THE LANDSCAPE USED BY EIGHT BAT SPECIES IN THE NIPIGON DISTRICT, ONTARIO

by

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ABSTRACT

Emergent diseases such as white nose syndrome (WNS) and habitat loss are negatively affecting the populations of Ontario bat species. There are eight bat species native to Ontario: *Estesicus fuscus*, *Lasiurus cinereus, L. borealis, Myotis leibii, M. lucifugus*, *M. septentrionalis, Perimyotis subflavus, and Lasionycteris noctivagans.* Of the native species, *M. lucifugus*, *M. septentrionalis*, and *P. subflavus* are listed as endangered in 2014 by the federal Species at Risk Act due to sudden population declines. In order to prevent any further decline in bat populations, the Ontario Ministry of Natural Resources and Forestry adopts acoustic monitoring as a non-invasive alternative to collect data on presence of native bats. Using data from this venture, I describe how presence of landscape features such as water, mature forest, and talus slopes to predict bat diversity hot spots in the Nipigon District.

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INTRODUCTION

There are eight species of bat common in Ontario, all in the family Vespertilionidae. Some are non-migratory and some are migrating bats that are present only in the spring and summer. The non-migratory bats include *Estesicus fuscus*, *Myotis leibii, M. lucifugus*, *M. septentrionalis,* and *Perimyotis subflavus.* The migratory bats include *Lasiurus borealis, L. cinereus* and *Lasionycteris noctivagans*. Of the native species, *M. lucifugus*, *M. septentrionalis*, and *P. subflavus* were emergency listed as Endangered on Schedule 1 of the federal Species at Risk Act in 2014 because of sudden population declines resulting from white-nose syndrome (WNS), an emergent disease of hibernating bats (Baker et al. 2015). In areas already affected by WNS, the significance of other threats to the three species of bats is heightened because of the small number of remaining individuals. Threats other than WNS include habitat loss, destruction or degradation of hibernacula, maternity roosts, and foraging areas.

Members of the family Vespertilionidae are insect predators and will exploit locally abundant patches of prey that may be temporally or spatially scattered, known as foraging habitat (Baker et al. 2015). The identification of foraging habitat is useful in conservation, since requirements are unique to each species. Some bats may forage in open habitats, such as over ponds, roads, and in open canopy areas of forest, whereas others may forage along or within dense forest, depending on where they find their preferred prey items. Foraging habitats are usually closely associated with roosting locations. The distance at which bats travel from roosts to foraging sites varies from species to species. *M. lucifugus* in Yukon boreal habitat travelled 3.8 ± 0.7 km from their day time roosts to foraging areas (Randell et al. 2014). In New Brunswick, *M. septentrionalis* females travelled an average distance of 457 m from their roosting site to foraging areas (Broders et al. 2006). For *P. noctivagans*, the distances travelled between roosting and foraging sites are generally unknown, but in some locations, may be up to 5 km (Quinn and Broders 2007). These values provide an idea of the scale of forest protection needed for some species to meet all habitat requirements.

Bats rely on echolocation to find their way in the dark and to identify prey items. When flying, a bat emits pulses of high frequency sound (20-130 kHz) that are generally inaudible to humans (Kurta 1995). In recent years, scientists have used specialized bat detectors or microphones to record these frequencies emitted by bats. From the recordings, it is possible to identify the species of bat that flies past the recorder at that specific moment (Miller 2001). The sounds recorded are unique for each bat, and can be identified using modern computer programs by the time between "clicks," duration of the sound, and frequency pattern (Miller 2001; Fukui et al. 2004; Walters 2012). In the past, bats could only be identified through netting, or by a professional able to identify bats based on flight pattern (O'Farrel and Gannon 1999; Miller 2001). Being able to identify bats through acoustic surveying has decreased the amount of effort and cost of bat research, and generated an abundance of information used in conservation initiatives (O'Farrel and Gannon 1999; MacSwiney et al. 2008; Adams et al. 2012). Audio recordings, however, can only provide so much information about the bat itself. Also, it proves difficult to pinpoint the exact location of the bat at the time of the recording. From analyzing acoustic sampling data, I hope to:

1. document the general locations where bats in the Nipigon District are found when feeding; and
2. determine suggested habitat preference based on land and water formations, elevation, and forest type in the surrounding area.

I predict that the location of landscape features such as water, mature forest, and talus slopes are ways to locate bat roosting and feeding habitat.

LITERATURE REVIEW

1. Acoustic Surveying

Closely associated with the evolution of nocturnal flight and the use of caves for roosting and hibernation is the manner in which bats find their way. All bats in the family Vespertilionidae use the echoes of their own sound to orient themselves (echolocation). Echolocation is accomplished by the emission of short pulses of sound and the subsequent reception of their echoes, reflected in the animal's path. These echoes provide information about direction, distance and velocity, as well as the size and nature of the objects. Many other bats use echolocation to avoid obstacles and find prey items (van Zyll de Jong 1985).

Acoustic surveys use bat detectors to monitor echolocation calls of bats, and bat detectors have been used extensively in recent years to meet a variety of management objectives. They offer a number of advantages for use in field studies because they can be used to survey bats in places where capture methods are ineffective and can be used to collect data automatically without disruption (Corben and Fellers 2001; Hayes and Hounihan 1994). In laboratory situations, echolocation call characteristics have been demonstrated to vary according to sex (Jones et al. 1992), age (Kazial et al. 2001; Masters et al 1995), and reproductive status (Grilliot et al. 2004). However, the age, sex or reproductive condition of a bat cannot be determined using existing acoustic devices.

Abundance can also not be determined from echolocation data because the detection of multiple bats, each recorded once, cannot be distinguished from a single bat recorded multiple times. Hence acoustic data may be useful to describe an area used by a particular species, but not the number of bats using the area (Hayes 2000; Miller et al. 2003). This leaves documenting species occurrence to be the only useful metric that acoustic surveys offer. In this respect, acoustic monitoring offers a variety of advantages over other inventory methods. For instance, open meadows and lakes are heavily inventoried areas because of their high bat activity but capturing bats to identify them in these locations has proven difficult. Acoustic sampling enhances the ability to survey in a wider variety of situations, explaining why acoustic surveys often can detect inconspicuous species that are often not captured using traditional survey methods (O'Farrell and Gannon 1999).

While acoustic surveys can be used to document species occurrence, it is important to remember that not all species calls are equally detectable (O'Farrell and Gannon 1999; Fenton 2003). Species echolocate at different intensities and those with greater intensities will be recorded more easily and over greater distances. In general, larger and faster flying species (e.g., hoary bats, *Lasiurus cinereus*) echolocate at a lower intensity, whereas, smaller, slower-flying species (e.g., northern myotis, *Myotis septentrionalis*) echolocate at lower intensity (Aldridge and Rautenbach 1987). Moreover, species of bats may vary the intensity of their echolocation calls to accomplish different tasks (Fenton 2003). Therefore, acoustic surveys will not necessarily result in detection of all of the species present at the survey location, rendering interspecific comparisons of activity problematic (Hayes 2000).

There are several factors influencing the ability to identify bats from their echolocation calls, including choice of detection system, instraspecies variability in call, and how representative calls are under controlled situations (Fenton 2003; Parsons and Jones 2000). Contributions to intraspecific variation include not only the age and sex of bats (Jones et al. 1992; Masters et al 1995; Kazial et al. 2001), but also the presence of conspecifics (Obrist 1995). Therefore, species identification from calls requires not only an understanding of intraspecific variation of the species of interest, but also the sympatric species with which it may be confused (Broders et al. 2004). Geographic variation in call structure across the range of a species may also contribute to intraspecific variation (Thomas et al. 1987; Barclay 1999). The nature of the surroundings where an individual bat is flying may be the largest contributor to intraspecific variation, since bats alter their calls as they move among areas with varying degrees of habitat clutter (Obrist 1995; Borders et al. 2004). The magnitude of this variation may cause the greatest impediment to the identification of bats by echolocation call (Tibbels 1999).

2. Habitat

Myotis leibii: small-footed bat

The small-footed bat or small-footed myotis is a very small bat that has a total length of 23-82 mm (Kurta 1995). It has silky, yellowish brown or golden-brown fur across its head and back, with ventral hairs giving it a lighter appearance (Godin 1977). Its naked ears and membranes are dark brown to black (van Zyll de Jong 1985). Its snout and skin surrounding the eyes are black as well, so that many describe this species as having a “mask”.

