

OCCUPANCY AND MATERNITY ROOST SELECTION OF NORTHERN LONG-EARED  
BATS IN THE LAKE STATES REGION

By

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## ABSTRACT

Among the bat species most impacted by White-nose Syndrome (hereafter; WNS) is the northern long-eared bat (*Myotis septentrionalis*), which has resulted in its recent listing as federally threatened under the Endangered Species Act. Currently the specific roosting habitat requirements of northern long-eared bats in the Lake States region is poorly understood. The recent occurrence of WNS in Wisconsin affords an important opportunity to establish baseline data on the northern long-eared bat for comparison to studies done elsewhere in the species' distribution both before and at later stages of WNS occurrence. Information also is still needed on specific detection and occupancy patterns for this species in the Lake States Region to allow for the implementation of better management practices in the face of WNS and to better document imminent population declines. Misidentification of bat calls, especially those within the *Myotis* genus, is extremely common. This misidentification can introduce bias into estimates of occupancy and lead to erroneous interpretation of results i.e., causing conservation measures or mitigations to occur when in fact the species is actually absent. Utilizing models that allow for false-positive and false-negative error rates produces models with better support and more accurate site occupancy estimates.

The objectives of my research were to determine if: (1) selection of maternal roost sites by northern long-eared bats in Wisconsin is influenced by characteristics of individual roost trees and site-level habitat conditions, (2) roost selection is attributed to overall availability within the stand, and (3) occupancy of northern long-eared bats is influenced by specific large-scale and site-level habitat characteristics using site occupancy models, which account for error that can be introduced by misclassification rates.

I captured bats via mist netting at three known pre-WNS maternity sites in south-central Wisconsin in 2015 and 2016 and affixed radio transmitters to 39 female northern long-eared bats. I tracked them daily to 53 confirmed day roosts and recorded information on site and tree characteristics. I used conditional logistic regression and an *information theoretic* approach and found that the best models contained variables related to relative tree size and age (DBH, canopy class, and decay stage). Oak (*Quercus spp*) species were used most frequently as roosts at Sandhill and Black River Falls, but were used in proportion to availability. Black locust (*Robinia*

*pseudeoacacia*) trees were used most commonly at Governor Dodge, and were used more than expected based on availability.

I deployed 20 zero-crossing, frequency division bat detectors at each of 9 sampling sites in 2015 and 2016 stratified by habitat type. Detectors were left out for 10-15 capture nights. I compared two automated classifiers to identify my call files and then used the *unmarked* package in the *R* statistical program to run a false-positive occupancy analysis. I recorded 51,064 bat calls across both field seasons. The best supported single-season model for 2015 showed that elevation had the strongest effect on probability of occupancy for northern long-eared bats. The best supported single-season model for 2016 contained habitat type (wet vs. dry) as the best covariate for detectability, and distance to road as the best predictor of occupancy. The multi-year models resulted in year being the best predictor for detectability and distance to road having the most effect on site occupancy for northern long-eared bats.

The results from this research provide region-specific data for the conservation of northern long-eared bats, along with baseline data for this species in the Lake States region to serve as a comparison to other regions at varying levels of WNS occurrence. Results from this research should also provide guidance regarding forest management practices that contribute to the conservation of this species, specifically increasing availability of potential day roosts on the landscape (i.e. snag retention). Increasing summer habitat and availability of roost trees during the reproductive period may improve recruitment for this species, which might mitigate the overall detrimental population effects of WNS during hibernation. It is important to continue to contribute invaluable ecological information on this species; however, it is also crucial to continue to evaluate methods used for bat call identification, as well as occupancy estimation. Proper evaluation and use of these methods will ensure that only quality data contributes to the management of this sensitive species.

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## **CHAPTER 1:**

### **Investigating maternity roost selection of Northern long-eared bats at three sites in Wisconsin**

#### **INTRODUCTION**

North American bats face multiple threats, including anthropogenic disturbances to the winter hibernacula of cave-dwelling bats, habitat loss and degradation, and wind energy impacts (i.e., wind turbine mortality) on migratory species (Jachowski et al. 2016). Fully understanding North American bat habitat and community ecology has become critically important in recent years because of the occurrence and subsequent negative effects of the fungal pathogen white-nose syndrome (*Pseudogymnoascus destructans*; hereafter WNS). In addition to the mass mortalities of bats caused by WNS within cave hibernacula during the winter, it has been hypothesized that forest disturbances (i.e., timber harvest) may contribute to the overall decline of bat populations by reducing the availability of maternal roost trees used by communal assemblages of female bats in the summer (Johnson et al. 2011). Currently, there is a need for region-specific data on habitat conditions that are needed for increasing survival and recruitment of these sensitive bat species, given the impacts of WNS (Silvis et al. 2015a).

White-nose Syndrome is an invasive fungal disease that has devastated populations of North American cave-dwelling bat species since its discovery in New York in 2006 (Frick, et al. 2010). Estimations of upwards of 6-7 million bats have died from this disease, with most infected sites having mortality rates of 90-100%. Physiological effects from WNS, including starvation, dehydration, and respiratory acidosis contribute to the mortality of these bats (Verant et al. 2014). Subsequently, WNS has spread across much of the eastern and central regions of North America. WNS arrived in Grant County, Wisconsin in March 2014. Most recently, the fungal pathogen has spread northward and been confirmed in 14 Wisconsin counties and 12 counties in the upper peninsula of Michigan. With the confirmed presence of WNS in the Lake States Region, researchers and managers are in critical need of information that will aid in the recruitment and survival of remnant bat populations in the region.

Historically, the northern long-eared bat (*Myotis septentrionalis*; Trouessart 1897) was among the most common bat species in North America, distributed across 37 eastern and north-

central U.S. states, and in all of the Canadian provinces from the Atlantic coast to the Northwest Territories, and eastern British Columbia (Caceres and Barclay 2000). Eastern North America distributional patterns of bats pre- and post-WNS, including the northern long eared bat, are influenced by a variety of site- and landscape-level factors, including availability of prey, level of habitat fragmentation, and climate (Ford et al. 2006; Silvis et al. 2012; Coleman et al. 2013; Pauli et al. 2015). Northern long-eared bats can be found throughout Wisconsin and adjacent lake states, although they are rarely common (Jackson 1961).

The reproductive cycle of northern long-eared bats begins during the fall swarm when males and females mate while making the short migration from summer to winter habitats. Northern long-eared bats exhibit obligate embryonic diapause, in which sperm is stored in the female's uterus during winter hibernation, and delayed fertilization occurs in the spring when the females emerge from hibernation (Caceres and Barclay 2000). During the winter, northern long-eared bats hibernate in caves. After spring emergence, they occupy primarily deciduous forest habitats, roosting almost exclusively in trees or snags during the day (Faure et al. 1993; Broders et al. 2004). The northern long-eared bat range spreads across multiple regions and latitudes, and due to this distribution, roosts have been found in a wide variety of forest stand types (Silvis et al. 2016). However, there has been no formal documentation of northern long-eared bat roosting ecology in Wisconsin.

Northern long-eared bats select forest habitat during the summer and have a unique echolocation call that is higher in frequency and much softer than other Myotine bats in eastern North America. The higher frequency facilitates the maneuverable flight patterns needed to navigate cluttered forest environments as well as allow for the use of gleaning (plucking insects off of vegetation) as well as hawking (catching prey mid-flight) foraging strategies (Faure et al. 1993; Caceres and Barclay 2000). Northern long-eared bats form non-random socially associating maternity colonies that consist mostly of related females during the maternity season (May-August) within cavities or under exfoliating bark of upland roost trees or snags (Garroway and Broders 2008; Lacki and Schwierjohann 2001; Perry and Thill 2007; Silvis et al. 2014; Silvis et al. 2015*b*). In warmer, more southerly portions of its range, solar radiation is likely not a limiting factor for roost tree selection (Menzel et al. 2002). In contrast, northern long-eared bats within more northerly climates may establish maternal roost colonies in relatively open-canopied

forests to facilitate thermoregulatory needs, especially after giving birth to a pup (Johnson et al. 2011; Silvis et al. 2012; Patriquin et al. 2016). The size of maternity colonies within roost sites range from 30-60 bats (Foster and Kurta 1999). Occasionally, northern long-eared bats will form smaller temporary satellite groups within the colony, potentially resulting in smaller numbers within individual day roosts but a larger area of overall occupancy (Silvis et al. 2014). The females remain in these colonies from late spring to late summer while pregnant, when giving birth, and when rearing their single pup to volancy (Caceres and Barclay 2000).

In addition to the overall decline of northern long-eared bats observed since the onset of WNS, surviving populations of this species have suffered from poor juvenile recruitment (Francil et al. 2012; Reynolds et al. 2016). Accordingly, it is now widely accepted that the summer maternity season should be a major focus of conservation efforts designed to stabilize and recover populations of northern long-eared bats (Silvis et al. 2015a; Jachowski et al. 2016). Recent research has confirmed that the identification and conservation of high quality day roosts during the summer maternity period is particularly important for the growth and survivorship of new offspring, as well as successful adult survival (Kunz and Lumsden 2003; Pauli et al. 2015). In response, an interim 4(d) rule under the ESA is in place to protect northern long-eared bats including prohibitions on removing known or occupied maternal roost trees during forest management or activities that may disturb sites. However, a lack of information in the Lake States region on specific characteristics of maternal roost colony sites prevents wildlife and forest managers from implementing effective measures to conserve the species in this region.

In eastern North America, the population and habitat ecology of northern long-eared bats is well studied. Several studies have been published on maternity roost selection (Sasse and Perkins 1996; Lacki and Schwierjohann 2001; Menzel et al. 2002; Jung et al. 2004; Perry and Thill 2007; Henderson et al. 2008a; Johnson et al. 2011; Silvis et al. 2012), colony social structure (Foster and Kurta 1999; Willis and Brigham 2004; Silvis et al. 2014; Silvis et al. 2015b; Ford et al. 2016a), and predicted responses to forest management practices (Menzel et al. 2002; Johnson et al. 2012; Silvis et al. 2014; Pauli et al. 2015; Ford et al. 2016b). Currently in the Lake States Region, there is a lack of information on the specific habitat ecology of northern long-eared bats (Silvis et al. 2012), in particular characteristics of maternal roost colony sites in

Wisconsin and the surrounding region. This lack of information creates a gap in knowledge and precludes national-scale analyses of roost site selection to determine if regional differences occur.

Scale of habitat selection is an important factor to consider, and the most recent research has suggested moving away from defining conservation strategies for summer roosting habitat based solely on features that must be measured at the fine-scale in the field (e.g. characteristics of specific roost trees), in part because land managers often lack the ability to apply such data effectively at larger spatial scales (Pauli et al. 2015). Instead, a more effective strategy may be to combine site-level data on maternal roost site selection with landscape-level patterns of occupancy (Pauli et al. 2015).

