14	910.49
Vault Cave	0.23	91.16	35	23,956.89	874.89
Woodville Cave	7.67	87.78	25	28,698.56	852.85