The small-footed bat has an irregular distribution across North America, and it is likely that eastern and western populations are distinct (van Zyll de Jong 1984, 1985). In the east, the bat ranges from Georgia and Alabama to Quebec (Barbour and Davis 1969). In the Great Lakes region, this uncommon species can be found along the east shore of Lake Superior and the north shore of Lake Huron in the summer (Fenton 1972). The eastern small-footed myotis usually occurs in mountainous regions (Adams 1950; McDaniel et al. 1982), but not always (Fenton 1972). It has been found in buildings (Hitchcock 1955; Neuhauser 1971), on the face of rock bluffs (McDaniel et al. 1982), in turnpike tunnels (Mohr 1942), and beneath slabs of rock and stones (Tuttle 1964; Barbour and Davis 1969). It is usually encountered during hibernation (Barbour ad Davis 1969). The only known hibernation sites are caves and old mines (Mohr 1933, Fenton 1972), often near the entrance in a dry, drafty location (Barbour and Davis 1969; Fenton 1972). *M. leibii* tolerates very cool temperatures in comparison to other bats, moving only if air temperature rises above 4°C. More than 400 can occupy a cave at once, but the average number is usually less than 20 at one time (Kurta 1995). One hundred and forty-two *M. leibii* where encountered in Fourth Chute Cave, Renfrew Co., Ontario hibernating in narrow cracks in the wall or ceiling on February 26th, 1946 (Hitchcock 1946).

The eastern small-footed myotis emerges at dusk shortly after sunset (van Zyll de Jong 1985). During this time, it will hunt flies, beetles, bugs, leafhoppers, and flying ants (Kurta 1995). It can be seen flying erratically at heights of 0.3-3.0 m in and out of caves and in open fields (Davis et al. 1965; van Zyll de Jong 1985). It uses echolocation to locate prey items, and it can emit a vocal frequency of 41-44 kHz (Kurta 1995).

Myotis lucifugus: little brown bat

The little brown bat or little brown myotis is considered a small bat with its total length ranging 80-95 mm (Collins 1981). It has an evenly coloured coat ranging from an olive brown to dark yellowish brown, with buffy grey underneath (Fenton and Barclay 1980; Collins 1981). Compared to the small-foot bat, the little brown bat lacks a dark “mask” and has a larger foot (Kurta 1995). The echolocation calls of *M. lucifugus* range from 40-80 kHz, with most of the energy at 45 kHz (Griffin 1958; Fenton and Bell 1979).

M. lucifugus is the most common species in Ontario and it is the best studied bat, because its range covers most of North America. Little brown bats can occupy three different types of roost site, depending on the season and setting: day roosts, nights roosts, and hibernation sites. Day roosts include sites in buildings, trees, under rocks, in piles of wood and occasionally in caves. Nursery roosts are usually located in and around buildings but may also be located in hollow trees or other natural crevices. Warm temperatures, to foster the rapid growth of the young and shelter, and locations away from predators appear to be the most determining factors when female little brown bats choose a nursery roost (Fenton and Barclay 1980). Attics in buildings have been found to harbor nursey colonies of *M. lucifugus* (Davis and Hitchcock 1965). Adult males and non-breeding females occupy day roosts away from nursery roosts. In comparison to nursery roosts, adult males and non-breeding females choose sites that are cooler, and bats in these roosts are frequently torpid (Fenton and Barclay 1980). Bats occupying roosts choose them with a southwestern exposure, so the heat generated from the sun will stimulate arousal from daily torpor (Fenton 1970).

M. lucifugus is active at all times of the night, but most foraging takes place during the second and third hours after sunset (Kurta 1995). It tends to prey heavily on insects with an aquatic larval stage such as mayflies and chironomid flies (Belwood and Fenton 1976; Anthony and Kunz 1977). Not surprisingly, *M. lucifugus* feeds over lakes, streams and ponds, often flying within 1 m of the water surface (Fenton and Bell 1979).

After feeding, *M. lucifugus* congregates in night roosts. Night roosts are located in the same buildings as day roosts, just in a different area (Fenton and Barclay 1980). These sites are usually in confined spaces. The purpose of night roosts still remains unclear, but it is theorized that bats pack themselves into these confined spaces to raise the roost temperature, suggesting that it is energetically beneficial to them (Anthony and Kunz 1977).

Caves and abandoned mines are suitable sites for hibernacula (Fenton and Barclay 1980). These sites commonly have high levels of humidity, usually reaching over 90%, with temperatures above freezing (Hitchcock 1949; Humphrey and Cope 1976). Northern populations of *M. lucifugus* in Ontario hibernate from early September until early or mid-May. More southerly populations might not enter hibernacula until sometime in November (Fenton and Barclay 1980).

Eptesicus fuscus: big brown bat

The big brown bat is a medium sized and heavy-bodied mammal (Miller 1907), reaching a maximum body length of 138 mm (Davis 1966; Hall 1981). Ears are thick, rounded and short, and when laid forward barely reach the nostrils. Fur colour depends on the location and subspecies, and ranges from tans to rich chocolates; ventral hairs are paler, from near pinkish to olive buff. Naked parts of the face, ears, wings, and tall membrane are blackish (Miller 1907). Echolocation pulses reach a maximum of 48 kHz down to 27 kHz (Thomas et al. 1987; Brigham et al. 1989).

The big brown bat ranges throughout the US, western Canadian provinces, and southern areas of eastern and central Canada. It is found throughout southern Ontario, along the Lake Superior shorelines, and west to the Ontario-Manitoba border (Dobbyn and Edger 1994). It is most abundant in landscapes dominated by farmland and least common in heavily forested regions (Kurta 1995).

Throughout the spring and summer, adult females form maternity colonies (Kurta and Baker 1990). Adult males are most often solitary in summer, but they may roost with females or in all-male colonies (Davis et al. 1968; Barbour and Davis 1969). In eastern North America, maternity colonies are most often located in manmade structures like barns, house, and churches (Barbour and Davis 1969), although some colonies have been found in hollow oak (*Quercus*) and beech (*Fagus grandifolia*) trees

(Christian 1956, Kurta 1980). In western Canada, maternity colonies are usually found in rock crevices and dead pines (*Pinus*; Brigham 1988). The size of maternity colonies varies from 5 to 700 animals (Davis et al. 1968; Mills et al. 1975).

Foraging occurs throughout the night with peak activity being the second hour after sunset (Kunz 1973). *E. fuscus* is considered a generalist, having no particular preference for foraging habitat (Geggie and Fenton 1985; Furlonger et al. 1987). In forested areas, it begins foraging at 50 m and later descends to 10-15 m above the ground (Whitaker et al. 1977). *E. fuscus* utilizes echolocation for obstacle avoidance and to capture flying insect prey. Small Coleoptera (beetles) are their most common prey item (Freeman 1981), but these bats also feed on flying ants, ichneumonids, flies, stoneflies, mayflies, true bugs, caddis flies, lace-wing flies, scorpion flies and orthopterous insects (Hamilton 1933). *E. fuscus* has incredible homing abilities; about 85% of a sample released 400 km north of their roost returned home, yet only 6% of those released 400 km to the south found their way home (Davis 1966).

Although summer colonies begin to disperse as early as August, many big brown bats do not appear at hibernacula until November (Barbour and Davis 1969). Bats may enter and leave hibernacula throughout the winter (Mumford 1958). These sites are cooler, drier, and more exposed to air current than those of *M. lucifugus* (Goehring 1972; Raesly and Gates 1987). *E. fuscus* hibernates in temperatures below freezing and is often found in cracks, crevices or beneath rocks in the hibernaculum floor (Barbour and Davis 1969; Fenton 1972). It often hibernates in buildings, caves and mines (Mills et al. 1975).

Myotis septentrionalis: northern myotis

The northern myotis or northern bat has a total body length of 77-92 mm (Kurta 1995). It has a light to dark brown coat with naked ears, wings and tail. *M. septentrionalis* can be distinguished from other small-bodied bats by its large ears and long, sharply pointed tragus (a fleshy projection at the base of the ear opening) (Fitch and Shump 1979). If the ears extend 3-4 mm past the nose, it is a northern myotis, anything less is a different species (Kurta 1995; Fitch and Shump 1979*). M. septentrionalis* has the highest echolocation frequency of any bats in the Great Lakes region, up to 126 kHz and as low as 60 kHz (Faure et al. 1993; Kurta 1995).

Myotis septentrionalis is widely distributed across Canada, confirmed in every province, and territory, with the exception of Nunavut (COSEWIC 2013). It resides in the boreal forest south of the tree line and into the montane forests of the west and deciduous and mixed wood forests of the east (van Zyll de Jong 1985; Burles et al. 2014).