My objectives for this research were to (1) determine if selection of maternal roost sites by northern long-eared bats in Wisconsin is influenced by characteristics of individual roost trees and site-level habitat conditions, and (2) determine if roost selection is attributed to overall availability of potential roost trees within the stand. I used methods similar to Silvis et al. (2012) and Ford et al (2006) to allow for consistency in data collection and interpretation, and for comparable results.

## **STUDY AREA**

I captured northern long-eared bats at three study sites in Wisconsin to investigate maternity roost selection: Governor Dodge State Park, Sandhill Wildlife Area, and Black River State Forest. Active capture for northern long-eared bats at all three maternity sites focused on forest corridors, areas that had acoustic detection success, and coordinates provided by the Wisconsin Department of Natural Resources (WDNR) where successful capture of northern long-eared bats had taken place in previous years (P. White, WI DNR, unpublished data).

Governor Dodge State Park (GD) (Figure 1) - GD is a 2,165-ha property located 6.6 km north of the central business district of the city of Dodgeville in Iowa County, WI. The park is dominated by oak (*Quercus spp*) – hickory (*Carya spp*) and mixed pine (*Pinus spp*) forests as well as open savanna and tallgrass prairies. This property is within the “Driftless Area” that was not subject to the most recent glaciation. As a result, hills and valleys that are much less common across the rest of the state characterize the area. Because this is a small state park used primarily for recreation, the area is not managed under any specific silvicultural regime.

Sandhill Wildlife Area (SH) (Figure 2) - SH is a 3,703-ha property located in southwestern Wood County, WI. The Grange family purchased the property in the 1930's and rehabilitated the land before ultimately selling the property to the state of Wisconsin in 1962 to be used as a wildlife education area. The state now actively manages this area to maintain early successional forest and wetland wildlife habitat. The land lies within a bed of an ancient glacial lake formed from the runoff of the glaciers in Wisconsin, and the present-day result consists of flat, marshy land interspersed with oak and aspen stands. Oak wilt (*Ceratocystis fagacearum*) has plagued Sandhill for the past 45 years and as a result, there is an abundance of available oak snags (WDNR Central Office 2014).

Black River State Forest (BR) (Figure 3a) - BR is a 27,519-ha state forest located in Jackson and Clark counties, 19 km south of Black River in west-central Wisconsin. Glaciation strongly influenced this area and the resulting topography includes buttes, hills, knolls, and ridges across the landscape. The area was originally dominated by red (*Pinus resinosa*) and white pines (*Pinus strobus*) until it was heavily logged from 1880 – 1895. The state actively manages 31 stands comprising 1,252 acres within the state forest (68.5% of all state forest acreage) for biannual timber harvest with a combination of thinnings and regeneration cuts (P. Bakken, WDNR, unpublished data). The dominant forest structure consists of jack pine (*Pinus banksiana*), oak, and aspen (*Populus* spp.) species.

## **FIELD METHODS**

I conducted nightly bat surveys using mist nets (Bat Conservation and Management Inc., Carlisle, PA, USA) to capture northern long-eared bats at each of my maternity roost sites (GD, SH and BR). I captured bats between May and July of 2015 and 2016 to target females during the maternity season. Mist net deployment was dependent on the site being netted, but generally consisted of one or two 6-12 m mesh nets set up across a forest corridor on a pulley system between two aluminum poles (Silvis et al. 2012; Owen et al. 2002). Netting began on the night of arrival at each site and concluded once a sufficient sample size of female northern long-eared bats was captured (n = 15 at each site) or after three consecutive weeks of netting. Nets were assembled and opened before sunset (approximately 20:00). Netting continued until capture rates decreased to one bat every hour or until 00:00. For every bat captured, I recorded sex, age (by degree of epiphyseal fusion), mass (g), right forearm length (RFA), and reproductive condition

(Silvis et al. 2012). Unique lipped aluminum identification bands were attached on the left forearms of all female bats and right forearms of all male bats according to WDNR protocol. I also removed a small section of fur and affixed radio transmitters (LB-2X, 0.27g; Holohil Systems Ltd., Woodlawn, ON) between the scapulae of female northern long-eared bats using surgical cement (Perma-Type; Plainville, CT, USA)(Silvis et al., 2012). The <6% of pre-attachment body weight (including transmitter and surgical glue) rule was followed when tagging individual females as required by the federal permit. Within 30 minutes of capture, bats were released near net sites. All field and handling procedures followed the guidelines of the Wisconsin Endangered and Threatened Species Permit #1005, the Federal Fish and Wildlife - Native Threatened Species Recovery permit #TE86141B-0, and were approved by UWSP IACUC #2015.04.05. Following federal protocol, after each capture night all nets and equipment were decontaminated using Lysol wipes and a 1:10 bleach solution to prevent any unintentional spread of fungal pathogen between study sites.

Each day following a successful capture, I used TRX-2000NB receivers (Wildlife Materials Inc., Murphysboro, IL, USA) and folding Yagi antennas (Models F151-3FB and F152-3FB) to locate transmitted females at the current day roost tree. Subsequently, all female northern long-eared bats were tracked daily to each day roost tree for the life of the transmitter or until it was dropped from the bat. A Garmin eTrex-10 handheld global positioning system was used to record all roost trees locations. Once a roost tree was located, and if the tree itself was nettable (roost entrance within mist net height, no obstructing trunk branches), nets were strung up around the tree in a circular fashion to obstruct the roost entrance and capture as many individuals within the colony as possible. Netting at individual roost trees never exceeded 2-3 nights in a row to reduce potential stress on the colony. At each confirmed roost tree, vegetative data collection was based on the methods found in Silvis et al. (2012) and included roost tree species, diameter at breast height (DBH), total tree height (m), roost entrance height (m), decay class (1: alive, 2: declining, 3: dead, 4: loose bark, 5: clean, 6: broken top, 7: stump), canopy class (1: emergent, 2: dominant, 3: mid-story, 4: suppressed), percent canopy cover (average of four densitometer readings in each cardinal direction), percent bark remaining, and basal area (factor 10).

The selection and measurement of neighboring trees followed the 4 point-quarter system (Silvis et al. 2012). For each of the four potential roost trees selected in each cardinal direction

quadrant, I recorded tree species, distance to roost tree (m), DBH, total tree height (m), decay class, canopy class, and whether or not roosting opportunities existed (bark/cavity).

Based on previous studies, it is still unclear whether or not day roost availability within a stand is a strong driving force for northern long-eared bat roost selection and social structure because northern bat roost use and social patterns vary widely amongst colonies and across regions (Jachowski et al. 2015; Silvis et al. 2012; Silvis et al. 2015). To investigate trends between used day roost trees and available potential roost trees in the forest stand, I recorded potential roosts (i.e. trees with exfoliating bark, cavities, or other visible defects) by species along a randomly directed transect (20m x 100m) emanating from the roost location (Ford et al. 2006; Silvis et al. 2012).

## **ANALYTICAL METHODS**

Comparing used roost tree parameters with both selected and random available roost trees is accepted as a valid method to assess evidence regarding roost selection (Clement and Castleberry 2013; Silvis et al. 2012; Silvis et al. 2014). I used a Chi-square Goodness of fit test to analyze the proportions of potential roost tree species within the stand compared to known and occupied roost trees to characterize larger unused roost availability for a secondary comparison of roost selection. I used an *information theoretic* approach (IT) coupled with conditional logistic regression to compare individual roost tree characteristics to the four nearest neighboring and available trees (Silvis et al. 2012; Anderson and Burnham 2002). To do this, I examined models that included a null and global model, models containing each variable individually, and candidate models representing site-level tree characteristics, site and year variables with the tree characteristics, and a model representing relative tree size and age (Table 1). I ranked models using Akaike's criteria (AICc) corrected for small sample sizes, delta AICc ( $\Delta$ ), and Akaike's weights ( $w_i$ ). I considered models with  $\Delta \leq 2$  to have sufficient empirical support among all models.

All analyses were conducted in the *R* statistical program (version 1.01.36). Preliminary data exploration included checking for overdispersion in the global model and correlations across variables, as well as a VIF (variance inflation factor) analysis (Zuur et al. 2010).

The diagnostic tests did not identify overdispersion or collinearity between variables; however, I discovered a weak positive correlation between DBH and tree height ( $r = 0.652$ ), as well as a weak negative correlation between canopy class and tree height ( $r = -0.613$ ). All other correlation coefficients were  $<0.60$ . I retained DBH and crown class, which are relative measures of tree size and height, and removed actual tree height as a measure (Johnson et al. 2012).

## RESULTS

I captured 40 adult females and 6 adult male northern long-eared bats during the summer field seasons of 2015 and 2016, from May 20 - June 29, across 3 maternity sites (GD, SH, BR). Of those females, 23 were pregnant or lactating, and the remaining 17 were non-reproductive at the time of capture. I caught 9 female and 4 male northern long-eared bats at GD in 2015 (Figure 1), 8 females at SH in 2015 (Figure 2), and 8 females at BR in 2015 (Figure 3). I caught 15 females and 2 males at SH in 2016 (Figure 2). I was not able to capture northern long-eared bats at GD or BR during the 2016 season. All females except one (an escapee) were affixed with a radio transmitter and tracked for an average of 7.2 days, excluding 6 transmitters that were defective due to soldering issues and did not provide movement data. Total number of tagged bats found occupying the same tree at one time ranged from 1-7. When emergence counts could be conducted, anywhere from 1-30 bats were observed exiting a roost tree, with an average of 12 bats sharing one tree at a given time. Some females roosted in different trees every day, while others returned to the same day roost for up to 4 days in a row. On average, females switched roosts every 1.45 days.

I was able to confirm 52 trees that consisted of 9 species as day roosts based on 94 total relocation events from telemetry data. Tagged females used 6 day roost trees at GD in 2015 (Table 5a), 13 trees at SH in 2015 (Table 5b), 16 trees at BR in 2015 (Table 5c), and 17 trees at SH in 2016 (Table 5b). Oaks (*Quercus spp.*) were most commonly used by bats at SH and BR, while Black Locust (*Robinia pseudoacacia*) trees were most commonly used at GD. Of those trees confirmed as day roosts, 69.8% were within the dominant canopy class, 22.6% were in the suppressed canopy class, 5.6% were in the midstory canopy class, and only 1.8% (a single roost tree) was in the emergent canopy class. Average DBH of used day roosts across all sites and years was 32.9 cm, average height was 16.9 m, average basal area was 10.45 (factor 10), and average level of canopy cover was 69.3%. Decay stage was 3.4 on average suggesting that most

confirmed day roosts were dead or declining to some degree. Based on an average of 83.6% bark remaining on day roost trees, bark retention was relatively high. Of the 53 day roosts located, 29 were under exfoliating bark, 21 were in cavities or crevices, and 2 were unknown. Roosting locations were on average 7.9 m high on the roost tree.

