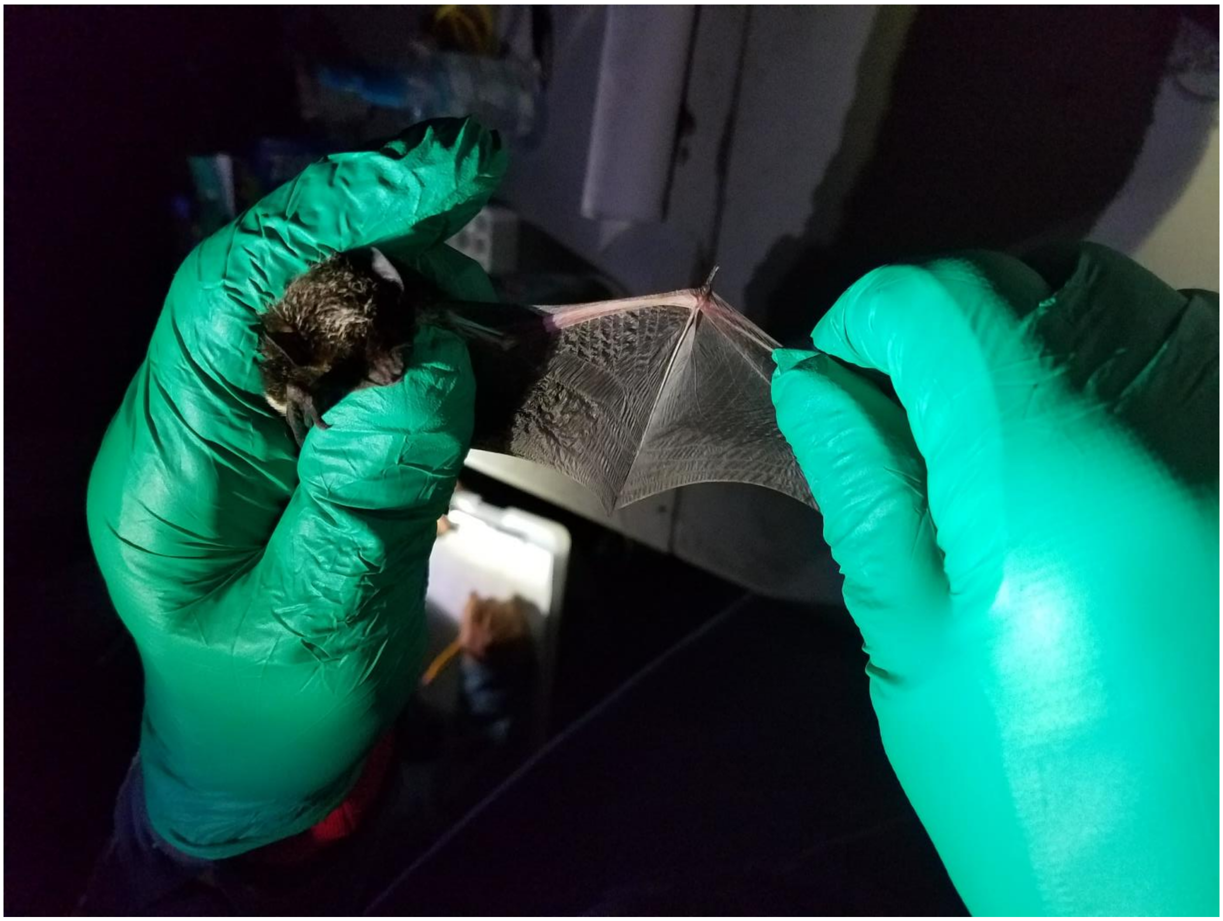
NRRI Technical Report - December 2018

Bat Radiotelemetry in Forested Areas of Minnesota 2015-2017



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Cover Image Caption
Silver-haired bat that was caught in mist-net at Sherburne National Wildlife Refuge, Minnesota.

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Summary

Minnesota's seven species of bats are a critical component of the state's ecosystems. A single bat can eat thousands of insects in a night, and although it has yet to be adequately documented, the state's bat populations probably provide millions of dollars in pest control each year. Four bat species are Species of Special Concern in Minnesota, and the northern long-eared bat is listed as threatened under the federal Endangered Species Act, largely due to the impact of white-nose syndrome on bat populations. White-Nose Syndrome (WNS) is a disease which causes extremely high mortality rates in cave-hibernating bats. While spreading westward from New York State, WNS has killed millions of bats.

This project began with a focus on the northern long-eared bat and WNS, but we can now say that its impact will be much greater. This was the first large-scale project that could determine presence of all bat species simultaneously across a large portion of Minnesota, and it significantly advanced our knowledge about bats in Minnesota with the mist-netting described in this report, and with the acoustic surveys described in a second report.