M. septentrionalis begins its hibernation in September to early November, and torpor lasts until March, April or May (Fenton 1969; Caire et al 1979). Caves or abandoned mines are common hibernacula (Whitaker 1992; Caire 1979). *M. septentrionalis* generally hibernates with large groups of other species, including *M. lucifugus*, *Eptesicus fuscus*, and *Pipistrellus subflavus* (Griffin 1940; Caire et al. 1979). Three hundred *M. septentrionalis* were found hibernating with about a thousand *M. lucifugus* in an abandoned mine in Quebec (Thomas 1993).

During the day, female *M. septentrionalis* occupy a variety of roosts. In New Hampshire and British Columbia, female *M. septentrionalis* were found in tall trees in the stages of early decay (Sasse and Pekins 1996), or in live trees with less canopy closure when compared to trees nearby (Caceres 1998). In Michigan, female *M. septentrionalis* roosted in crevices, in hollows, or under bark or live and dead deciduous trees. They were also found roosting in large-diameter trees (maples, *Acer*, and green ash, *Fraxinus pennsylvanica*), but characteristics of occupied and unoccupied trees were not significantly different (Foster and Kurta 1999). Individual bats frequently switch roost trees, and roost trees tend to be clustered together (Sasse and Pekins 1996; Foster and Kurta 1999). In New Hampshire, roost trees were grouped an average of 602 m from foraging areas (Sasse and Pekins 1996). Sometimes, caves have served as temporary night roosts for adult males and non-reproductive females when travelling between foraging habitats (Barbour and Davis 1969).

The northern bat leaves the roost to forage shortly after sunset (Kunz 1973). This species most often feeds within forests, below canopy but above the shrub layer (Kurta 1995). *M. septentrionalis* feeds on moths, beetles, bugs, caddisflies, stoneflies and insects (LaVal and LaVal 1980; Caceres 1998). *M septentrionalis* feeds on flying insects, but also gleans prey from substrates. Gleaning bats use passive listening as well as echolocation to locate insects resting on leaves, tree trunks, or against buildings (Faure et al. 1993).

Lasiurus borealis: eastern red bat

L. borealis is a moderately sized bat with a total length of 110 mm (Miller 1897). It has a brick red to rusty red coloration; it is slightly paler underneath and the anterior part of shoulder has a buffy white patch (Miller 1897; Barbour and Davis 1969; Hall 1981). The Eastern Red Bat ranges throughout eastern North America south to South America. It is found throughout Ontario north to James Bay, and it is most common in the lower Great Lakes region (Dobbyn and Edger 1994). *L. borealis* flies into Ontario in late May and migrates to the southern US states for the winter, where it hibernates in trees (Shump and Shump 1982). Female bats have been reported in Missouri, southern lower Michigan, Central Iowa, Indiana, Louisiana, and southern Illinois during the summer months (Layne 1958; Kurta 1980). Mumford (1973) reported that most bats leave Indiana by October or November and return between March and April.

Red bats are solitary, roosting mostly in trees or shrubs, sometimes near or even on the ground (Hall and Kelson 1959). During the day, red bats commonly roost in edge habitats adjacent to streams, open fields and in urban areas (Constantine, 1958; Mumford, 1973). Roosts are distanced from human population centers (McClure 1942). Roost locations must provide dense shade cover above and at the sides but are open from below. Red bats generally begin to forage 1 to 2 h after sunset, with some bats feeding throughout the night (Kunz 1973). *L. borealis* usually forages high above trees and pastures consuming Homoptera, Coleoptera, Hymenoptera, Diptera, and Lepidoptera insects (Ross 1967; LaVal et al. 1977). They also feed on ground-dwelling insects including crickets, flies, bugs, beetles, cicadas, and grain moths (Lewis 1940; Connor 1971).

Lasionycteris noctivagans: silver-haired bat

The silver-haired bat is a medium-sized bat with a total length of 92 to 115 mm (Jackson 1961). External characteristics of adults include black wings, ears and interfemoral membrane. Individual hairs have silvery-white tips, giving it a frosted appearance. Ears are short, rounded and naked, with a broad, blunt tragus (Merriam 1884; Nason 1948). This species is distinctive, and is not likely confused with others. They are not easily surveyed using bat detectors because they are heard at the same frequency as big brown bats (30 kHz), making them difficult to tell apart (Dobbyn and Edger 1994).

The silver-haired bat is not well documented in Ontario. The accepted range for this bat includes most of the US, southern Canada as far north as James Bay and northern British Columbia. There are several dozen records of *L. noctivagans* in Ontario, but only a few in the north. Mammal Atlas records indicate that this species can be found at least as far north as Nipigon in the west and James Bay in the east (Dobbyn and Edger 1994). The migratory patterns of *L. noctivagans* are not well known, because they are often not seen. Current information on the migratory patterns of *L. noctivagans* is often based on published observations rather than banding. These observations suggest that the species range shifts north in the spring and south in the winter, females migrating farther than males (Baker and Patton 1978; Izor 1979).

L. noctivagans is commonly regarded as a solitary tree-roosting bat, but there are very few reliable records. Assuming that trees are the preferred habitat, extensive deforestation and forest management practices over the last two centuries may have reduced the roosting sites available. Little is known about *L. noctivagans* summer roosting habits (Kunz 1982). In the winter, however, they have been documented to roost in mines, caves, in hollow trees, under loose bark, in rock crevices, and in houses (McTaggart-Cowan 1933; Turner 1974)

L. noctivagans emerges from its day roost often after other species have begun feeding (Seton 1907; Kunz 1973). In Iowa, this bat was characterized as having a bimodal pattern of foraging activity, with major peak occurring 2-4 h after sunset and a second period occurring 6-8 h after sunset (Kunz 1973). *L. noctivagans* forages in and or near coniferous and/or mixed deciduous forests, adjacent to ponds, streams, and other bodies of water (Merriam 1884; Yates et al. 1979). *L. noctivagans* is opportunistic in its feeding habits, preying on a variety of insects (Whitaker 1972; Whitaker et al. 1977). Black (1974) regarded *L. noctivagans* to be a “moth strategist,” but this bat also feeds opportunistically on beetles and flies (Jones et al. 1973).

Lasiurus cinereus: hoary bat

Lasiurus cinereus is not easily confused with other bats in the lasiurine genus, because of its large size and distinctive colour. They can reach a total length of 134.5 mm and weigh 20-35 g (Shump and Shump 1982). Other members of this genus have yellowish to reddish fur, like *Lasiurus borealis*, while the hoary bat is mixed dark brownish and grayish, with a frosty or hoary effect. *L. cinereus* has whitish shoulder patches and a distinctive yellow throat patch (Miller 1897; Barbour and Davis 1969).

L. cinereus is distributed across the US, as well as through parts of Alberta, Saskatchewan, and southeastern Canada. In Ontario, it can be found as far north as James Bay in the east and Lake of the Woods in the west (Dobbyn and Edger 1994). *L. cinereus* migrates south to the US each winter prior to hibernation to Michigan, New York, Connecticut and Indiana (Sanborn and Crespo 1957; Zinn and Baker 1979).

L. cinereus is a solitary bat that roosts primarily among foliage of trees but it has been found in tree cavities (McTaggart-Cowan and Guiguet 1965), caves (Mumford 1953; Myers 1960), a gray squirrel nest (Neill 1952), under a driftwood plank (Connor 1971), and clinging to sides of buildings (Bowers et al. 1968). Hoary bats roost 3-5 m above the ground in trees such as elm (*Ulmus*), black cherry (*Prunus serotina*), plum (*Prunus*), box elder (*Acer negundo*), osage orange (*Maclura pomifera*), and spruce (*Picea*; Shump and Shump 1982; Kurta 1995). Bats are well hidden from above but visible from below, and usually prefer the edge of a clearing (Constantine 1966).

Hoary bats emerge late in the evening to forage, although they may arouse and fly on warm winter afternoons (Barbour and Davis 1969; Hamilton and Whitaker 1979). In New Mexico, hoary bats were quite active 1 h 40 min after sundown, just after the appearance of *L. borealis* (Jones 1965). In Missouri, hoary bats were the last vespertilionids to be noted in the sky, about 1 h 15 min after sunset (Watkins and Shump, pers. observ.). *L. cinereus* is most active in juniper (*Juniperus*) scrub, riparian forest and desert habitats after midnight in southwestern United States (Bell 1980). They are most observed foraging over glades or lakes in forested areas (Banfield 1974).