At GD, the most commonly used tree species was black locust, and it was used more than expected based on general species availability on the landscape ( $X^2 = 18.547$ ,  $df = 3$ ,  $P = 0.0003$ ). Oak species were used proportionally according to their availability at both SH and BR (SH:  $X^2 = 0.964$ ,  $df = 2$ ,  $P = 0.617$ ; BR:  $X^2 = 0.472$ ,  $df = 2$ ,  $P = 0.789$ ).

The best supported model differentiating used day roosts from nearby available trees contained covariates describing site-specific tree characteristics such as tree species, DBH, decay stage, and canopy class. However, two models were within 2 AICc points of the best model, and all three top models had a  $\Delta AICc \leq 2$  (Table 2). Therefore, I interpreted the most parsimonious model. Under this model, the odds of a tree being used by a bat increased with DBH and decay stage, and decreased with canopy class (Table 3). This model provided a better fit than both the null and global models (log-likelihood = -120.35), and accounted for 18% of the model weight ( $w_i = 0.18$ ).

## DISCUSSION

This is the first in-depth study modeling roost selection for the northern long-eared bat in Wisconsin. Extensive monitoring by the DNR in the past coupled with the results from this study should provide crucial information regarding maternal roost usage by northern long-eared bats in this region.

Results from the analysis on roost tree selection comparing used roost tree characteristics to available trees in the stand supports previous studies relating site-level tree characteristics to overall roost availability (Henderson & Broders 2008; Jachowski et al. 2016; Jung et al. 2004; Lacki & Schwierjohann 2001; Sasse & Perkins 1996; Thomas 1988). Models representing tree characteristics and relative tree size (i.e. DBH, decay stage, and canopy class) best explained the differences in the odds of a bat using a tree as a roost. While I was able to show that my data accurately fit the models through preliminary data exploration, overall results from the models were relatively weak. The null model ranked higher than most single variable models, and

differences in AICc values was minimal amongst top models. However, all three best supported models, including the most parsimonious model, support results found elsewhere in the country, and further exploration with similar studies may strengthen the results obtained by this project for this region.

There has been considerable research in recent years on roost selection by northern long-eared bats during the summer months. Previous research supports our findings that this species roosts most often in larger, taller, more mature trees in later stages of decay (Jung et al. 2004; Lacki & Schwierjohann 2001; Pysllakis & Brigham 2005; Sasse & Perkins 1996; Thomas 1988). Johnson et al. (2009) found that in the presence of a prescribed burn regime in the Appalachia Region, the fire disturbance allowed this species to use trees that were smaller in diameter and in higher canopy classes, but in their control group they found bats selecting trees of greater size and decay stage, as expected. Trees that have these characteristics tend to have greater amounts of quality roosting habitat (i.e. exfoliating bark, cavities, crevices), and the presence of more trees with these characteristics within a stand increases overall suitable roost habitat availability for these bats (Henderson & Broders 2008; Jung et al. 2004; Thomas 1988).

A number of previous studies have documented that solar radiation is a crucial habitat requirement for female bats during the reproductive period to satisfy thermoregulatory needs during the lactation period (Garroway & Broders 2008; Perry & Thill 2007). This means that roosts are generally higher in the canopy, or in trees that are in more open-canopied forests (Garroway & Broders 2008; Pysllakis & Brigham 2005). It is also suggested that this requirement may vary depending on regional differences. In southern regions, where the climate is generally warmer, females may not be as dependent on open-canopied roosting areas to meet their energy demands (Silvis et al. 2012). Average canopy cover at roost tree sites across all sites and years was 69.3% (+/-25.7), and this supports findings of similar studies in more northern climates (Garroway & Broders 2008; Owen et al. 2002), and as expected is in contrast to similar studies conducted further south (Ford et al. 2006; Silvis et al. 2012).

The role that tree species composition plays in roost selection varies among studies. However, availability of quality day roost opportunities tends to be the most widely accepted contributing factor for selection, and can vary depending on the region and the species pool of roosts therein. Results from the secondary analysis of roost selection comparing proportions of

used day roost trees to available trees in the stand revealed that at two field sites (SH and BR), roost tree species were used within proportion to availability, while at GD black locust trees were used more than expected based on stand availability. Similar studies on the northern long-eared bat in the east have documented selection of black locust as a quality roost tree due to it being a canopy-dominant and long-lasting species, thereby supporting consistent and stable roosting areas for bats across multiple seasons (Ford et al. 2006; Johnson et al. 2009; Menzel et al. 2002; Silvis et al. 2012). Black locust trees are native to a small area in southeast North America, but considered an invasive species in Wisconsin and adjacent states. Sandhill and Black River Falls are both actively managed forests in Wisconsin, SH is managed primarily managed for wildlife habitat and timber sale, while BR is extensively managed for timber sale and invasive species control. Alternatively, Governor Dodge lacks any forest management due to a deficit in personnel, small land area, and its purpose as a park for non-consumptive recreation. It is entirely possible that SH and BR lack black locust trees on the landscape due to the active forest management that takes place, while black locust thrives and outcompetes the other early successional species at GD in the absence of management. The presence of a population of high quality black locust trees could explain the unexpected use of that species compared to availability of other common roost species on the landscape at GD.

For future studies investigating maternal roost selection of the northern long-eared bat in Wisconsin and adjacent states, consideration of a number of variables not measured in this project would strengthen overall knowledge and support for ecological data on this species. For example, capture rates were low most nights, and obtaining a sufficient sample size was difficult. In Europe, the use of acoustical lures to attract bat species to netting sites proves a valid method to increase overall capture success (Hill & Greenway 2005). This approach is now emerging as a strategy in North America. Additionally, emergence counts are crucial data for sensitive species like the northern long-eared bat. A lack in emergence count consistency for this project was due to a shortage in personnel and competing objectives. In the future, if data on emergence counts were coupled with roost selection data, a network and social structure analysis could take place and be compared to similar studies done in the east for a further investigation into the roosting ecology of this species regionally (Silvis et al. 2014). Finally, differences in female northern long eared bat roosting behavior temporally throughout the maternity season has been demonstrated in previous studies (Silvis et al. 2012; Silvis et al. 2014; Garroway & Broders 2008), although it

was not a variable considered for this project. Expanding on this study with the addition of a network analysis and seasonal variation would further expand our knowledge of this species in Wisconsin and the surrounding region.

## **MANAGEMENT IMPLICATIONS**

The northern-long eared bat is currently facing severe population declines because of the recent occurrence of WNS, coupled with previous stressors including habitat loss and wind energy development (Langwig et al. 2015; Henderson et al. 2008b; Arnett et al. 2008; Barclay et al. 2007). A primary threat to this species is WNS, and currently there are no proven population-level treatments for this disease. Therefore, until a viable solution for WNS is developed the focus for mitigation strategies should be on more controllable stressors such as habitat loss and forest fragmentation. USFWS declined to determine critical habitat for this species based on literature suggesting the species is opportunistic in terms of roost selection, and is able to use a wide variety of roost habitats. The supportive results from this research provides guidance regarding forest management practices for the summer roosting habitat of this species in Wisconsin, specifically by maintaining the availability of roosting opportunities on the landscape. According to my results, limiting hardwood timber harvest or management during the summer season, and retaining snags and trees of a larger DBH and in later stages of decay will avoid direct take of northern long-eared bats and mitigate detrimental effects on populations during the summer reproductive season. Managing for availability of maternal roosts during the reproductive period for the northern long-eared bats has the potential to increase juvenile recruitment and adult survivorship entering into winter hibernation, which may in turn mitigate the detrimental impact of WNS on populations overall.

## CHAPTER 2:

### Occupancy of Northern long-eared bats in the Lake States Region using models that allow for misclassification errors

#### INTRODUCTION

Fully understanding North American bat distributions and ecology has become critically important in recent years because of the emergence of the fungal pathogen *Pseudogymnoascus destructans*, the causative agent of White-nose syndrome, hereafter WNS. Among the species most impacted by WNS is the northern long-eared bat, resulting in the recent listing of the species as federally threatened under the Endangered Species Act. In the summer, this species is forest-dwelling, which results in additional stressors from forest fragmentation and land use shifts during the reproductive months (Yates and Muzika 2006). With the recent confirmation of WNS in the Lake States Region, there is a need for additional information on detection and occupancy patterns for this species. Managers are in critical need of information that will improve tactics for monitoring and managing remnant populations.

Historically, the northern long-eared bat was among the most common bat species in North America, distributed across 37 eastern and north-central U.S. states, and in all of the Canadian provinces from the Atlantic coast to the Northwest Territories, and eastern British Columbia (Caceres and Barclay 2000). Eastern North America distributional patterns of bats pre- and post-WNS, including the northern long eared bat, are influenced by a variety of site- and landscape-level factors, including availability of prey, level of habitat fragmentation, and climate (Ford et al. 2006a; Silvis et al. 2012; Coleman et al. 2013; Pauli et al. 2015). Northern long-eared bats are found throughout Wisconsin and adjacent lake states, but they are not common (Jackson 1961). Previous research indicates that at smaller habitat scales, bat activity levels are related to proximity of riparian habitats, higher basal area, and invertebrate prey abundance (Jung et al. 1999; Ford et al. 2005; Menzel et al. 2005; Ford et al. 2006a; Henderson et al. 2008a; Jachowski et al. 2016). At larger spatial scales, bat occupancy and activity is related to overall abundance of day roosts, proximity of foraging habitats to roost sites, and the frequency and level of disturbances on the landscape (Henderson et al. 2008a; Silvis et al. 2014; Pauli et al. 2015). In eastern North America, the ecology of northern long-eared bats has been well studied, including

patterns of occupancy (Ford et al. 2005; Weller 2008; Coleman et al. 2013; Burns et al. 2015; Pauli et al. 2015). However, in other parts of the range, including the Lake States Region, there is a lack of information on specific patterns of detection and occupancy for this species.

Because bats can be identified from the ultrasonic echolocation calls they use to forage and communicate, as some calls of each species are unique and adapted to its specific ecology (Jones and Holderied 2007), acoustics yield an efficient way to document bat distribution and activity patterns. Acoustic identification of bats may be performed quantitatively with automated classification software, or classification keys (Britzke et al. 2002, Britzke et al. 2011) using call parameters (i.e. frequency, slope, duration of call), or qualitatively with visual examination of call characteristics (i.e. pattern in minimum frequency, call shape). Relative to other Myotine species in the eastern United States, northern long-eared bat calls typically have a characteristic short duration, high frequency, and high slope call of low amplitude (Faure et al. 1993). These call characteristics are reflective of the gleaning foraging strategy (plucking insect prey off surfaces versus exclusively aerially hawking) used by this species, as well as its use of dense forest conditions.