Beyond the mist-netting and acoustic surveys, a specific goal of this project was to identify summer maternity roosting habitat of female northern long-eared bats. Female northern long-eared bats roost together in maternity colonies in which bats give birth and raise their young together. Young bats nurse from their mothers and are able to fly after 3-4 weeks. Reproductive success is critically important because WNS typically results in 90% or more reduction in population size in hibernacula. In addition, most bat species have only 1 young per year, which makes it difficult for populations to recover.

We captured 1,202 bats with mist-nets at 150 sites in 26 counties throughout the forested region of the state of Minnesota from 2015 to 2017. We captured individuals of all seven bat species previously recorded in Minnesota, and also captured the first evening bat (*Nycticeius humeralis*) that has been recorded in Minnesota. The most common species captured were the little brown bat and the big brown bat. More than 90% of bats captured were adults. Most captured adult female bats were pregnant or lactating. The first lactating bats were captured on June 13th, and the latest we captured pregnant bats was July 21st. Juveniles were first captured in late June.

We attached transmitters to 117 bats, including 89 female northern long-eared bats. We tracked 84 northern long-eared bats, 13 little brown bats, and 8 big brown bats to roosts in 262 trees and 12 buildings. The female northern long-eared bats that were tracked to roosts in trees spent an average of 1.3 days in each roost. Most of the time female northern long-eared bats only spent one night in a roost, even when lactating. Based on emergence surveys, the average number of female northern long-eared bats in a maternity roost was 15, with a range of 1 to 79 bats. The average distance from the capture location to the first roost for northern long-eared bat females was about 700 m. The average maternity roost home-range size for female northern long-eared bats was 7 ha (18 acres). Based on the distance from capture location to roost, an average foraging home range of about 150 ha (380 acres) could be estimated.

From a management perspective, flightless pups would be in maternity roosts from mid-June to the end of July and into early August. Females would likely be identifying maternity roost locations during late pregnancy in early June. Females would move pups to different maternity roosts frequently, although the maternity roost home range was relatively small. At the larger scale, another important management finding is that the northern long-eared bat is distributed throughout the state. In general, our findings for northern long-eared bat mist-netting and roost tree use were consistent with findings reported elsewhere, but there are Minnesota-specific outcomes that will be used in management.

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Introduction

Bats are a critical component of Minnesota's ecosystems. A single bat may eat 1,000 insects per hour, and although it has yet to be adequately documented, the state's bat populations probably provide millions of dollars in pest control each year. Seven species of bats are residents of Minnesota: little brown bats (*Myotis lucifugus*), northern long-eared bats (*Myotis septentrionalis*), big brown bats (*Eptesicus fuscus*), tri-colored bats (*Perimyotis subflavus*), silver-haired bats (*Lasionycteris noctivagans*), eastern red bats (*Lasiurus borealis*), and hoary bats (*Lasiurus cinereus*). Four of these species (northern long-eared bat, little brown bat, tricolored bat, and big brown bat) hibernate in caves during the winter, and disperse widely across the state in spring, summer, and fall. Silver-haired bats, eastern red bats, and hoary bats migrate to southern states in the fall, and return to Minnesota in the spring.

The four cave-hibernating bats are all Species of Special Concern in Minnesota, and the northern long-eared bat is listed as threatened under the federal Endangered Species Act, largely due to the impact of white-nose syndrome on bat populations. White-Nose Syndrome (WNS) is a disease caused by the fungus *Pseudogymnoascus destructans*, which causes increased winter activity and extremely high mortality rates of cave-hibernating bats. It was first detected in New York State in 2006 and has killed an estimated 5.7 million bats through 2011 (U.S. Fish and Wildlife Service 2012). Many more bats would have died by now with expansion of WNS to different states. The fungus associated with WNS was detected on bats at Mystery Cave State Park and Soudan Underground Mine State Park in 2013 (MN DNR 2013). WNS has since been confirmed to be spreading in Minnesota (MN DNR 2016a, 2017).

Soudan Underground Mine is the largest known hibernaculum in Minnesota, and had about 10,000 bats prior to the arrival of WNS (Nordquist et al. 2006). About 2,000 bats hibernated at Mystery Cave, the second largest known hibernacula in Minnesota, before the arrival of WNS (Nordquist et al. 2006). In addition to the northern long-eared bat, three other Minnesota bat species (tri-colored bat, little brown bat, and big brown bat) use hibernacula and could be susceptible to WNS in the future. In the northeastern U.S., the disease has reduced bat populations by up to 99% over the past decade (Frick et al. 2010), although the decline may vary somewhat by species, with the big brown bat being less susceptible than the other two species (Turner et al. 2011). Similar declines in Minnesota would have an extreme effect on winter populations in each hibernacula.