Little is known of the hoary bat's diet, but they appear to have a strong preference for moths (Ross 1967; Black 1972). Hoary bats are also known to eat beetles, flies, grasshoppers, termites, dragonflies, and wasps (Dalquest 1943; Zinn and Baker 1979). The only time hoary bats seem to associate with other species of bats in summer is while foraging. They have been reported feeding with other species of bats, but in areas where *L. borealis* is abundant, *L. cinereus* is uncommon.

Perimyotis subflavus: tricoloured bat

Perimyotis subflavus can be easily distinguished from other smaller species of *Myotis*, with which it is easily confused, by its distinctly tricoloured hairs that are dark at the base, lighter and yellowish-brown in the middle, and dark at the tip (Nason 1948; Barbour and Davis 1969). *P. subflavus* reaches a total length from 77-89 mm and a mean weight of 7.5-7.9 g in September (Davis 1959a; Fitch 1966). The coloration of *P. subflavus* varies from pale yellow-orange to dark reddish brown dorsally, and from pale yellow-orange to dark mahogany ventrally (Davis 1959). When captured, *P. subflavus* can emit an echolocation frequency of 73 kHz, and as low as 43 kHz (Griffon 1958).

The tricoloured bat has the southernmost distribution of any bat in Ontario. In North America, it ranges throughout the eastern half of the US, north to the Great Lakes and the St. Lawrence River. In Ontario, the tricoloured bat is mostly common along the north shores of lakes Ontario and Erie, and from Kingston to Renfrew in the southeast. The northernmost records for this species were documented at hibernation sites near Espanola and Alona Bay (Dobbyn and Edger 1994).

Pipistrellus subflavus inhabits open country with large trees and also the edge of woodlands (Davis and Mumford 1962). *P. subflavus* hibernates singly, as opposed to in clusters (Guthrie 1933; McNab 1974). Common hibernating locations for *P. subflavus* include caves, mines, and other man-made structures (Hall 1962; Mumford and Whitaker 1975). Winter hibernacula and summer maternity sites are generally in separate locations (Guthrie 1933; Griffin 1936). In spring, pipistrelles disperse from hibernacula and migrate to maternity roosts. Maternity colonies are found most frequently in barns (Poole 1938; Hoying 1983) and other man-made structures (Allen 1921; Jones and Suttkus 1973). Trees, caves, and rock crevices (Allen 1921; Humphrey 1975) may also serve as maternity sites.

P. subflavus emerges from its day roost early, at about sunset. It has intermittent feeding periods to midnight and another period of feeding activity toward dawn. It flies slowly or erratically as it forages back and forth over small areas near trees or water (Dobbyn and Edger 1994). The food habits of the tricoloured bat are not well known in Canada, but in the United States, analyses of the contents of digestive tracts revealed that they feed on a variety of small insects including Homoptera, Coleoptera, Diptera and Hymenoptera (Ross 1967; Whitaker 1972).

A summary of roosting and foraging habitat for the eight species of Ontario bat may be helpful in forest management planning (Table 1). It is used to guide the interpretation of this thesis.

Table 1. Roosting and foraging habitat for eight species

Species	Abundance in Northern Ontario	Primary summer Roosts	Roosting habitat preference	Foraging habitat preference
Big brown bat (*Estesicus fuscus*)	Common	Man-made structures, hollow oak or beech trees, dead pine	Generalists	Forested areas
Eastern red bat (*Lasiurus borealis*)	Presumed rare, can be locally common	Trees, shrubs, dense shade cover	Mixed hardwood stands	Open areas, edges
Hoary bat (*Lasiurus cinereus*)	Common	Foliage, deciduous and conifers	Generalists	Glades or lakes in forested areas
Little brown bat (*Myotis lucifugus*)	Very common	Buildings, trees, under rocks, in piles of wood, occasionally in caves	Generalists	Lakes, streams, and ponds
Northern myotis (*Myotis septentrionalis*)	Common	Tall decaying trees, little canopy closer, crevices, hollow deciduous trees, maples, green ash	Forest interior	Within forests, below canopy, above shrub layer
Silver-haired bat (*Lasionycteris noctivagans*)	Erratic, can be common	Tree hollows, under loose bark	Open regions	Near coniferous and/or mixed deciduous forests, adjacent to ponds, streams
Small-footed myotis (*Myotis leibii*)	Uncommon	Buildings, face of rock bluffs, turnpike tunnels, beneath slabs of rock and stones	Hilly, mountainous regions	Open fields
Tricoloured bat (*Perimyotis subflavus*)	Uncommon	Deciduous foliage	Moderate temperatures	Riparian forest, forest-field edges

Sources:

(1) Christian 1956, Barbour and Davis 1969, Whitaker et al. 1977, Kurta 1980, Geggie and Fenton 1985, Furlonger et al. 1987, Brigham 1988

(2) McClure 1942, Constantine, 1958, Hall and Kelson 1959, Mumford, 1973, LaVal et al. 1977

(3) McTaggart-Cowan and Guiguet 1965, Banfield 1974, Shump and Shump 1982, Kurta 1995

(4) Fenton and Bell 1979, Fenton and Barclay 1980

(5) Sasse and Pekins 1996, Caceres 1998, Foster and Kurta 1999

(6) Merriam 1884, McTaggart-Cowan 1933, Turner 1974, Yates et al. 1979

(7) Mohr 1942, Adams 1950, Hitchcock 1955, Tuttle 1964, Davis et al. 1965, Barbour and Davis 1969, Neuhauser 1971, Fenton 1972, McDaniel et al. 1982

(8) Dobbyn and Edger 1994

MATERIALS AND METHODS

Study area

Transect surveys were carried out along three logging roads in Nipigon, Ontario: Black Sturgeon Road, Camp 81/Lachance Road, and Catlonite Road. The transect at Black Sturgeon Road was 45 km long, and extended 31 km southwest of Nipigon. The survey began at the northern most point of the transect and ended a few kilometers before Highway 17. Half of Black Sturgeon Road is adjacent to the Black Sturgeon River, and it also runs briefly along steep (>800 m) cliffs (Boyko 2015). The Camp 81/LaChance Road transect is a 45-km loop, beginning 1 km north of where the road intersects Highway 17, 20 km east of Nipigon. The road loops around a cliff and runs alongside a river most of its way. The forest along the road has been harvested within the past 15 years. The transect on Catlonite Road is 100 km east of Nipigon and north of Terrace Bay. The transect begins 5 km after the Highway 17 intersection and continues for 45 km. Catlonite Road runs adjacent to Aguasabon River the majority of its way.

Sampling

A SongMeter, model SM2bat, was placed on the passenger seat of an F-150 pickup truck and a microphone was duct-taped to a tent pole, which held it vertically 1 m above the roof of the truck. The microphone had a recording radius of approximately 20 m. To minimize noise, a blanket was placed over the roof of the truck and tucked into the doors. Sampling was done from year to year on two nights for each survey between June 1 and July 15, an interval during which female bats are in maternity colonies, and before migration takes place. All three transects were driven continuously at a speed of 30 km/h, and the SongMeter was recording from start to finish. Sampling began 30 min after local sunset time. Surveys were carried out under optimal conditions: wind speed <20 km/h; temperature > 13° C; no rain or fog. Fieldwork was coordinated by Ontario Ministry of Natural Resources and Forestry biologist Raymond Tyhuis (Nipigon, ON).

The recordings were uploaded and converted to .wav format. They were then assessed using an auto-detection function in SonoBat, software designed for analyzing bat echolocation calls. Identification to bat species was done by Ontario Ministry of natural Resources and Forestry biologist Mark Browning (Peterborough, ON).

Estimating bat locations

Files indicated when driving began and when it ended, also when the truck had to slow down to avoid traffic and obstacles. As well, included in the bat call analysis was the species, time when call was heard, and duration of the call.

To calculate distances, the survey end time was subtracted from the time of the call. The total trip time was calculated by subtracting the survey end time from the start time. The difference between the first two calculated values was converted into a useable decimal number. The decimal number was then divided by 60 min/h. The sum of the last calculation was multiplied by 30 km/h, representing the speed at which the vehicle was travelling, giving the final distances travelled along the survey transect where the bats were recorded in kilometers.