In situations where program agreement on call identification is inconsistent (Table 7), there is support for the use of a new method of modeling occupancy of a species that is rare or difficult to detect, as the northern long-eared bat is. Support for using models that account for false-positive and false-negative detections versus traditional occupancy models is well documented in the literature (Royle and Link 2006; Miler et al. 2011). According to Miller et al (2011), removing uncertain detections from the dataset and running traditional occupancy models on the data resulted in weaker model performance and estimates overall. This suggests that when imperfect detection is accounted for in the modeling procedure, uncertain detections contain critical information that improve detection and occupancy estimates overall.

Recently it has been reported that shifts are taking place in forest ownership in Wisconsin (Yates and Muzika 2006; Perry et al 2007). The majority of Wisconsin forests are privately owned (68%), with 56% being nonindustrial owners. However, private entities are selling their land to state and other private owners, leading to shifts in owner goals and land management. This can result in changes in availability of forest for natural resource management, protection and monitoring (Perry et al 2007). These shifts in forest management and the recent occurrence

of WNS in Wisconsin provides an important opportunity to establish baseline data on the detection and occupancy of northern long-eared bats in this region.

My objective was to determine if site occupancy by northern long-eared bats in Wisconsin and the Upper Peninsula of Michigan is related to site- or landscape-level habitat characteristics using site occupancy models, which account for error that can be introduced by misclassification rates, i.e., false positive and false negative errors.

## **STUDY AREA**

Acoustic surveying took place at nine field sites, seven in Wisconsin, and two in the Upper Peninsula (UP) of Michigan. In Wisconsin, detectors were deployed at Governor Dodge State Park (Iowa county), Sandhill Wildlife Area (Wood county), Black River Falls State Forest (Jackson county), Brule River State Forest (Douglas county), the northwestern portion of Chequamegon-Nicolet National Forest (Bayfield county), multiple sites on private land owned by The Forestland Group (TFG) near Pelican Lake (Oneida county), and Necedah Wildlife Refuge (Juneau county). In the UP of Michigan, two sites owned by TFG were visited in Ontonagon, Baraga, and Alger counties. Aside from the TFG properties, all sites were public lands. The definition of an acoustic “site” is detectors that were out consecutively at a spatially independent location for the same amount of time (10-15 nights).

## **FIELD METHODS**

I used Song Meter SMZC acoustic recorders (Wildlife Acoustics; Maynard, MA, USA) to survey bat species during the summers of 2015 and 2016 at 247 detector survey locations for 153 nights across 9 sites (Figure 4). Each detector was programmed to record from sunset to sunrise to preserve battery life and data storage space. To determine the location of detectors, ArcMap (version 10.3.1) was used to create twenty random points stratified by wet (e.g. riparian) and dry (e.g. upland) cover types for each site. The only exception to this was at Necedah Wildlife Refuge, where arrangement of detectors was in short transects in specific areas of the refuge to meet the goals and interests of the refuge. Each detector was strapped to a mature tree at least 2m into the canopy with bungee cords. Detectors recorded for 10-15 consecutive detection nights pre-programmed to record from sunset to sunrise to maximize battery life and data storage. To reduce the risk of multiple detectors recording data from the same bat simultaneously, I ensured

separation of detectors by at least 200-250m (Coleman et al. 2014). At each detector deployment location, I recorded the coordinates using a Garmin eTrex-10 handheld global positioning system along with the following site-level habitat characteristics: distance (m) and canopy class (1- emergent, 2- dominant, 3- mid story, 4- suppressed) of the four closest neighboring trees in each cardinal direction, elevation, basal area (factor 10), and a brief site description (Coleman et al. 2014).

## **ANALYTICAL METHODS**

Before analyzing the call files with automated classifiers, I used the Britzke and Murray (BM) noise filter reviewed by Clement et al. (2014) to scan files in program Analook (version 4.1t, Corben 2015) and identify all those that contained  $\geq 3$  pulses (Johnson et al. 2008). I then used the *R* statistical program (version 0.99.903) to extract and delete all call files that did not meet the criteria for a bat call.

I ran the entirety of my cleaned call data through the Kaleidoscope Pro (version 3.1.6, Wildlife Acoustics; Maynard, MA, USA) and Echoclass (version 3.1, Eric Britzke, ERDC) programs, both of which are federally-approved automated classifiers. Both of these programs supply output information that has an associated probability of misidentification within a range of zero to one (0 : no chance of misidentification – 1 : almost certainly misidentified) for each species identified at each detector site. I also manually checked a small subset of my call files to ensure the programs were operating properly, but without altering any of the assigned IDs to avoid introducing an immeasurable amount of error into call identification.

I assigned occupancy values for each detector site based on whether or not the two programs agreed on species ID (2 – certain), disagreed (1 – uncertain), or there was no detection at all (0) (Royle & Link 2006; Miller et al. 2011). Data cards collected from songmeters that provided no data were not included in the analysis. I ran an occupancy analysis in the *R* package *Unmarked* using the “occuFP” function, which accounts for false-negative and false-positive errors.

I used an a priori approach to fit models containing the covariates of year, site, distance to water, distance to road, wet vs. dry habitat type, elevation, and canopy class to see if detection or site occupancy estimates were associated with any site- or landscape-level habitat

characteristics for the northern long-eared bat. To determine if these covariates influenced detectability or probability of occupancy, I ran single season models for both 2015 and 2016. To determine if year had any influence on the models I ran multi-year models on only those sites (GD, SH, BR, BF) that I visited in both 2015 and 2016. I began by fitting the data to a null model with detection ( $p$ ) and occupancy ( $\Psi$ ) held as constant. For each round of modeling I then built the best model for detection by exploring which covariate led to the lowest overall AIC value (Yates and Muzika 2006). After determining the best model based on AIC for detecting the northern long-eared bat, I ran each of the covariates in single variable occupancy models, while retaining my best covariate for detection, to find the best model of site occupancy.

## RESULTS

Out of the 247 detector survey locations, 233 successfully recorded 51,064 bat calls across both years (Table 7). Detectors recorded northern long-eared bats at all sites except two in 2015 (Brule and Pelican Lake). Kaleidoscope identified 2,878 northern long-eared bat calls while Echoclass identified 2,291, suggesting some inconsistencies between the two programs for bat call ID. Seven bat species were detected in Wisconsin and Michigan during the 2 seasons of capture effort: the big brown bat (*Eptesicus fuscus*), Eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivigans*), little brown bat (*Myotis lucifugus*), northern long-eared bat (*Myotis septentrionalis*), and tri-colored bat (*Perimyotis subflavus*).

Out of 316 detections of northern long-eared bats by the automated classifiers, 206 were considered “uncertain” detections due to program disagreement on ID or the error probabilities not meeting the significance threshold. This means that only 35% of the northern long-eared bat calls recorded were identified with confidence, while the remaining 65%, although labeled as northern long-eared bats, could not be considered definitive identifications going into the occupancy analysis.

I found no significant covariates related to detectability of northern long-eared bats in the single-season models for 2015. The occupancy models with detection probability ( $p$ ) held as constant for 2015 resulted in a top model including elevation as the best covariate for predicting occupancy (Table 8; Figure 5). In this top model, probability of occupancy increased ( $\Psi = 0.15$ ,

SE = 0.03) as elevation decreased (Table 11), and probability of false-positive detection error with no covariates added was 0.004.

The single-season models for 2016 revealed the covariate for habitat type (wet vs. dry) having the most effect on detectability of northern long-eared bats. The best occupancy model was a model containing distance to road as the best indicator of site occupancy. Under this top model (Table 9), detection probabilities were lower in wet habitat types ( $p = 0.42$ , SE = 0.05) compared to dry habitat types ( $p = 0.55$ , SE = 0.04), probability of occupancy increased ( $\Psi = 0.43$ , SE = 0.08) as a function of distance to road (Table 11; Figure 6), and probability of false-positive detection error with no covariates added was 0.05.

The multi-year model investigating year effects on the detection and occupancy of northern long-eared bats along with site- and landscape-level variables resulted in year being the best predictor for detectability, and distance to road having the most effect on site occupancy (Table 10). Under this top model, detection probabilities decreased in 2016 ( $p = 0.43$ , SE = 0.03) compared to 2015 ( $p = 0.69$ , SE = 0.03), probability of occupancy increased ( $\Psi = 0.45$ , SE = 0.05) as a function of distance to road (Table 11; Figure 7), and probability of false-positive detection error with no covariates added was 0.01.

## DISCUSSION

For the 2016 single- and multi-year models, probability of occupancy for the northern long-eared bat increased with distance from road. In the single-season model for 2016, detection probabilities also improved when detectors were located in dry habitats. The results from both of these models is in contrast to the knowledge we have on other North American bat species, who commonly use forest corridors created by roads to travel between forest patches and forage for invertebrate prey (Ford et al 2006; Humphrey et al 1977). However, specific knowledge on the foraging and roosting ecology of the northern long-eared bat may offer a logical explanation. The northern long-eared bat is specially adapted to forage and roost in densely-cluttered forested environments by using an echolocation call that is higher in frequency and softer. This adaptation allows maneuverability in cluttered environments along with the utilization of a gleaning foraging strategy in conjunction with the typical hawking strategy (Ratcliffe and Dawson 2003). Based on this information, it is logical that the northern long-eared bat is more

likely to occupy sites that are further away from roads and in dryer environments because foraging habitat is located in dense forest environments. Northern long-eared bats do not travel far between roosting and foraging habitat ( $\geq 1$ km), and if both habitats are located in dense inner forests (Brooks and Ford 2005; Johnson et al. 2008), this may help explain occupancy patterns for this species.

A number of studies have documented bat habitat use in relation to elevation gradients (Cryan et al 1999; Grindal and Brigham 1999; Lacki et al 2009). Northern long-eared bats tend to roost in areas of higher elevation on midslopes and upperslopes versus lower elevations (Lacki et al 2009). However, successful detection of other sympatric species increases at lower elevations (Cryan et al 1999; Grindal and Brigham 1999) because of the abundance of prey resources typically associated with lower habitat types (i.e. riparian streams). The relationship between northern long-eared bat occupancy and lower elevations could be an additional factor that relates to foraging habitat. Results from 2015 showing that this species is also more likely to occupy sites in lower elevations may suggest that they may also use riparian and stream habitat types for foraging and drinking, as other similar species do. However, results from 2016 indicate that this species was more detectable in dry habitat types and more likely to occupy sites further away from roads, suggesting the use of cluttered forest environments for roosting and foraging. Results from all models suggest that while the northern long-eared bat is a forest specialist, they may use multiple habitat types as foraging habitat. The results from the single-season 2015 model relating northern long-eared bat occupancy to lower elevations may be significantly explaining a regional difference in this species' ecology. The Lake States Region is very flat, with minimal elevation gradient changes when compared to other parts of the country. It is possible that northern long-eared bats were more likely to occupy lower elevations in this region because due to the more northern climate, even slight elevation changes may result in significant changes in temperature or habitat overall.