Research and monitoring of bat populations in Minnesota was reviewed in 1985 with funding from the MN DNR Nongame Wildlife Program (Nordquist and Birney 1985). Even though several biologists had worked on bats in Minnesota, primarily locating hibernacula and then banding bats, Nordquist and Birney indicated that "*… the paucity of investigation on bats in Minnesota points to the unfortunate fact that we lack simple baseline information with which scientists and managers of nongame wildlife can assess the status of bat species in the state, detect any changes in distribution and abundance, and formulate management policy to ensure their continued representation in the state. …*" Some research has been done since the 1980s (e.g., Nordquist 2006, Nordquist et al. 2006, Dixon 2011, Abel and Moen 2011). The Minnesota Biological Survey has been documenting bat presence in counties in recent years with mist-netting and with acoustic surveys. Other research has been done to estimate the effect of wind turbine development on bats; much of this research is proprietary and not in the public domain (see Moen and Swingen 2018). However, there is still much to learn about bats in Minnesota.

This project began with a focus on the northern long-eared bat and WNS, but we can now say that its impact will be much greater. This was the first large-scale project that could determine presence of different bat species simultaneously across a large portion of Minnesota, and it advanced our knowledge about bats in Minnesota significantly. All species of bats were caught with mist-netting, not just the northern long-eared bat. Therefore, it is possible to learn about distribution and relative abundance of all species of bats present in an area. Similarly, acoustic surveys can detect all species of bats in Minnesota, and by deploying acoustic detectors across much of Minnesota, this project almost doubled the locations where acoustic detectors had been deployed in Minnesota (Moen et al. 2018a).

Beyond the general nature of mist-netting and acoustic surveys, a specific goal of this project was to identify summer maternity roosting habitat of female northern long-eared bats. Prior to this project, no complete ecological studies had been conducted on female northern long-eared bats in the western Great Lakes region. Pilot projects in 2013 and 2014 led to finding the first known maternity roosts in Minnesota, with 2 roosts found in 2013 in the Superior National Forest, and 34 roosts found in 2014 (Catton 2014). Roosts were located in six tree species, with most roosts in trembling aspen (*Populus tremuloides*) on the Superior National Forest and in northern red oak (*Quercus rubra*) at the Camp Ripley Training Center. With the results presented below, this project became the largest bat radiotelemetry project in Minnesota and significantly expanded baseline knowledge of bat populations in Minnesota. A smaller project was undertaken in Wisconsin in response to the appearance of WNS and the listing of the northern long-eared bat (WI DNR 2014, 2015).

The main reason for attaching radiotransmitters to bats affected by WNS is to learn more about reproductive strategies used by females to raise young in the summer. Female bats roost together in maternity colonies in which bats give birth and raise their young together. Young bats nurse from their mothers and are able to fly after 3 – 4 weeks. It is critical to know what species of trees are used as maternity roosts, if trees used are alive or dead, when females have young, and other types of information that can be used by managers to mitigate the effects of WNS on the population. Reproductive success is critically important because WNS typically results in 90% or more reduction in population size in hibernacula. The northern long-eared bat is particularly susceptible to WNS, with declines of 90 – 100% in many eastern U.S. hibernacula (Turner et al. 2011). In addition, most bat species have only one young per year, which makes it difficult to increase population sizes.

In this report we summarize data collected from mist-netting and radiotelemetry conducted throughout the forested area of Minnesota. The focal species for radiotelemetry was the northern long-eared bat, although in the last year we also deployed radiotransmitters on other species. In other reports we summarize roost trees that were used (Moen at al. 2018a), results of acoustic detectors that were deployed across the forested area Minnesota (Moen et al. 2018a), and distribution of the northern long-eared bat in Minnesota (Moen et al. 2018b).

Study Area

We captured bats with mist-nets at 150 sites in 26 counties throughout the forested region of Minnesota from 2015 to 2017 (Table 1, Fig. 1). Effort in the first year of the project was in the northern counties; in years 2 and 3 effort was more evenly distributed across Minnesota. A report on mist-netting results for each location is publicly available (see Appendix 1).

Figure 1. Map of all mist-netting locations within the forested region (shaded) of Minnesota. Each dot represents a separate mist-netting site. Counties in which mist-netting took place are labeled with abbreviations listed in Table 1.