For example, *Estesicus fuscus* was recorded at 11:13:45 PM; the SongMeter began recording at 10:25:00 PM and stopped at 11:55:57 PM. The 'time from end of transect' was calculated using (11:55:57 PM – 10:25:00 PM), to give a time difference of 0:42:12. The 'total trip time' was calculated using (11:55:57 PM – 10:25:00 PM), to give a total time of 1:30:57. The 'time from end of transect' was subtracted from 'total trip time' (1:30:57 – 0:42:12), to give a time difference of 0:48:45, which was converted into a decimal, 48.75. The decimal was divided by 60 and multiplied by 30 to get distance travelled as 24 km (24375 m), which was then converted into meters to be used in ArcMap.

Mapping bat locations

Location tables were exported to Arc Catalog. Using Script provided by Tomislav Sapic (Lakehead Univ.) and Python software, I referenced the file locations of the exported distance tables and the created point shapefiles to automatically generate a distribution of bats along the survey transects. GPS track shape files taken of each roadway were modified to match the start and end survey locations suggested by Ray Tyhuis to increase the accuracy of call locations.

Five-hundred-meter buffers were added to each point to represent the distance a bat could travel from roosting to foraging areas. In theory, a bat should be within 20 m of the travelling vehicle when it is picked up by the recorder, and their roosting and foraging locations should appear within the allotted 500-m buffered area. Even though some bats may travel up to 1 km from their roosting to their foraging locations, a 500-m buffer was selected to prevent extreme overlap of buffered areas.

Selecting "no bat call" locations

"No bat call" locations were selected to serve as a reference for bat call locations. It was expected that "no bat call" locations would generally be further from habitat features. Once bat call locations were mapped using Python, there were naturally large gaps of areas where bats were not recorded or very few existed. In these large gaps, five points on each transect were randomly placed (Figure 1). Five-hundred-meter buffers were also added to these points and treated in the same manner as bat call locations throughout a comparison of distances to various habitat features.

Finding roosting and foraging areas

Using talus slope data (NEOGTS) from the Ministry of Northern Development and Mines and water shapefiles from the Ontario Ministry of Natural Resources and Forestry—Provincial mapping unit (Figure 2), I was able to calculate the distances between the call points/buffered areas and potential roosting/foraging areas with the Near Tool in ArcMap. There was no specific criteria for how landscape features were chosen. For water, I measured directly from the call point files by using the call points or buffers as the input feature and the land features as the output feature.

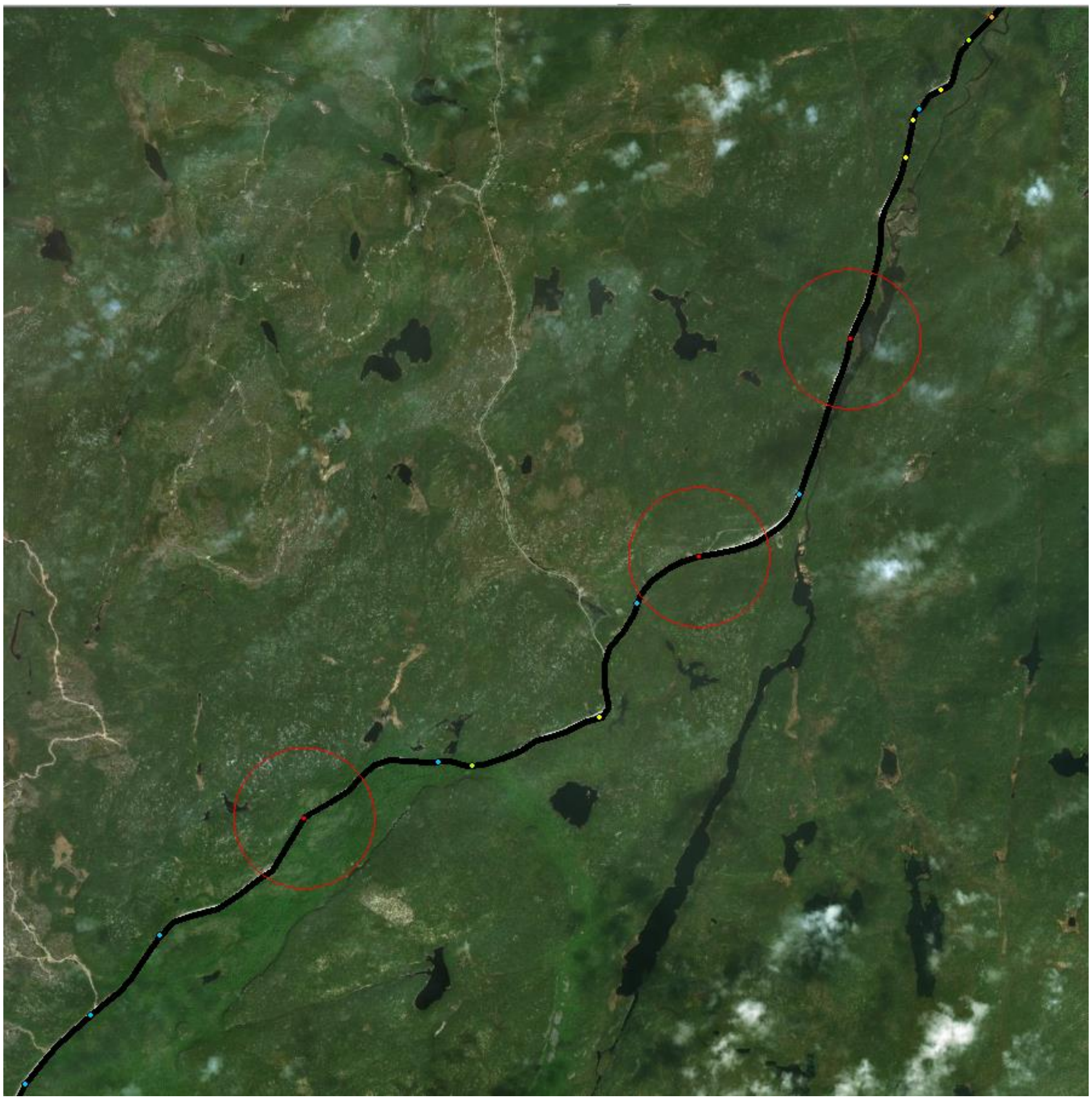

Figure 1. Placements of “no bat call” locations along Camp 81/LaChance road. No bat call locations can be seen as red dots, with a surrounding buffer zone.

Source: Dykeman 2018

The fraction of mature forest present in each buffer was estimated using the Clip Tool in ArcMap. Using Forest Resource Inventory (FRI) data as the input feature and the circular buffers around bat call and “no bat call” locations as the Clip Features, I was able to run an SQL query to select polygons that contained mature forest. Mature