The significant year effect in the multi-year models coupled with difficulties in mist-net captures in 2016 may be explained by documentation of population declines for this species attributed to WNS. Although Yates and Muzika (2006) also found year to be the best covariate for detecting northern long-eared bats in Missouri Ozark forests from 2002 – 2003 prior to WNS, temporal variation has played a part in detecting this species for a number of years even in the

absence of WNS declines. A number of factors can contribute to the detectability of a species, especially if it is as uncommon as the northern long-eared bat currently is post-WNS. Sampling methodology, specifically detector placement and positioning, can have a significant impact on overall detectability of bats during acoustical surveys (Weller and Zabel 2002). Species with softer low-intensity calls can be increasingly more difficult to detect in cluttered habitats. Therefore, ensuring microphones reach into the mid-story of uncluttered environments improves detectability and quality of bat calls overall (Barclay 1999). This can complicate attempts to acoustically capture northern long-eared bat calls, as they are known to use a higher frequency and quieter echolocation call to forage and roost in densely cluttered forested environments (Broders et al 2002; Brooks and Ford 2005; Johnson et al 2008; Yates and Muzika 2006). Inconsistency in the actual height of microphones between the 2015 and 2016 field seasons, portions of detectors devoted to cluttered forest environments, and failing to test microphone functioning between field seasons may have contributed logistically to the decline in detection probability.

While the declines seen in detection probability for this study may be partially explained by sampling methodology, the northern long-eared bat is still at a high risk for population and distribution shifts with the recent discovery of WNS in the Lake States region (Wisconsin in 2014, UP Michigan in 2012). Therefore, to continue to document the imminent decline as WNS progresses across our country, continued acoustical monitoring and analysis is needed to gather more occupancy and detection specific data in the coming years.

In future studies seeking to further document detection and occupancy probabilities for the northern long-eared bat, a number of variables that were not considered in this study (i.e. within season variation, insect prey abundance) may contribute to overall understanding and potentially elucidate additional information that will aid in the better management of this species. Coupling information on local insect prey abundance with bat acoustic detection is a significant predictor for overall bat abundance (Ford et al 2006a; Coleman et al 2014). Supporting insect prey populations (e.g. lepidopterans, coleopterans, and dipterans) on the landscape could have a positive bottom-up effect on the local bat populations. Additionally, including seasonal changes as a covariate in modeling to account for the variation in behavior across the reproductive season, as well as juvenile recruitment at the end of the maternity season, could have an effect on

model performance and results. In other studies, it has been shown that rare species are more easily detected in the juvenile post-volancy period when more individual bats are on the landscape overall (Coleman et al 2014). Therefore, focusing acoustical surveys on certain periods during the reproductive season, along with targeting efforts based on foraging and roosting behavior, may increase the likelihood of detecting a target species. Finally, to strengthen results gained from models in this study, investigating an interaction between elevation and latitude would confirm elevation as a regional difference in terms of habitat selection for this species. It would also be important to include potential sources of detection error as covariates into future modeling procedures, such as microphone height and orientation.

## **MANAGEMENT IMPLICATIONS**

The northern-long eared bat is currently facing severe population declines because of the recent occurrence of WNS, coupled with factors including forest fragmentation, land use changes, and wind energy development (Arnett et al. 2008; Barclay et al. 2007; Ford et al. 2011; Henderson et al. 2008*b*; Langwig et al. 2015). As these stressors continue to degrade North American bat populations, properly documenting populations with acoustic monitoring in regions at different levels of WNS occurrence will contribute crucial data that will be invaluable in the future as WNS continues to spread. The results from this research suggest that the northern long-eared bat occupies dense forest environments, away from anthropogenic roads, likely due to foraging and roosting habitat requirements. Using this information in conjunction with studies documenting the roosting ecology of the northern-long eared bat should inform land managers on what types of forested environments should be preserved and managed to support this threatened species. Additionally, this study found a decrease in detectability for the northern long-eared bat across years. This could be a baseline documentation of declines from WNS, which will serve as critical data to have in the future as WNS progresses. Documenting patterns of detection and occupancy estimations for this species across its range that also account for the inevitable error that comes along with misclassification rates in bat identification should provide important ecological information regarding the management for this species in all regions of North America in which it occurs.

## LIST OF FIGURES

Figure 1. Map of Governor Dodge State Park in Iowa county, Wisconsin. There were 6 successful captures of female northern long-eared bats and 6 confirmed day roosts used by 9 transmitted females.

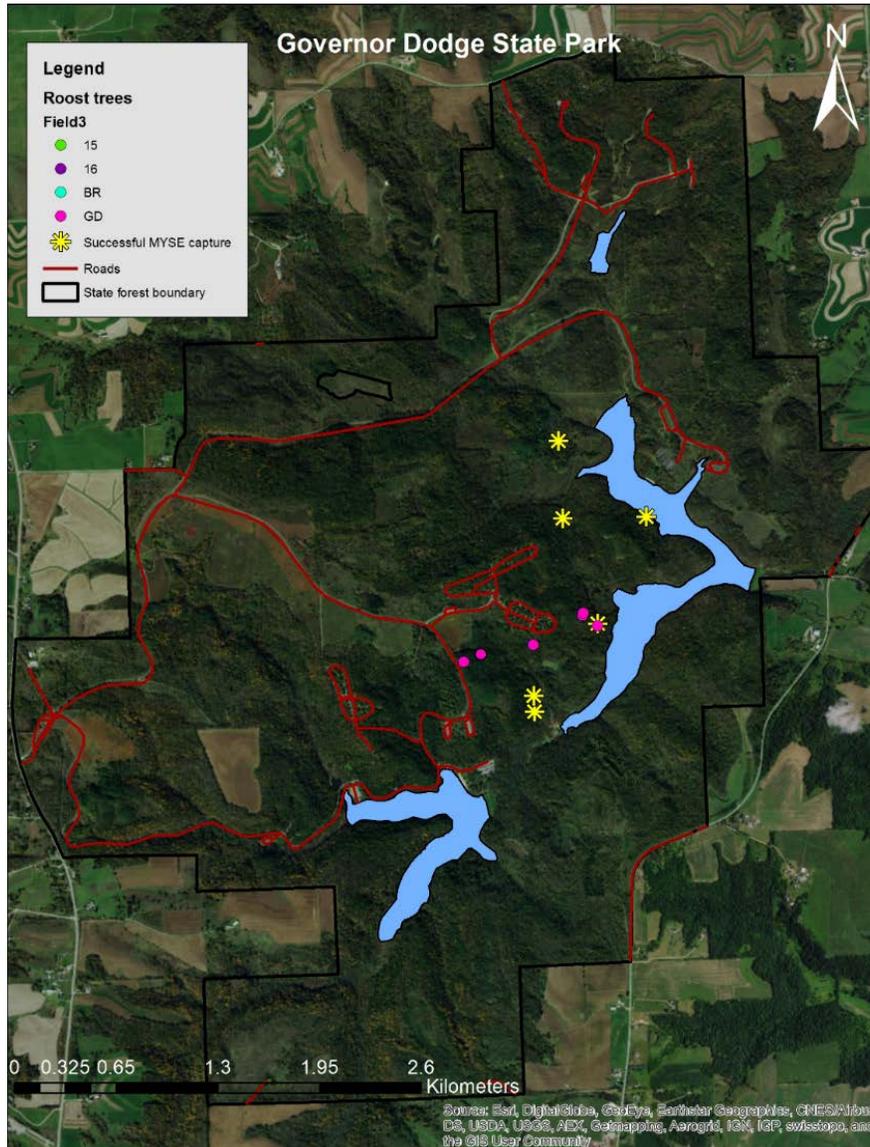


Figure 2. Map of Sandhill Wildlife Area in Wood county, Wisconsin. There were a total of 8 successful captures of female northern long-eared bats and 30 confirmed day roosts used by 23 transmitted females across both years.

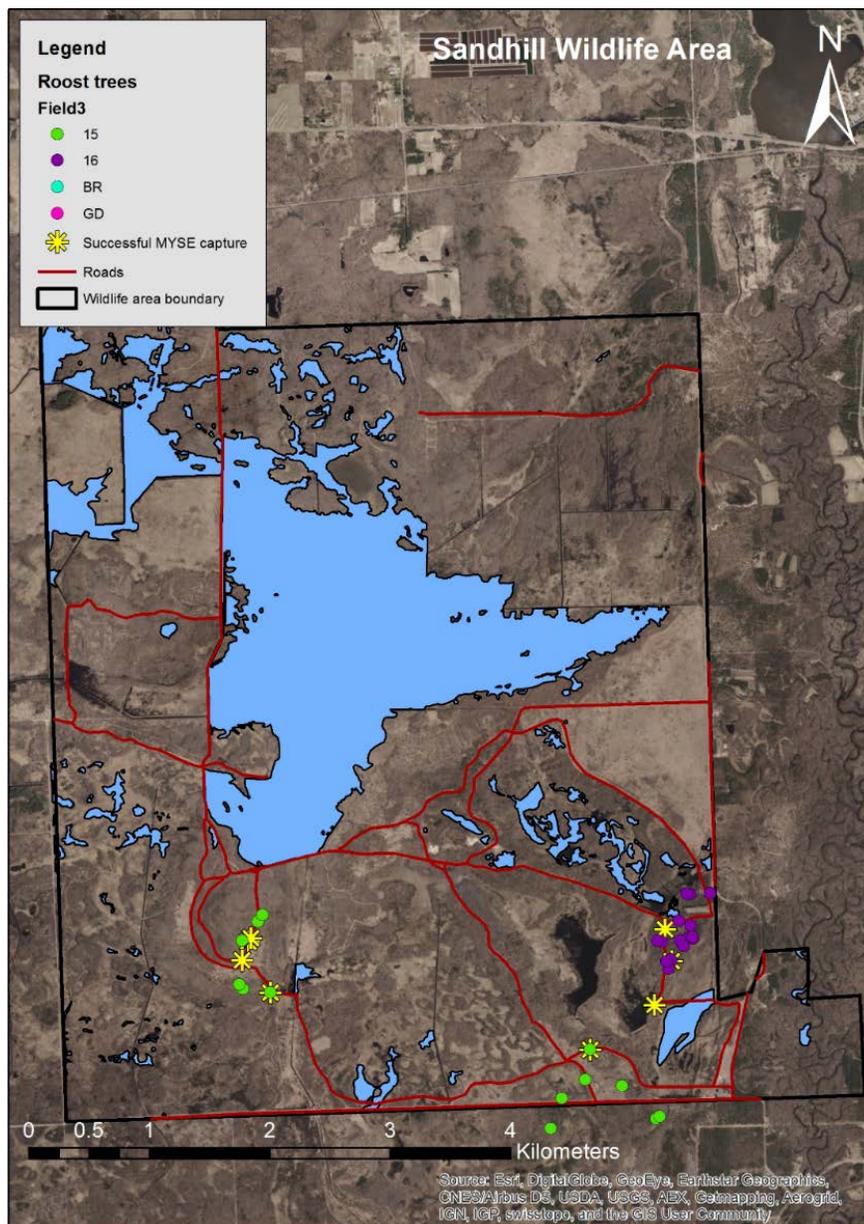


Figure 3a. Map of Black River Falls State Forest in Jackson county, Wisconsin. Displays state forest outline, roads, confirmed roost trees, and successful northern long-eared bat capture in 2015 and 2016.