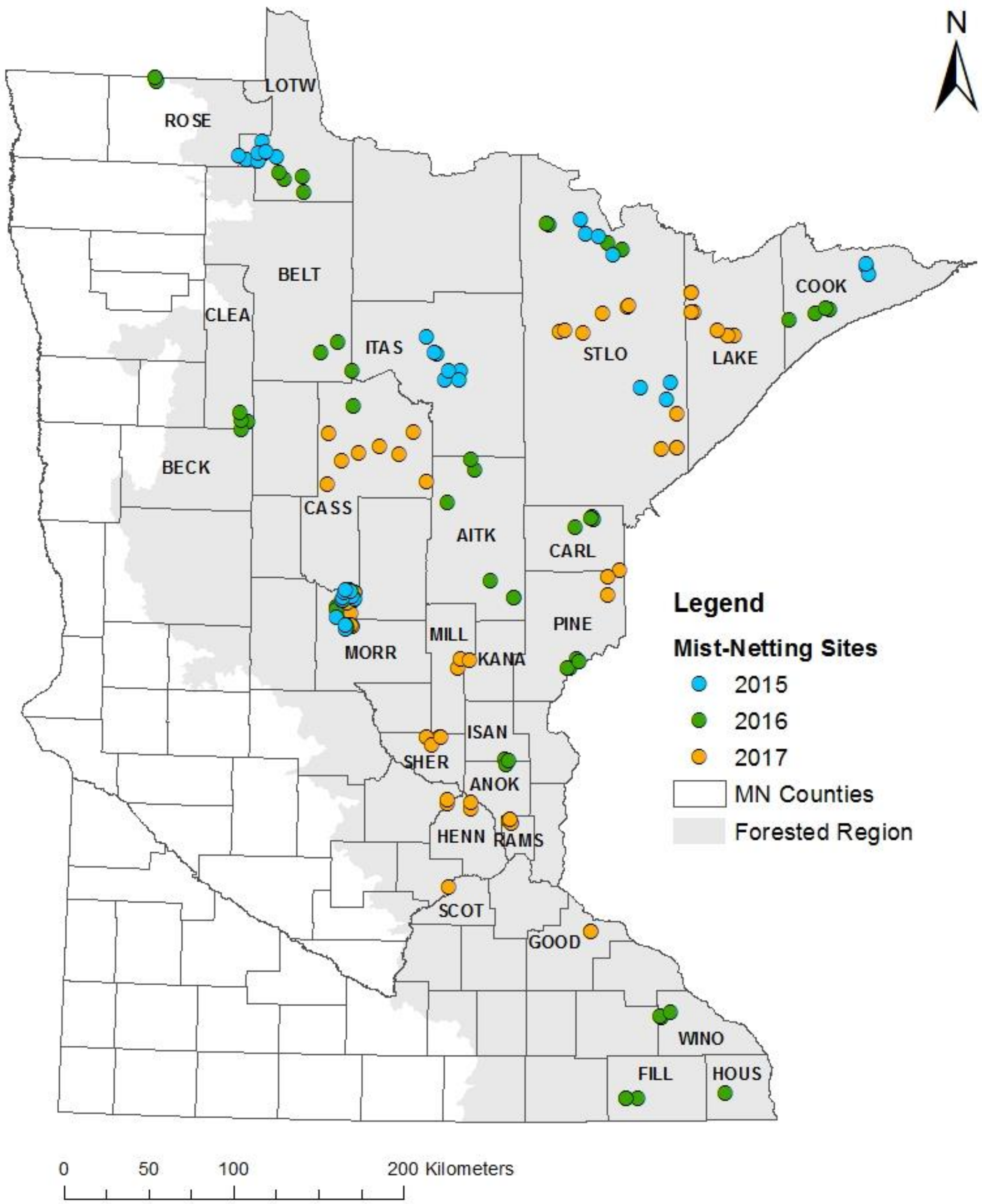


Table 1. Names and abbreviations of Minnesota counties in which bat mist-netting took place from 2015 – 2017. In most cases, new sites were surveyed each year (i.e. the same locations within a county were not surveyed repeatedly).

County	Code	Sites	Locations Surveyed	Years
Aitkin	AITK	6	Hill River, Savanna, and Solana State Forests	2016
Anoka	ANOK	2	Cedar Creek Ecosystem Science Reserve	2016
Becker	BECK	1	Itasca State Park	2016
Beltrami	BELT	2	Chippewa National Forest	2016
Carlton	CARL	4	Cloquet Forestry Center	2016
Cass	CASS	9	Cass County Forest Land O'Lakes State Forest Chippewa National Forest	2017 2017 2016, 2017
Clearwater	CLEA	3	Itasca State Park	2016
Cook	COOK	7	Superior National Forest	2015, 2016
Fillmore	FILL	3	Mystery Cave State Park	2016
Goodhue	GOOD	2	Richard J. Dorer State Forest	2017
Hennepin	HENN	4	Three Rivers Park District	2017
Houston	HOUS	1	Beaver Creek State Park	2016
Isanti	ISAN	1	Cedar Creek Ecosystem Science Reserve	2016
Itasca	ITAS	8	Chippewa National Forest	2015, 2016
Kanabec	KANA	1	Mille Lacs Wildlife Management Area	2017
Lake	LAKE	7	Superior National Forest	2017
Lake of the Woods	LOTW	11	Red Lake Wildlife Management Area Beltrami Island State Forest	2015, 2016 2015, 2016
Mille Lacs	MILL	2	Mille Lacs Wildlife Management Area Rum River State Forest	2017 2017
Morrison	MORR	33	Camp Ripley Training Center	2015 - 2017
Pine	PINE	7	St. Croix State Park Nemadji State Forest	2016 2017
Ramsey	RAMS	8	Arden Hills Army Training Site	2016, 2017
Roseau	ROSE	5	Beltrami Island State Forest, Roseau River Wildlife Management Area	2015, 2016 2015, 2016
Scott	SCOT	1	Minnesota Valley National Wildlife Refuge	2017
Sherburne	SHER	4	Sherburne National Wildlife Refuge	2017
St. Louis	STLO	21	Cloquet Valley State Forest, Lk Vermilion–Soudan Underground Mine St. Park Superior National Forest	2017 2017 2015 - 2017
Winona	WINO	3	Whitewater State Park Whitewater Wildlife Management Area	2016 2016