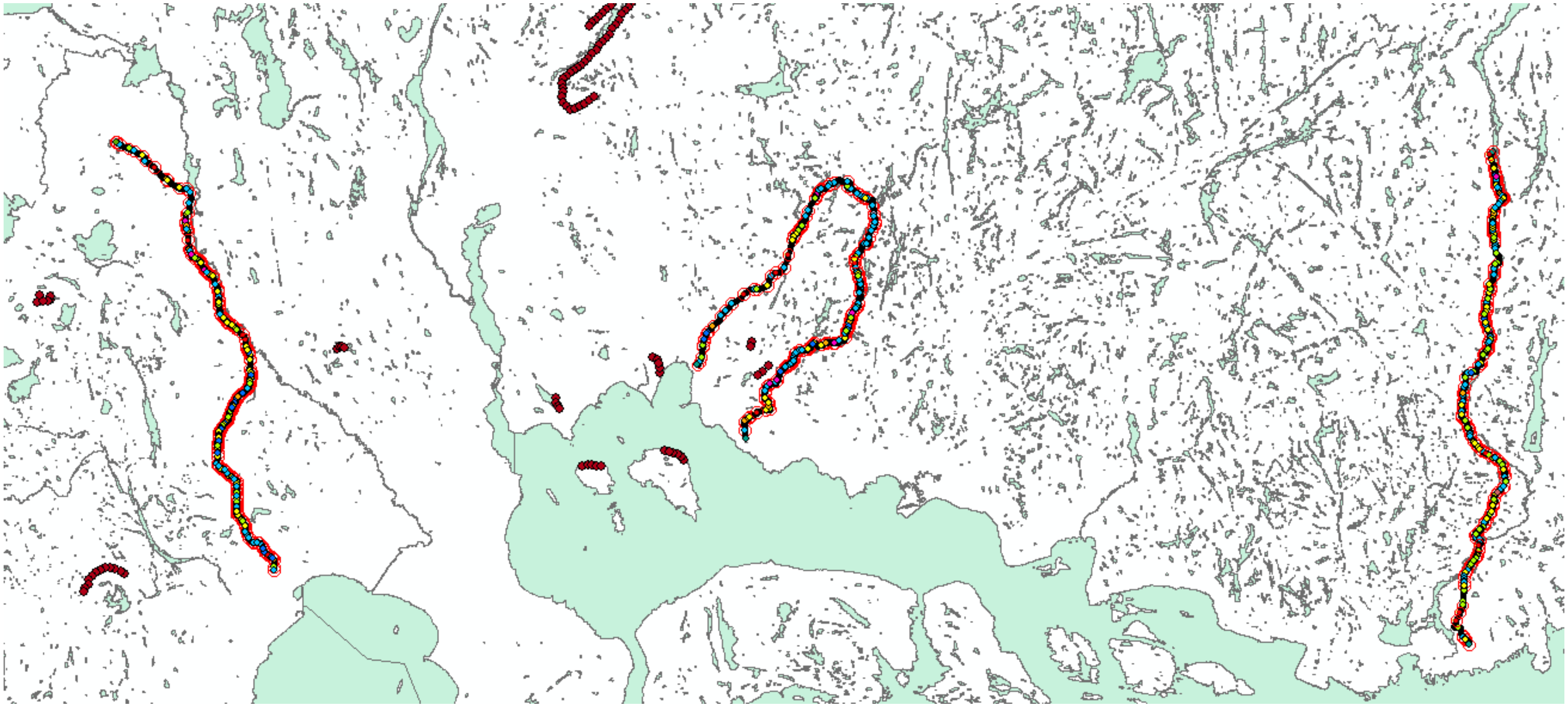

Figure 2. Habitat features used are pictured as burgundy circles (talus slopes), and water (base layer)

Source: Dykeman 2018

forest was selected if the year updated was at least 2000 and the age of the forest was ≥80 years. To calculate the total percentage of buffered area containing mature forest, I ran statistics on the 'area_shape' field and the result divided by total buffered area gave a percentage of mature forest associated with each bat location. For comparison, the same method was used to calculate the percent total mature forest in the entire Nipigon District using FRI from the Lakehead, Black Spruce, Nipigon, and Kenogami Forests, which span the locations of the transects used in the study (Figure 3).

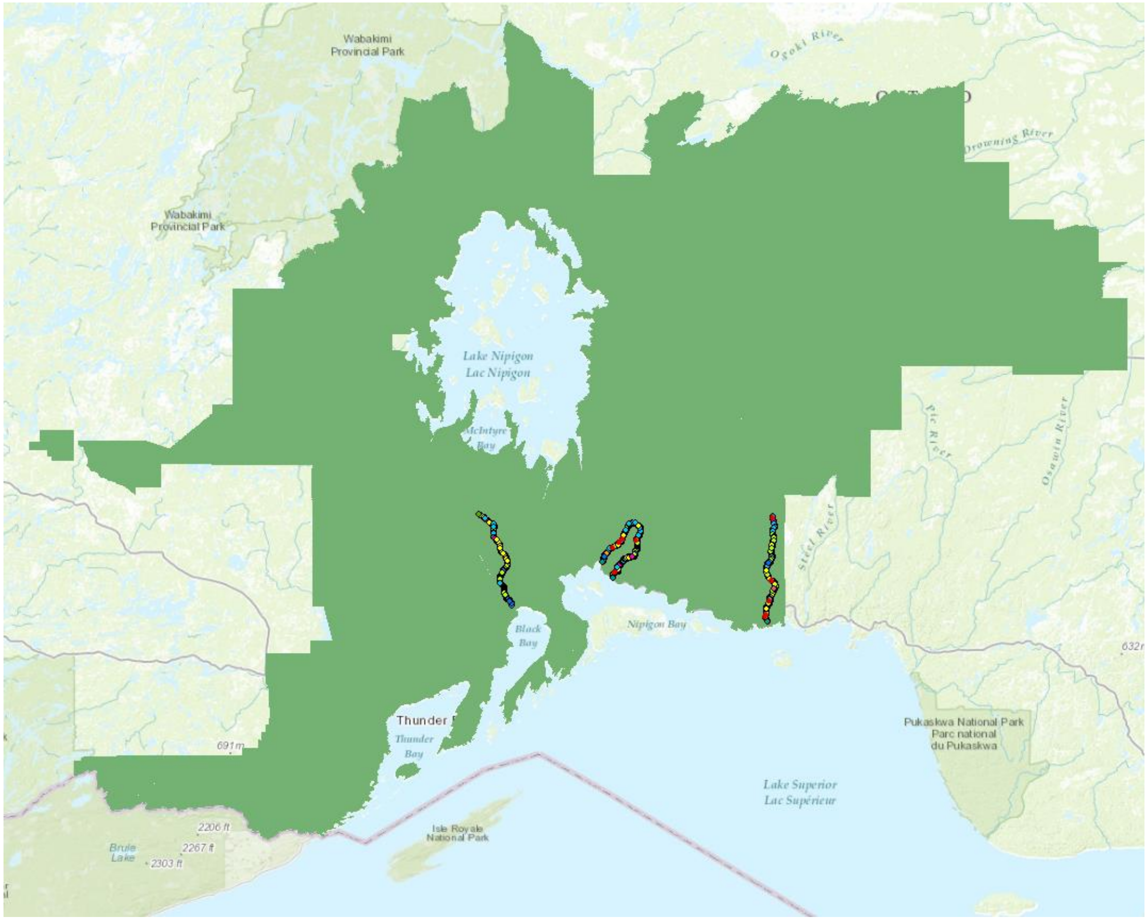

Figure 3. The area (in green) used to determine percent old-growth in the Nipigon District forest, showing a merged FRI layer of the Lakehead, Black Spruce, Nipigon, and Kenogami Forests. Source: Dykeman 2018

Selecting a talus slope for conservation

In addition to finding roosting and foraging areas, I used the near distance output data to select a talus slope that could be potentially protected in conservation measures in the future. Along with the ‘near_dist’ field found in the output table there is also an ‘Near_FID’ field that shows the talus slope feature number that the individual bat call locations are closest to. The talus slope location nearest to the most bat points was selected as a hot spot to be researched with further detail in the future.

RESULTS

In total, there were 713 bats surveyed from 2012 to 2016. *M. lucifugus* was the most commonly surveyed bat, followed by *L. cinereus* and *L. borealis* (Table 2). The least common species surveyed was *M. leibii*, with only one bat surveyed from 2012-2016, followed by *P. subflavus*. There was no significant pattern of increasing and decreasing numbers of bats surveyed over time.

Table 2. Total number of bats surveyed each year by species

Year	*E. fuscus*	*L. borealis*	*L. cinereus*	*L. noctivagans*	*M. leibii*	*M. lucifugus*	*M. septentrionalis*	*P. subflavus*	Total
2012	13	45	25	4	0	48	3	2	140
2013	13	10	28	10	0	9	2	0	72
2014	8	21	87	13	0	53	7	0	189
2015	12	28	48	20	0	102	4	0	214
2016	9	8	41	3	1	33	1	2	98
									713

Source: Dykeman 2018

Water was in closest proximity to all call locations (Table 3) and talus slopes were the furthest habitat feature from call locations (Table 4). Given its small sample size, *P. subflavus* was up to 59 km away from talus slopes in comparison with other species found to be a maximum of 18 km away from talus slopes. Most bat call locations (n = 289) were closest to a talus slope located 749 m from the Camp 81/LaChance Road (Figures 4, 5). Areas with no bat call locations were larger distance ranges to all habitat features than bat call locations (Table 3).