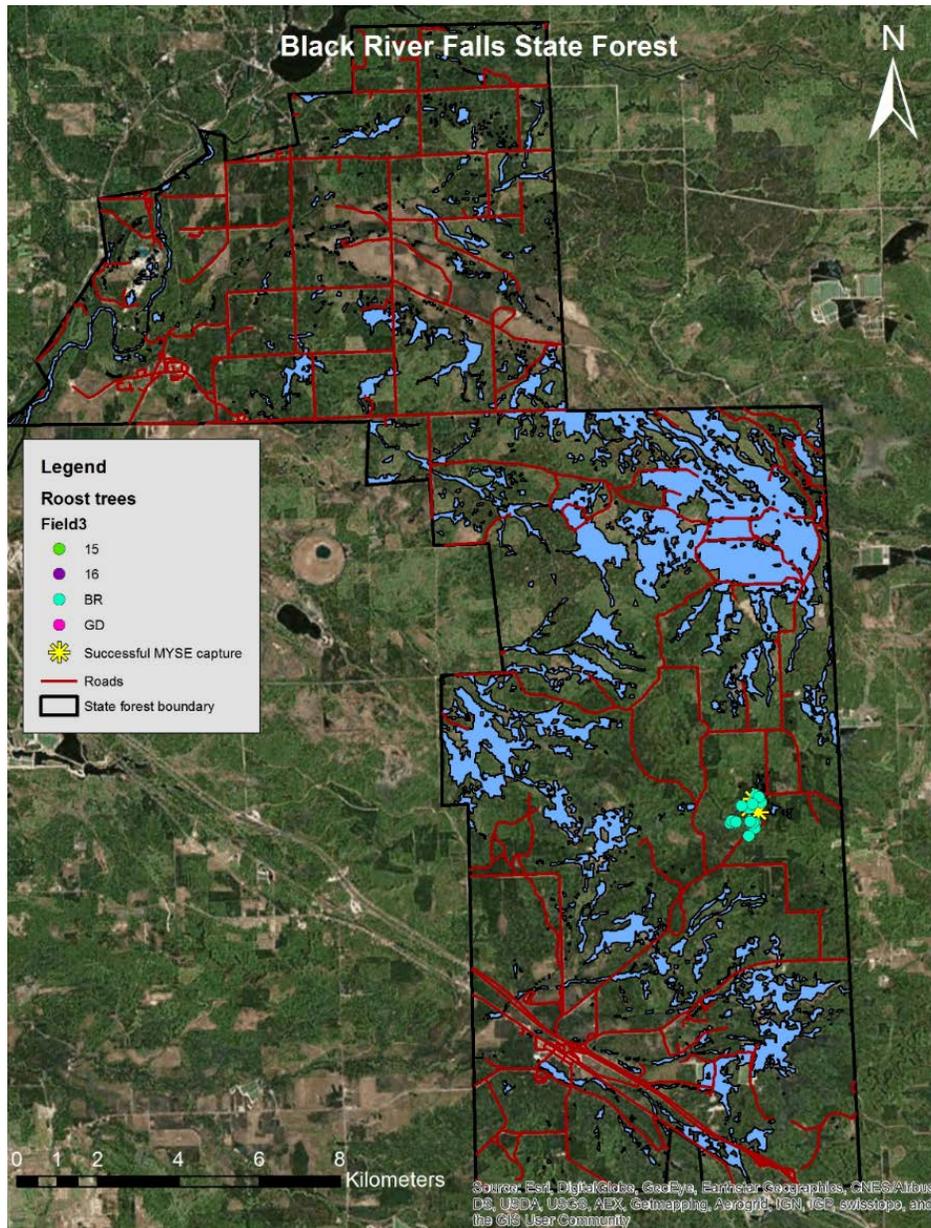


Figure 3b. Map shows detailed display of concentrated roosting area at Black River Falls State Forest in 2015. There were 3 successful captures of female northern long-eared bats and 16 confirmed day roosts used by 8 transmitted females.

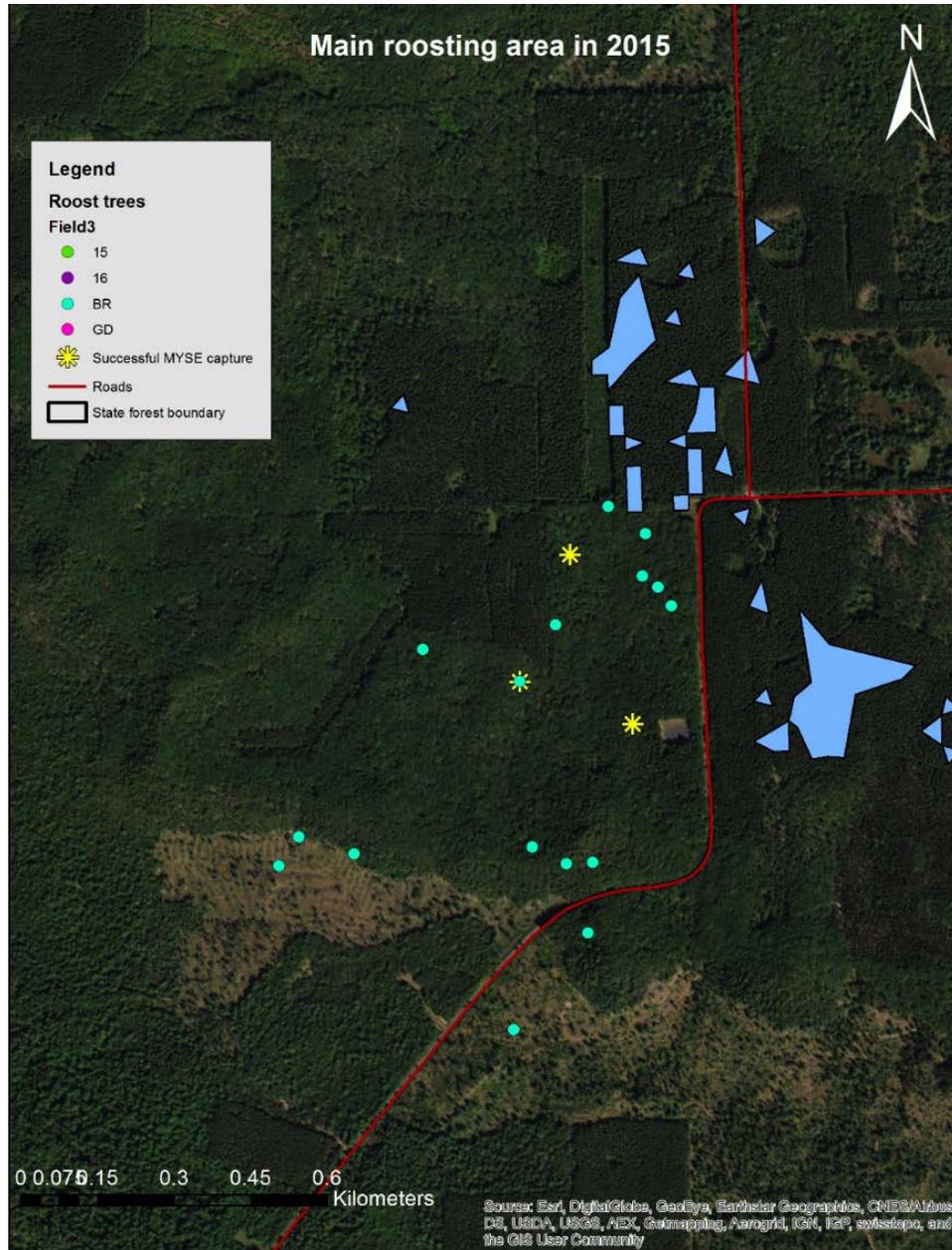


Figure 4. Total sampling effort displayed across study areas in Wisconsin and the Upper Peninsula of Michigan. Each red point represents the location of a single songmeter SMZC detector.

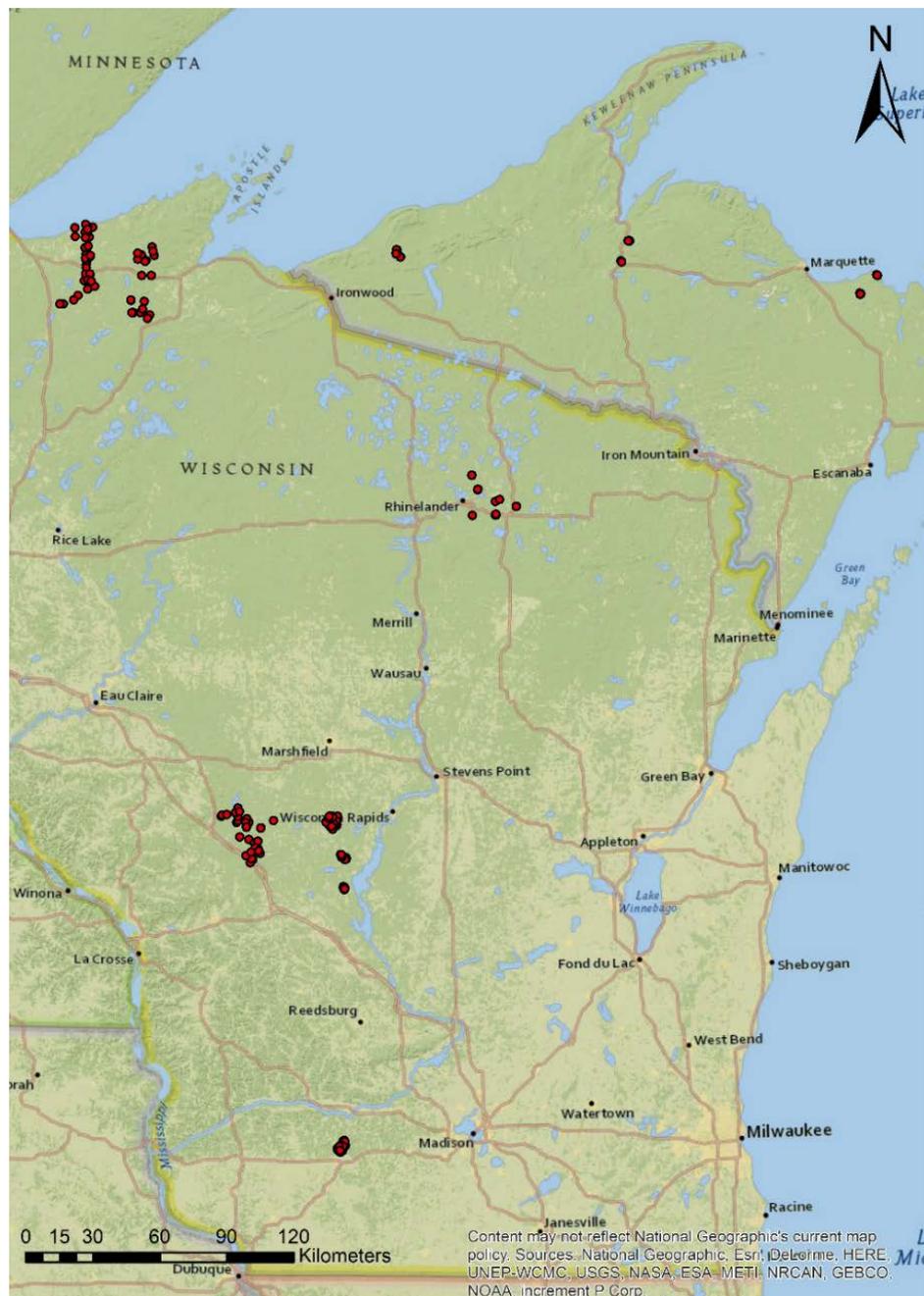


Figure 5. Probability of occupancy for northern long-eared bats in 2015 relative to elevation (m).