Methods

Bat Capture and Processing

Fine mesh mist-nets (Avinet Inc., Dryden, NY, USA) were set along forested roads, trails, and streams (Fig. 2). Each net was 2.6 m tall and 4, 6, or 9 m wide. We used Forest Filter Triple High mist-net pole systems (Bat Conservation and Management, Carlisle, PA, USA), stacking up to three nets vertically (maximum height 7.3 m). Each night, 2 – 4 pole sets were set up within ~250 m of a central processing location. Each set of poles and associated nets is one "net set" regardless of the number of individual nets stacked on the poles. We opened mist-nets after sunset. Nets were checked at 15 minute intervals for 2 – 5 hours, depending on capture rates and weather conditions.

After each night all equipment was decontaminated following the national white-nose syndrome decontamination protocol ("National White-Nose Syndrome Decontamination Protocol" 2016). Non-porous items were decontaminated using Clorox® Wipes, or Clorox® Bleach and porous items (including outer clothing layers) were decontaminated by submersion in hot water (≥ 55°C for 20 minutes).

We identified species of each captured bat and determined sex, age, and reproductive condition by physical examination. Each bat was weighed and measured, and wings were inspected for damage potentially caused by white-nose syndrome (Fig. 2). Wing condition was scored from 0 – 3 according to the Reichard Wing Damage Index (WDI), where 0 indicates no damage and 3 indicates severe damage (Reichard and Kunz 2009). We put an individually-numbered lipped aluminum wing band (Porzana Ltd., Icklesham, United Kingdom) on each bat. The wing band was put on the left forearm in females and on the right forearm in males.

We attached radiotransmitters (A2414 Advanced Telemetry Systems Inc., Isanti, MN; or LB-2X, Holohil Systems Ltd., Carp, ON, Canada) to adult bats. Transmitter weight was < 5% of bat body weight (Aldridge and Brigham 1988). At the beginning of each summer, we attached transmitters to adult female northern long-eared bats. We deployed transmitters on other species and sexes if we would not be able to deploy all transmitters on female northern long-eared bats. We trimmed a section of hair in the center of the back and used surgical adhesive (Perma-Type, Permatype Company Inc., Plainville, CT, USA) to attach the transmitter to the skin (Fig. 1). We released all bats at the processing site, which was usually within 250 m of the mist-net capture site.

We compared capture rates (bats captured / net hour) across the state and across years and compared trends in capture rates among species. We used chi-squared tests to test observed sex ratios against a 1:1 expected ratio. We also compared capture rates by reproductive class (adult male, adult females either pregnant, lactating, or post-lactating, and juveniles) and determined peak periods and duration of capture for each reproductive class. Weights and forearm length of captured bats were compared with ANOVA when appropriate for each species. We also evaluated capture rates throughout the night for each species.

We tracked bats with radiotransmitters to roosts each day until the transmitter battery failed or the transmitter fell off. Characteristics of roost trees, including species, size, and landscape matrix, are analyzed in a separate report (Moen et al. 2018b). We calculated the distance from the capture location to the first roost for each bat, and distances between consecutive roost trees. We compared distances moved among species using ANOVA and between sexes using Student's t-tests. For bats with ≥ 4 roost tree locations we created a Minimum Convex Polygon (MCP) around the roost trees with ESRI ArcMap10.3.1. MCP areas were compared between reproductive conditions using a Student's t-test. We conducted emergence surveys at tree roosts to determine the number of bats using a roost tree. We also conducted emergence surveys at buildings and compared colony sizes between species and between roost types.