Table 3. Distance ranges (m) to habitat features based on species of bat with no bat call locations for comparison

Habitat Feature	*E. fuscus*	*L. borealis*	*L. cinereus*	*L. noctivagans*	
Water	270 – 290	270 – 290	270 – 290	270 – 290	
Talus slopes	15830 – 17240	15780 – 17200	15690 –17080	16100 – 17540	
Sample size	55	112	229	50	
	M. leibii	*M. lucifugus*	*M. septentrionalis*	*P. subflavus*	No bats
Water	200	270 – 290	260 – 290	120 – 150	270 – 570
Talus slopes	8780	15760 – 17180	16810 – 18370	51730 – 58870	15350 – 26930
Sample size	1	245	17	4	15

Source: Dykeman 2018

Table 4. Distance ranges (m) to habitat features based on the total number of bats surveyed

Habitat Feature	Range
Water	270 – 290
Talus slopes	15660 – 17040
Sample size	713

Source: Dykeman 2018

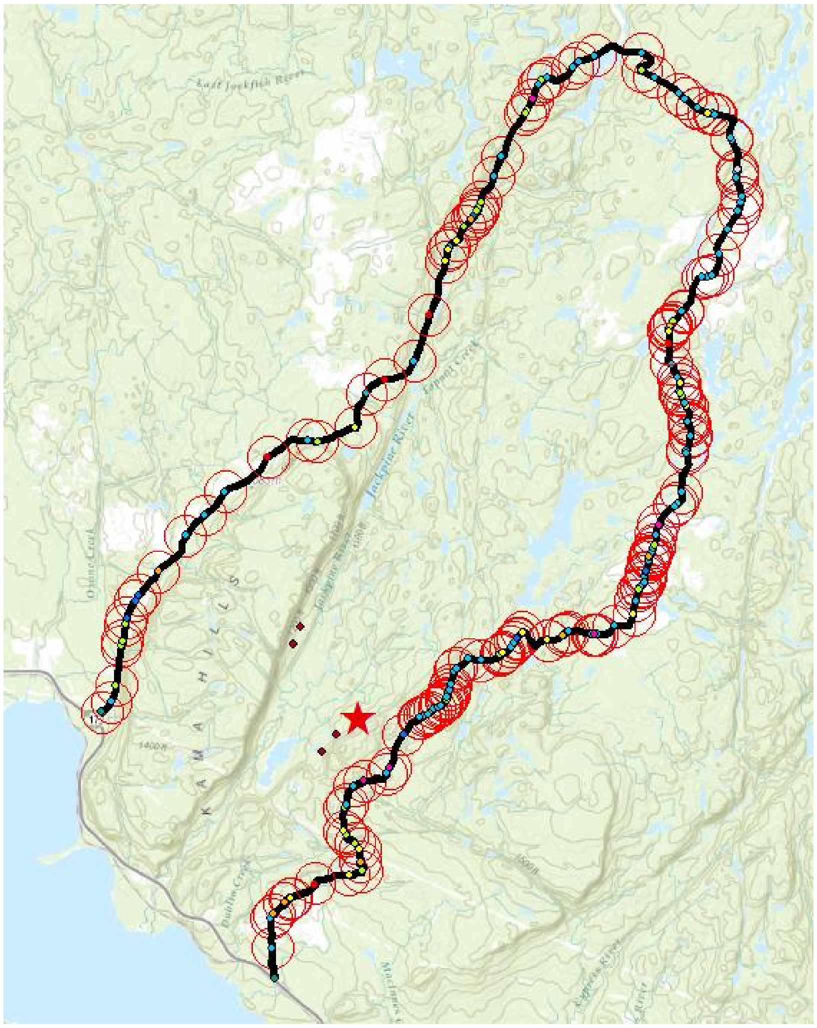

Figure 4. Bird’s-eye view of the Camp 81/LaChance Road transect in Nipigon, ON with mapped no bat and bat call locations. The talus slope (ID: 521) closest to greatest number of bat call locations is labelled with a red star.

Source: Dykeman 2018

According to the Lake Nipigon Forest Management Plan, old-growth forest definitions are tailored to individual forest types which specify their age of onset—usually between 80-150 years. In this case, however, old-growth was not selected based on species or forest unit, but selected as long as it was equal to or older then 80 years. An 80-year-old forest is usually the minimum standard for what is considered old-growth on an economic threshold. Altogether, forests representing the Nipigon District including the Nipigon, Lakehead, Black Spruce, and Kenogami forests had 4.8 % old growth. The buffered areas around the bat locations were similar, containing 4.5 % old growth forest. However, the highest concentration of this old growth occurred along the Catlonite Road transect, and none was present in buffers along the Camp 81/LaChance Road transect. “No bat buffers” had only 0.3 % old growth forest.

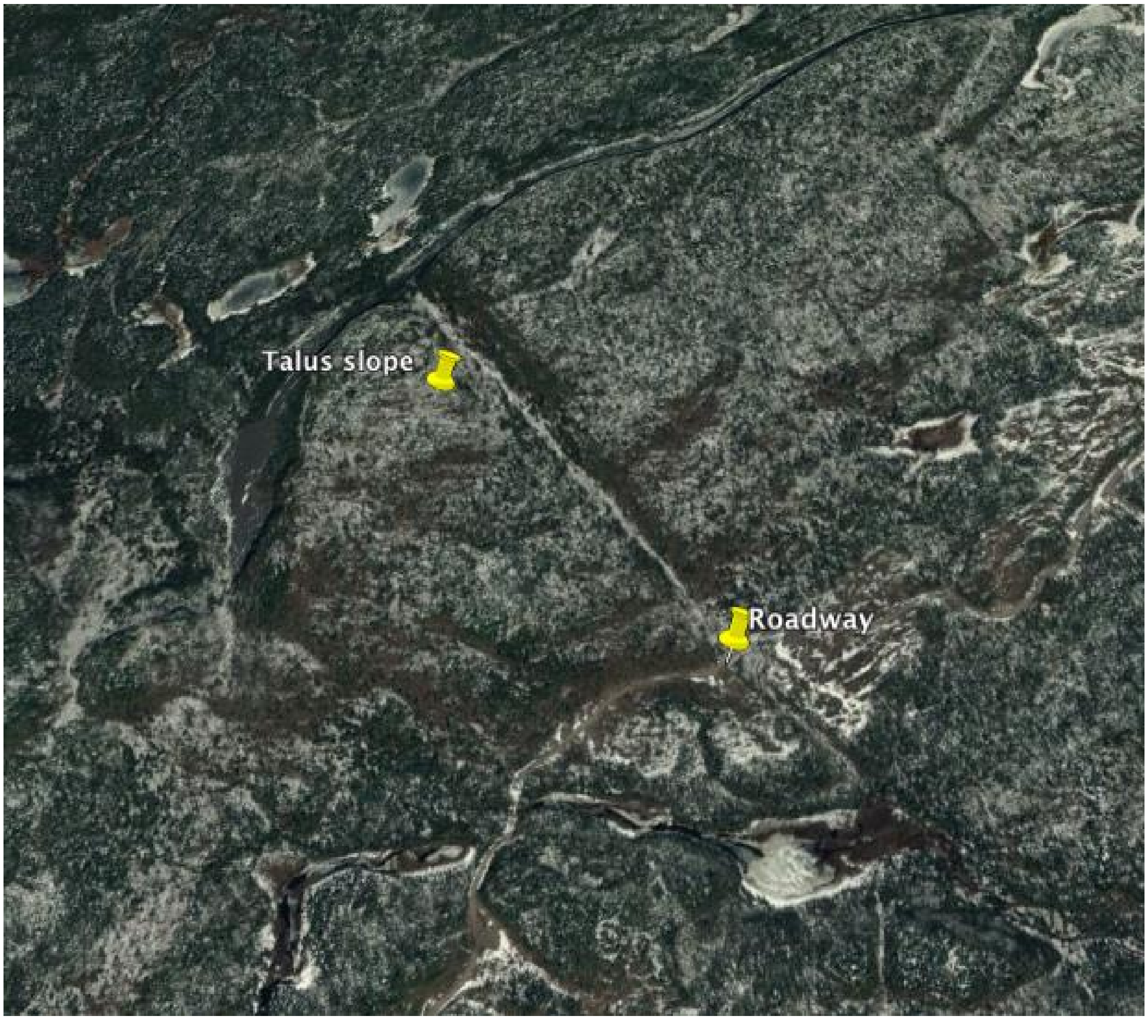

Figure 5. Close-up Google Earth view of talus slope (ID: 521) showing the proximity to Camp81/LaChance Road.