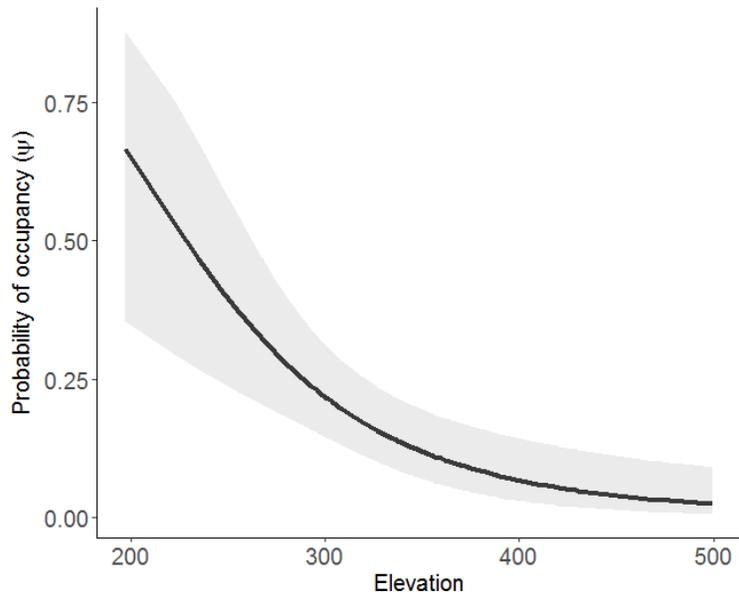


Figure 6. Probability of detection (left) and occupancy (right) of northern long-eared bats in 2016 relative to habitat type (0 - dry habitats, 1 - wet habitats) and distance to road (m), respectively.

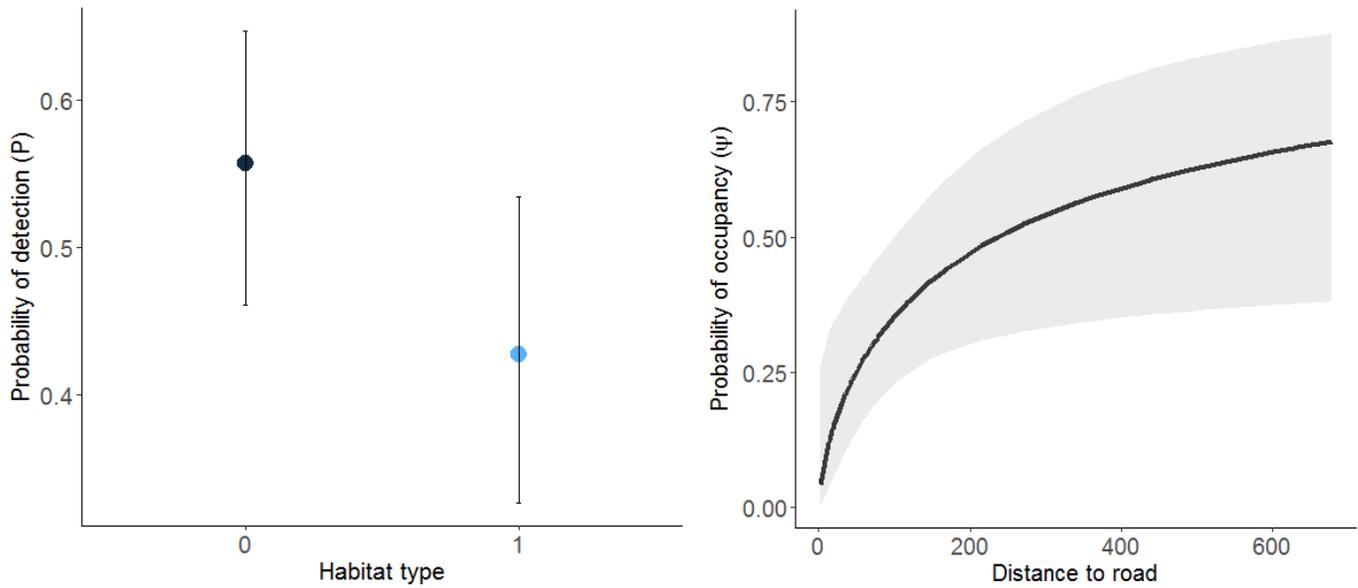
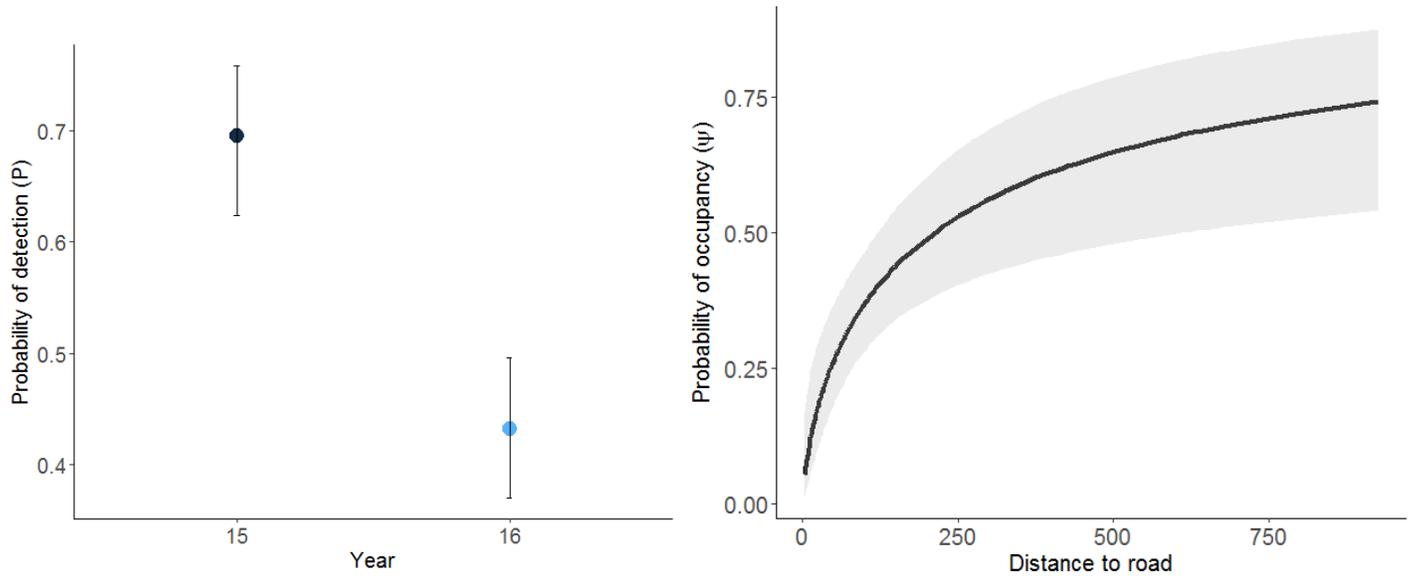


Figure 7. Probability of detection (left) and occupancy (right) of the northern long-eared bat at four sites in Wisconsin relative to year (2015-2016) and distance to road (m), respectively.



## LIST OF TABLES

Table 1. Model sets used to compare used day roost trees to unused potential trees nearby at three field sites (GD, SH, BR) across two field seasons (2015-2016). Models 1-2 represent the global and null models for comparison to candidate and single variable models, candidate models 3-6 represent hypotheses based on relative tree size, age, and other site-level characteristics, and models 7-12 represent single variable models for each variable considered in the analysis.

<b>Model</b>	<b>Parameters</b>
1	Global (saturated) model
2	Null model
3	Tree species + DBH + decay stage + canopy class
4	DBH + canopy class + decay stage
5	Tree species + DBH + decay stage + canopy class + year
6	Tree species + DBH + decay stage + canopy class + site
7	Tree species
8	Site
9	DBH
10	Decay Stage
11	Canopy class
12	Year

Table 2. Rankings of models based on AICc. Models were used to compare used day roost tree characteristics to unused potential trees nearby at three field sites (GD, SH, BR) across two field seasons in 2015 and 2016. Models (Table 2) are given with the number of parameters (K), Akaike's information criteria value corrected for small sample sizes (AICc), difference in AICc value between the top model and ith model ( $\Delta_i$ ), and model weight ( $w_i$ ).

<b>Model</b>	<b>K</b>	<b>LogLik</b>	<b>AICc</b>	<b><math>\Delta_i</math></b>	<b><math>w_i</math></b>
3	6	-116.62	245.6	0.00	0.327
4	3	-120.34	246.8	1.19	0.180
5	7	-166.20	246.9	1.27	0.172
10	1	-122.97	247.9	2.36	0.100
6	8	-116.13	248.8	3.27	0.063
2	0	-124.91	249.8	4.22	0.039
1	9	-115.78	250.3	4.73	0.030
9	1	-124.18	250.4	4.77	0.030
11	1	-124.57	251.1	5.55	0.020
7	3	-122.80	251.7	6.10	0.015
12	1	-124.86	251.7	6.14	0.015
8	2	-124.88	253.8	8.21	0.005

Table 3. Most parsimonious model parameter summary comparing used day roost trees to unused potential trees nearby with variables that describe relative tree size and age.

<b>Variables</b>	<b>Parameter estimates</b>	<b>SE</b>	<b>Pr(&gt;z)</b>	<b>Odds Ratio</b>
DBH	0.006	0.012	0.607	1.00
Decay stage	0.271	0.100	0.007	1.31
Canopy class	-0.449	0.235	0.056	0.63

Table 4. Average and standard deviations of all variables measured for all used day roost trees across all sites (N = 3) and all years (2015-2016).