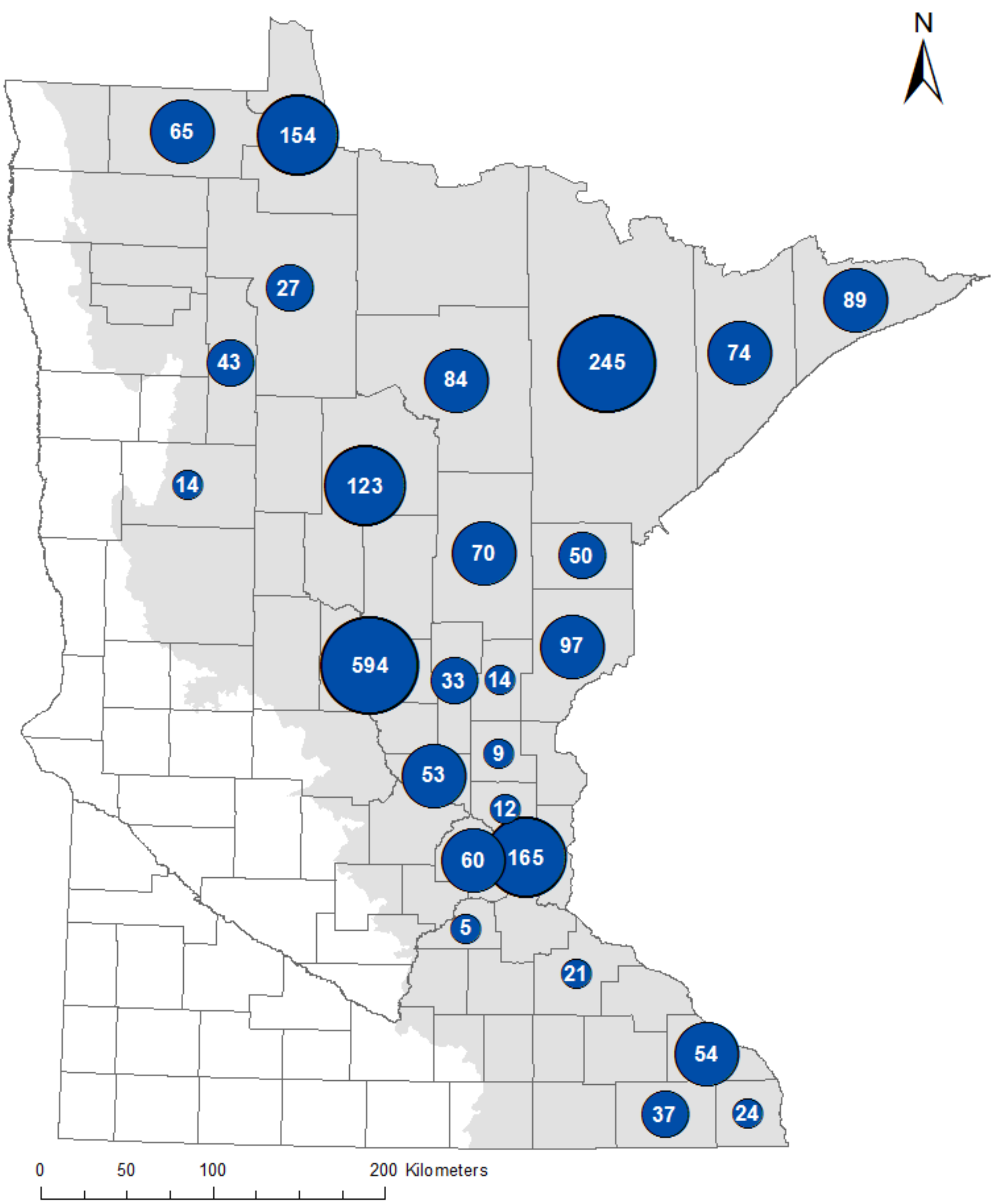
Figure 2. Photos showing the techniques for capturing and processing bats. Photo Credits: A – Superior National Forest; B – Brian Houck, NRRI; C – Peter Kienzler, NRRI, D – Christi Spak, MN DNR; E – Ryan Pennesi, USFS; F – Nancy Dietz, MN DNR - CRTC.