Source: Dykeman 2018

DISCUSSION

The main purpose of the study was to use habitat features such as water, talus slopes, and mature forest to find ways to predict hot spots of bat diversity in the Nipigon District. Water was the closest habitat feature to bat call locations and talus slopes were the furthest. Distance ranges to habitat features for each species were very similar, other than those of *P. subflavus*. Van Zyll de Jong (1985) suggests that *P. subflavus* roosts in the foliage of trees during the summer months and forages over water. This may explain why *P. subflavus* was found within closer proximity to water, and further from talus slopes, since talus slopes are a common roosting location. In general, the consistency of distance ranges to habitat features suggests that there is a correlation between habitat features and bat call locations, further implying the importance of conserving these areas. Even-aged management of forests creates challenges to providing within-stand structural diversity that is likely needed by bats (Kunz 1982b; Jung et al. 1999). Some species may need a diversity of tree species within a stand (Campbell et al. 1996; Kalcounis et al. 1999a); this compositional diversity is also generally lacking in intensively managed forest stands. Of greatest concern to forest management should be the provision of roost trees, in particular in larger snags and leaf trees. Several studies have documented higher use by bats of old-growth forest over young forests (Krusic et al. 1996; Jung et al. 1999). This behaviour is attributed to high availability of roosts, especially large-diameter snags (Crampton and Barclay 1996; Kalcounis et al. 1999), and a greater vertical complexity for foraging (Bradshaw 1996; Kalcounis et al. 1999). The Nipigon District as a whole was found to have a higher concentration of old-growth forest than what was found in buffered areas around bat call locations. However, clear-cuts were the most commonly documented management strategy in the FRI, suggesting that there may be a need to be strategies implemented to conserve more mature forest for bat habitat, especially in areas surrounding Black Sturgeon Road, and Camp 81/LaChance Road, where the least amount of old growth forest was found within buffered and no bat buffered areas. It may also be noted that the higher level of old-growth in the Nipigon District is due to multitude of protected forests surrounding the study area including Black Sturgeon River Provincial Park and Gravel River Conservation Reserve (Figure 6).

Currently, leaving behind residual trees after harvest is practiced in forest management, but it is possible that the level of decay and species is not carefully considered for tree roosting bats. The Lake Nipigon Forest Management Plan states that a wildlife tree must be ≥ 10 cm dbh (diameter breast height) and ≥ 3 m in height unless it is a 'large' stem or stub wildlife tree or cavity, veteran trees or super canopy trees are to be retained in which case the minimum dbh is normally ≥ 25 cm (Ministry of Natural Resources and Forestry 2015). Lacki et al. 2007 compiled information from almost 50 studies on the roosting ecology and behavior of cavity and bark roosting bats in Canada and the United States, and other parts of the world. It seems that most bats preferred to roost in deciduous and pine trees, and less likely, fir, cedar, spruce, and tamarack. Many studies report bats roosting in pines (*Pinus*), perhaps reflecting the fact that the bark of many pines loosens in large sheets as the tree decays, thereby providing roosting spaces (Vonhof and Barclay 1996; Rabe et al. 1998). Other trees,

Figure 6. Protected areas in the Nipigon District.

Source: Ministry of Natural Resources and Forestry, 2016 such as trembling aspen (*Populus tremuloides*), are used because the decay process results in internal cavities in the heartwood with entrances at branch scars or woodpecker holes (Crampton and Barclay 1998). Bats tend to also select larger trees, both in height and circumference. Larger trees have more cavities and thus more roosting opportunities (Lindenmayer et al. 1993; Evelyn et al. 2004). Roost trees tend to be in more open areas or extend above the canopy, thereby making detection and access easier, and perhaps increasing the amount of solar radiation they receive (Vonhof and Barclay 1996; Waldien et al. 2000).

Taking this into consideration, it is difficult to say whether or not the current forest management strategies in the Nipigon District are meeting the needs of tree roosting bats. It is possible that over-harvesting in the past has limited the number of large pine and hardwood trees available for roosting, and snags that are left behind are undesirable habitat for bats. There is limited information on the required amount of old growth an individual bat would require, especially since a bat's home range can be quite large (Callahan et al. 1997). We only know that old-growth forest has characteristics most desired by bats i.e., vertical complexity, higher number of roosts, and species diversity. Despite this understanding, a lack of knowledge of number of roosts required by individual bats, the extent to which roosts are limiting to bats, the relationship between number of snags and abundance and viability of bat populations makes it difficult to provide science-based advice on management strategies for bats, beyond the most general recommendations such as "maintain higher number of roost structures." Some forest plans such as the Revised Land and Resource Management

Plan for the Daniel Boone National Forest in Kentucky, call for retention of all dead and dying, potential, primary roost trees, including hardwood snags, hollow trees, and trees with rot, splits, or cracks (Krusac and Mighton 2002). Such an approach should be effective in providing for many of the roosting needs of bats, even those that frequently switch roosting sites, and it should have significant positive implications for other species closely associated with dead or decaying trees. However, this strategy may not be possible in all forest management situations, so an adaptive management strategy may be the best option in the face of so many uncertainties.

Talus slopes are considered to be very unique habitats that occupy a very small portion of the landscape but contribute significantly to the roosting and foraging activities of bats. Although many species of bats utilize these habitats, little work has been done to quantify their importance as wildlife refuges (Scharpf and Dobler 1985). As part of this research, I was able to identify a specific talus slope (ID: 521) in the Nipigon District in the closest proximity to the majority of bats surveyed, located adjacent to the Camp 81/LaChance roadway. Talus slopes may be fairly stable, but microclimates within them are very fragile and easily affected by outside disturbance (Scharpf and Dobler 1985). Even small changes in and around these features can lead to drastic changes in their indigenous wildlife, bats included. Removal of forests adjacent to these geomorphic features alters food sources, wind currents and light patterns and periodically removes visual barriers, modifies drainage patterns, and opens the area to increased human harassment, all of which impact bats that utilize these habitats (Scharpf and Dobler 1985). If it is the goal of the land manager to maintain stable environments within ‘unique habitats,’ the forest environment adjacent to the talus slopes must remain stable.

While old-growth forests have many benefits to bats with regards to roosting habitat and vertical complexity, it is important to note that some species can benefit from forest edges, clearings, and gaps for foraging habitat. A bat’s preference for foraging habitat can be judged based on its body and wing size or wing aspect ratio. Wing aspect affects the maneuverability of bats, determining their ability to forage in open or cluttered spaces (Aldridge 1986, 1987). Clear-cuts are only preferred by *Lasiurus cinereus* and *Lasionycteris noctivagans*, which are the two larger-bodied Ontario bats. In North America most bats have bodies designed for feeding in forest canopies or near the clutter of vegetation (Lacki et al. 2007). On the other hand, edges, clearings, and gaps can be maintained in forest management practices and may serve to benefit the larger-bodied species. While some positive effects result from a fragmented landscape, it difficult to conclusively say how it will impact bat populations, therefore we should make careful decisions in forest management. Maximizing the size of contiguous forest patches could increase the likelihood that the home range of the colony could be encompassed by a single patch. If fragmentation must occur, maintain wooded corridors between adjacent patches, because many species of bat consistently follow tree-lines paths rather than cross open areas (Verboom and Huitema 1997; Winhold et al. 2005).

Although acoustic sampling is a cost-effective and less invasive means of surveying bats, there are some limitations that occurred during the study that were difficult to avoid. Acoustic sampling does not provide enough information to dictate where the bats were located when the call was heard, only that the bat was within a 20-m radius of the recorder. There is also no way of knowing an exact number of bats that were recorded during a survey since a singular bat could be recorded multiple times in one night. In addition, the start and end coordinates documented for each survey were inconsistent, making it difficult to know for certain that the locations given were correct. In order to solve this issue, a common start and end coordinate should be chosen for each survey. The vehicle may have also driven above and below the assumed speed of 30 km/h which could have also affected the positioning of the bat calls. During data analysis, I was also not able to determine what makes the selected talus slope unique compared to others, but may provide a means to visit this site by foot in the future and to prevent repeatability. If a study were to take on a similar methodology, it would be wise to take a GPS track during each survey to ensure the accuracy of start and end locations and to stay consistent with detailed notes. With that all being said, the limitations in the methodology could be overlooked, since bats are naturally mobile animals, and unless we used more invasive and time-consuming methods of surveying, there is no way of calculating the exact locations of the bats.

CONCLUSION

In general, it is understood that a particular forest management strategy is desirable or undesirable for wildlife, depending on how the habitat for the wildlife species or community of interest is affected. Thus, if a logging operation creates early successional conditions, it will favour wildlife species that use early successional habitat. The Strategic Forest Management Model, or SFMM, enables Ontario foresters to analyze highly complex relationships between forest condition, silvicultural practices, wood supply and potential wildlife habitat, to understand how a forest develops through time, and to explore alternative forest management strategies and trade-offs (Zhang 2014). Unfortunely, bats are not currently represented in habitat modelling. Acoustic sampling could give a better understanding of bat habitat so it could be modelled for in SFMM, especially for species at risk. Furthermore, bat diversity hot spots, like talus slopes and the surrounding forest should be protected under the Ontario Endangered Species Act, as this study shows these areas to support the declining species in Ontario.

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