<b>Variable</b>	<b>Used day roost trees (N = 53)</b>
DBH (cm)	32.99 +/- 11.98
Tree height (m)	16.97 +/- 7.24
Roost height (m)	6.79 +/- 5.13
Percent bark remaining (%)	83.58 +/- 19.50
Basal area (factor 10)	10.45 +/- 4.60
Percent canopy cover (%)	69.33 +/- 25.70

Table 5a. Day roost tree species used by female northern long-eared bats at Governor Dodge State Park in 2015. Available roosts were trees located along a 20x100m transect randomly emanating from each confirmed day roost tree that showed visible roosting availability (i.e. visible cavities or exfoliating bark).

<b>Species</b>	<b>Available (%)</b>	<b>Roost trees (%)</b>
Black locust ( <i>Robinia pseudoacacia</i> )	24 (31.1)	2 (33.3)
Northern red oak ( <i>Quercus rubra</i> )		1 (16.6)
Unidentifiable snag	16 (20.7)	1 (16.6)
Shagbark hickory ( <i>Carya ovata</i> )	3 (3.8)	1 (16.6)
Black walnut ( <i>Juglans nigra</i> )	1 (1.2)	1 (16.6)
White oak ( <i>Quercus alba</i> )	17 (22)	
Sugar maple ( <i>Acer saccharum</i> )	5 (6.4)	
Red pine ( <i>Pinus resinosa</i> )		
White pine ( <i>Pinus strobus</i> )	1 (1.2)	
Black oak ( <i>Quercus velutina</i> )	1 (1.2)	
White ash ( <i>Fraxinus Americana</i> )	4 (5.1)	
Red maple ( <i>Acer rubrum</i> )		
Northern pin oak ( <i>Quercus ellipsoidalis</i> )	5 (6.4)	
Trembling aspen ( <i>Populus tremuloides</i> )		

Table 5b. Day roost tree species used by female northern long-eared bats at Sandhill Wildlife Area in 2015 and 2016. Available roosts were trees located along a 20x100m transect randomly emanating from each confirmed day roost tree that showed visible roosting availability (i.e. visible cavities or exfoliating bark).

<b>Species</b>	<b>Available (%)</b>	<b>Roost trees (%)</b>
Northern red oak ( <i>Quercus rubra</i> )	155 (23.6)	9 (29)
White oak ( <i>Quercus alba</i> )	49 (7.4)	6 (19.3)
Trembling aspen ( <i>Populus tremuloides</i> )		5 (16.1)
Unidentifiable snag	98 (14.9)	5 (16.1)
Red maple ( <i>Acer rubrum</i> )	117 (17.8)	3 (10.3)
Northern pin oak ( <i>Quercus ellipsoidalis</i> )	59 (8.9)	3 (10.3)
Sugar maple ( <i>Acer saccharum</i> )	42 (6.4)	
Red pine ( <i>Pinus resinosa</i> )	30 (4.5)	
White pine ( <i>Pinus strobus</i> )	22 (3.3)	
Black oak ( <i>Quercus velutina</i> )	1 (1.5)	
White ash ( <i>Fraxinus Americana</i> )		
Black locust ( <i>Robinia pseudoacacia</i> )	83 (12.6)	
Black walnut ( <i>Juglans nigra</i> )		
Shagbark hickory ( <i>Carya ovata</i> )		

Table 5c. Day roost tree species used by female northern long-eared bats at Black River Falls State Forest in 2015. Available roosts were trees located along a 20x100m transect randomly emanating from each confirmed day roost tree that showed visible roosting availability (i.e. visible cavities or exfoliating bark).

Species	Available (%)	Roost trees (%)
Northern red oak ( <i>Quercus rubra</i> )	53 (22)	7 (43.7)
White oak ( <i>Quercus alba</i> )	73 (30.4)	3 (18.7)
Trembling aspen ( <i>Populus tremuloides</i> )	27 (11.25)	3 (18.7)
Red maple ( <i>Acer rubrum</i> )	31 (12.9)	2 (12.5)
Northern pin oak ( <i>Quercus ellipsoidalis</i> )	41 (17)	1 (6.2)
Unidentifiable snag		
Sugar maple ( <i>Acer saccharum</i> )		
Red pine ( <i>Pinus resinosa</i> )	12 (5)	
White pine ( <i>Pinus strobus</i> )	3 (1.2)	
Black oak ( <i>Quercus velutina</i> )		
White ash ( <i>Fraxinus Americana</i> )		
Black locust ( <i>Robinia pseudoacacia</i> )		
Black walnut ( <i>Juglans nigra</i> )		
Shagbark hickory ( <i>Carya ovata</i> )		

Table 6. Grouping of tree species for analysis.

Group	Species
Aspen	Trembling aspen ( <i>Populus tremuloides</i> )
Oak	Red oak ( <i>Quercus rubra</i> ), Pin oak ( <i>Quercus palustris</i> ), White oak ( <i>Quercus alba</i> )
Maple	Red maple ( <i>Acer rubrum</i> ), Sugar maple ( <i>Acer saccharum</i> )
Other	Shagbark hickory ( <i>Carya ovata</i> ), Basswood ( <i>Tilia americana</i> ), Black locust ( <i>Robinia pseudoacacia</i> ), Box elder ( <i>Acer negundo</i> ), Black walnut ( <i>Juglans nigra</i> ), White ash ( <i>Fraxinus americana</i> ), Red pine ( <i>Pinus resinosa</i> ), White pine ( <i>Pinus strobus</i> ), Unidentifiable snag

Table 7. All cleaned (deleted noise files) call files recorded for each field site across in 2015 and 2016. Totals are averaged due to unequal sampling efforts across sites and years. The northern long-eared bat (MYSE - *Myotis septentrionalis*) and six other species of bat were recorded across the sampling period, including the big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivigans*), little brown bat (*Myotis lucifugus*), and tri-colored bat (*Perimyotis subflavus*). All northern long-eared bat calls confirmed by two automated classifiers for all sites and years listed to show inconsistency between the programs.

Site	Total no. calls recorded		Total no. MYSE calls identified (2015 – 2016)	
	2015	2016	Kaleidoscope	Echoclass
Governor Dodge State Park	6,277	3,254	1,038 - 79	704 - 96
Sandhill Wildlife Area	7,975	4,615	622 - 199	427 - 215
Black River Falls State Forest	6,963	7,407	479 - 218	360 - 207
Brule River State Forest	1,180	2,439	0 - 3	0 - 5
Chequamegon National Forest	3,986	-	3	1
Pelican Lake, WI	539	-	-	-
Necedah Wildlife Refuge	-	4,903	184	209
Porcupine Mountain, UP	368	-	22	30
L'Anse/Marquette, UP	1,158	-	31	37
<b>Average totals:</b>	<b>3,555</b>	<b>7,578</b>	<b>365 - 136</b>	<b>259 - 146</b>

Table 8. Rankings of occupancy ( $\Psi$ ) models using AIC and  $\Delta$ AIC for the single-season 2015 model investigating the effects of various site- and landscape-level habitat characteristics on the detection of northern long-eared bats in the Lake States region. Number of parameters (K), Akaike's information criteria (AIC), the change in AIC between the top and other models ( $\Delta$ AIC), and model weight ( $w_i$ ) are included.

Model	K	AIC	$\Delta$ AIC	$w_i$
$\Psi$ (elevation) p(.)	3	634.08	0.00	0.97
$\Psi$ (distance to road) p(.)	3	641.61	7.52	0.02
$\Psi$ (habitat type) p(.)	3	646.25	12.16	0.002
$\Psi$ (.) p(.)	2	647.50	13.41	0.001
$\Psi$ (canopy class) p(.)	3	647.69	13.60	0.001
$\Psi$ (distance to water) p(.)	3	647.71	13.62	0.001

Table 9. Rankings of detection ( $p$ ) and occupancy ( $\Psi$ ) models using AIC and  $\Delta$ AIC for the single-season 2016 model investigating the effects of various site- and landscape-level habitat characteristics on the detection and occupancy of northern long-eared bats in the Lake States region. Number of parameters (K), Akaike's information criteria (AIC), the change in AIC between the top and other models ( $\Delta$ AIC), and model weight ( $w_i$ ) are included.

<b>Model</b>	<b>K</b>	<b>AIC</b>	<b><math>\Delta</math>AIC</b>	<b><math>w_i</math></b>
$\Psi$ (distance to road) $p$ (habitat type)	4	859.75	0.00	0.80
$\Psi$ (elevation) $p$ (habitat type)	4	864.18	4.43	0.08
$\Psi$ (.) $p$ (.)	2	866.23	6.47	0.03
$\Psi$ (canopy class) $p$ (habitat type)	4	866.52	6.76	0.02
$\Psi$ (habitat type) $p$ (habitat type)	4	866.62	6.87	0.02
$\Psi$ (distance to water) $p$ (habitat type)	4	866.66	6.90	0.02

Table 10. Rankings of detection ( $p$ ) and occupancy ( $\Psi$ ) models using AIC and  $\Delta$ AIC for the multi-year model investigating the effects of year and site- and landscape-level habitat characteristics on the detection and occupancy of northern long-eared bats at 4 sites in Wisconsin. Number of parameters (K), Akaike's information criteria (AIC), and the change in AIC between the top and other models ( $\Delta$ AIC) are included.

<b>Model</b>	<b>K</b>	<b>AIC</b>	<b><math>\Delta</math>AIC</b>
$\Psi$ (distance to road) $p$ (year)	4	1245.48	0.00
$\Psi$ (year) $p$ (year)	4	1260.32	14.84
$\Psi$ (canopy class) $p$ (year)	4	1261.44	15.96
$\Psi$ (elevation) $p$ (year)	4	1262.02	16.54
$\Psi$ (habitat type) $p$ (year)	4	1262.77	17.28
$\Psi$ (.) $p$ (.)	2	1288.53	43.04
$\Psi$ (distance to water) $p$ (year)	4	1562.19	316.70

Table 11. Occupancy ( $\Psi$ ) and detection ( $p$ ) probabilities for the 2015 models, 2016 models, and multi-year occupancy models respectively. Covariates were averaged for the calculation of occupancy probabilities.

<b>Models</b>	<b><math>p</math> (SE)</b>				<b><math>\Psi</math> (SE)</b>	
	<b>Wet</b>	<b>Dry</b>	<b>2015</b>	<b>2016</b>	<b>Distance</b>	<b>Elevation</b>
2015	-	-	-	-	-	0.15 (0.03)
2016	0.42 (0.05)	0.55 (0.04)	-	-	0.43 (0.08)	-
Multi-year	-	-	0.69 (0.03)	0.43 (0.03)	0.45 (0.05)	-

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