Results

Mist-Netting

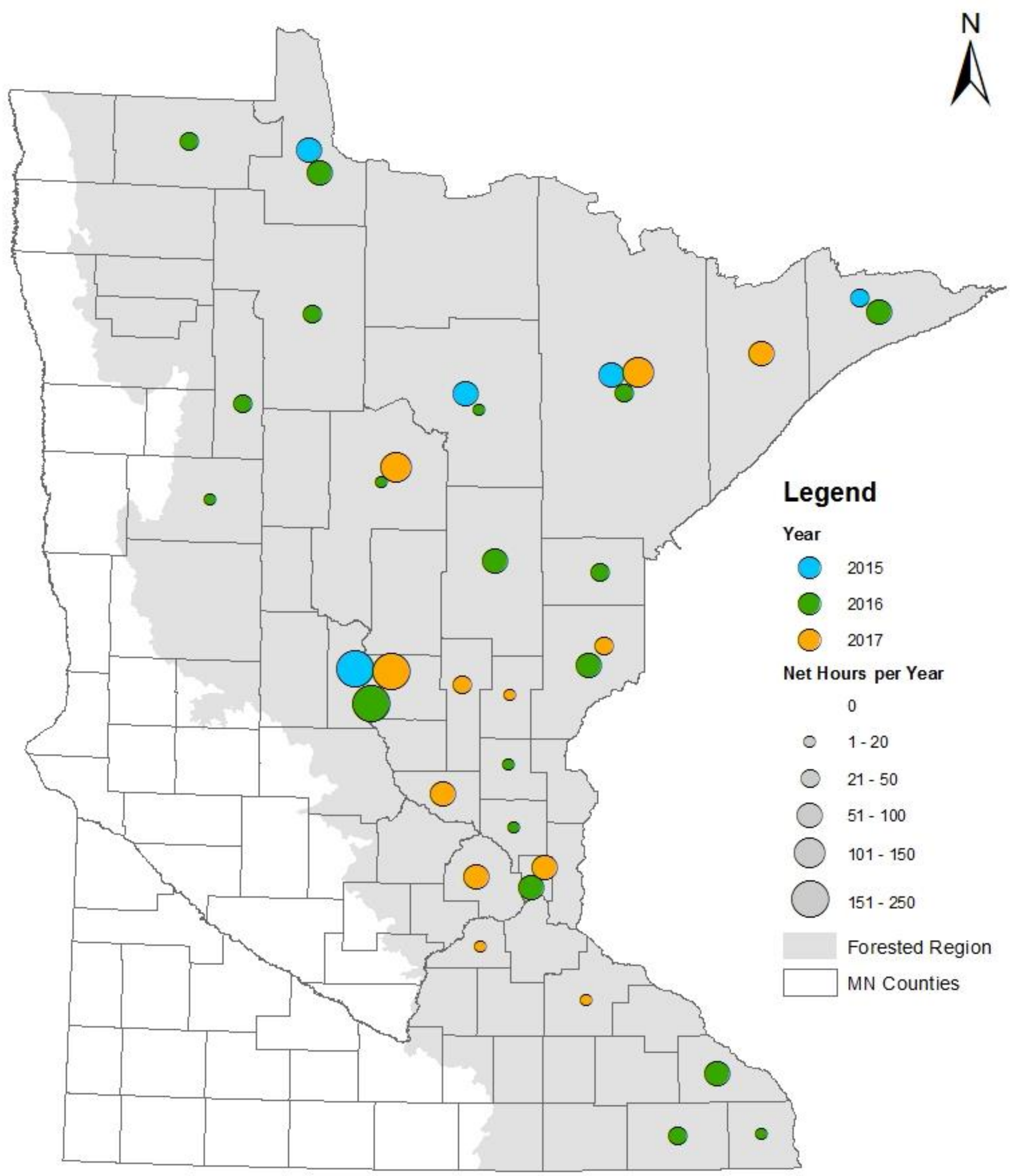
We conducted 156 nights of mist-netting in June and July of 2015 - 2017, with multiple crews operating simultaneously across the state. Bats were captured in every county that we mist-netted. The number of bats captured per site per night ranged from 0 – 38. At least one bat was captured on 141 of the 156 nights of netting.

Figure 3. Map of bat mist-netting effort in each county. The size of the symbol in each county indicates the relative overall effort in net-hours, and the label indicates the total number of net-hours in that county during the project.



Mist-netting was distributed throughout the forested portion of Minnesota, but effort varied spatially over the three years (Fig. 4). In the first year of the project effort was concentrated in the northern parts of Minnesota, and in the next two years effort was more broadly distributed. We mist-netted 507 net-hours in 2015, 933 net-hours in 2016, and 775 net-hours in 2017. One net-hour was equal to one net set open for one hour, and all sites had 2 to 4 net sets open simultaneously.

Figure 4. Map of bat mist-netting effort in each county by year. The size of the symbol in each county indicates the relative overall effort in net-hours, and the color indicates the year sampling was conducted.



Species Captured

We captured and processed 1,202 bats over 2,215 net-hours (Table 2). We captured individuals of all seven bat species previously recorded in Minnesota and also captured the first evening bat (*Nycticeius humeralis*) that has been recorded in Minnesota. The most common species captured were the little brown bat and the big brown bat. About 200 northern long-eared bats, and < 100 eastern red bat, hoary bat, and silver-haired bat were captured. Only one tri-colored bat and one evening bat were captured.

Table 2. Count of bats captured during each field season by species and sex. EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat, MYLU – little brown bat, MYSE – northern long-eared bat, NYHU – evening bat, PESU – tricolored bat.

Year	Sex	MYSE	MYLU	EPFU	LABO	LACI	LANO	NYHU	PESU	Total
2015	F	36	20	12	6	11	5	0	0	90
	M	40	48	21	5	0	2	0	0	116
2016	F	58	175	76	23	6	12	1	0	351
	M	37	109	108	30	1	9	0	1	295
2017	F	24	35	73	21	1	25	0	0	179
	M	8	53	83	12	3	12	0	0	171
Total		**203**	**440**	**373**	**97**	**22**	**65**	**1**	**1**	**1202**

More female northern long-eared bats were captured than male northern long-eared bats in 2016 and 2017 (χ^2_5 = 12.5, p = 0.02), while for little brown bats there were more males captured in 2015 and 2017, and more females in 2016 (χ^2_5 = 30.6, p < 0.001). Sex ratios of big brown bats and eastern red bats were not different from 1:1 (χ^2_5 = 8.7, p = 0.12 and χ^2_5 = 3.5, p = 0.63). There were not enough captures of hoary bats and silver-haired bats to test the sex ratio with χ^2 , although sex ratios seemed to be biased towards females across all years (4.5:1 and 1.8:1, respectively). Analysis of sex ratio for tricolored bats and evening bats was not possible, with only one bat of each species caught.

Capture rate of northern long-eared bats declined by 70% from 2015 to 2017 (Table 3). Trends in other species were not consistent. The little brown bat had a capture rate more than twice high in 2016 compared to 2015 and 2017. This was due to high capture rates of little brown bats at four sites: 19 little brown bats / 10 net hours near Mystery Cave (Swingen et al. 2016a), 9 little brown bats / 10 net hours at Whitewater State Park and Wildlife Management Area (Swingen et al. 2016b), 6 little brown bats / 10 net hours at Arden Hills Army Training site, (Dirks et al. 2016), and 7 little brown bats / 10 net hours on the Chippewa National Forest (Swingen et al. 2016d). Capture rates at these four sites were 4 to 6 times greater than the average capture rates at other sites that we mist-netted.

The big brown bat had a lower capture rate in 2015 than either 2016 or 2017. This could have been in part due to spatial distribution of effort. More brown bats were caught in the central part of Minnesota than the north or the south (see Fig. 6 below), so the low capture rate in 2015 could be because most of the mist-netting effort was in the northern part of the state (Fig. 4).

Capture rates of eastern red bat, hoary bat, and silver-haired bat were lower across all years, less than 1 bat / 10 net hours (Table 3). The pattern of eastern red bat capture rates was similar to the big brown bat. The pattern of capture rate of hoary bats decreased over the three years, similar to the northern long-eared bat. Finally, the silver-haired bat capture rate increased over all three years of the project.

Table 3. Bat captures / 10 net hours during each field season by species (MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat).

	Captures / 10 net hours					
Year	**MYSE**	**MYLU**	**EPFU**	**LABO**	**LACI**	**LANO**
2015	1.50	1.34	0.65	0.22	0.22	0.14
2016	1.02	3.04	1.97	0.57	0.08	0.23
2017	0.41	1.14	2.01	0.43	0.05	0.48

Patterns were similar for the percent of bat species captured each year (Table 4). The difference between Table 3 and Table 4 is that the different amounts of mist-netting effort each year are accounted for in Table 3 when bat captures / 10 net hours are calculated. From 2015 to 2017 the percentage of northern long-eared bats captured decreased from 37% to 9% of bats caught, while the percentage of big brown bats increased from 16% to 45% of bats caught (Table 4). There was no trend in capture rates of little brown bats. Fewer than 10% of bats captured were eastern red bats, hoary bats, and silver-haired bats. With only one tri-colored bat and one evening bat caught, there would be no trend in capture rates.

Table 4. Percent of bats captured during each field season by species (MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat).

	Percent of Captures					
Year	**MYSE**	**MYLU**	**EPFU**	**LABO**	**LACI**	**LANO**
2015	37	33	16	5	5	3
2016	15	44	28	8	1	3
2017	9	25	45	9	1	11
Total	**17**	**37**	**31**	**8**	**2**	**5**

The distribution of species captured when broken down into males and females was similar (Table 5), because the sex ratio was relatively similar for all species except the little brown bat.

Table 5. Percent of bats captured by species and sex as a percentage of the yearly total (MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat).

Year	Sex	MYSE	MYLU	EPFU	LABO	LACI	LANO
2015	F	17	10	6	3	6	2
	M	19	23	10	2	0	1
2016	F	9	27	12	4	1	2
	M	6	17	17	5	0	1
2017	F	7	10	21	6	0	7
	M	2	15	24	3	1	3

The sex ratio differences were not caused by juveniles, because statistical differences in sex ratios were the same for adults only (Table 6). There were more female adult northern long-eared bats than male adult northern long-eared bats in 2016 and 2017 (χ^2_5 = 12.8, p = 0.03) and for little brown bats there were more adult males in 2015 and 2017, and more adult females in 2016 (χ^2_5 = 29.9, p < 0.001). Sex ratio of adult big brown bats and adult eastern red bats was not different from 1:1 (χ^2_5 = 8.0, p = 0.15 and χ^2_5 = 3.6, p = 0.6). Although sample size was not large enough for statistical tests, the sex ratio of adult hoary bats was 5.7:1.0, and the sex ratio of adult silver-haired bats was 3.1:1.0, indicating a likely bias towards females when mist-netting.

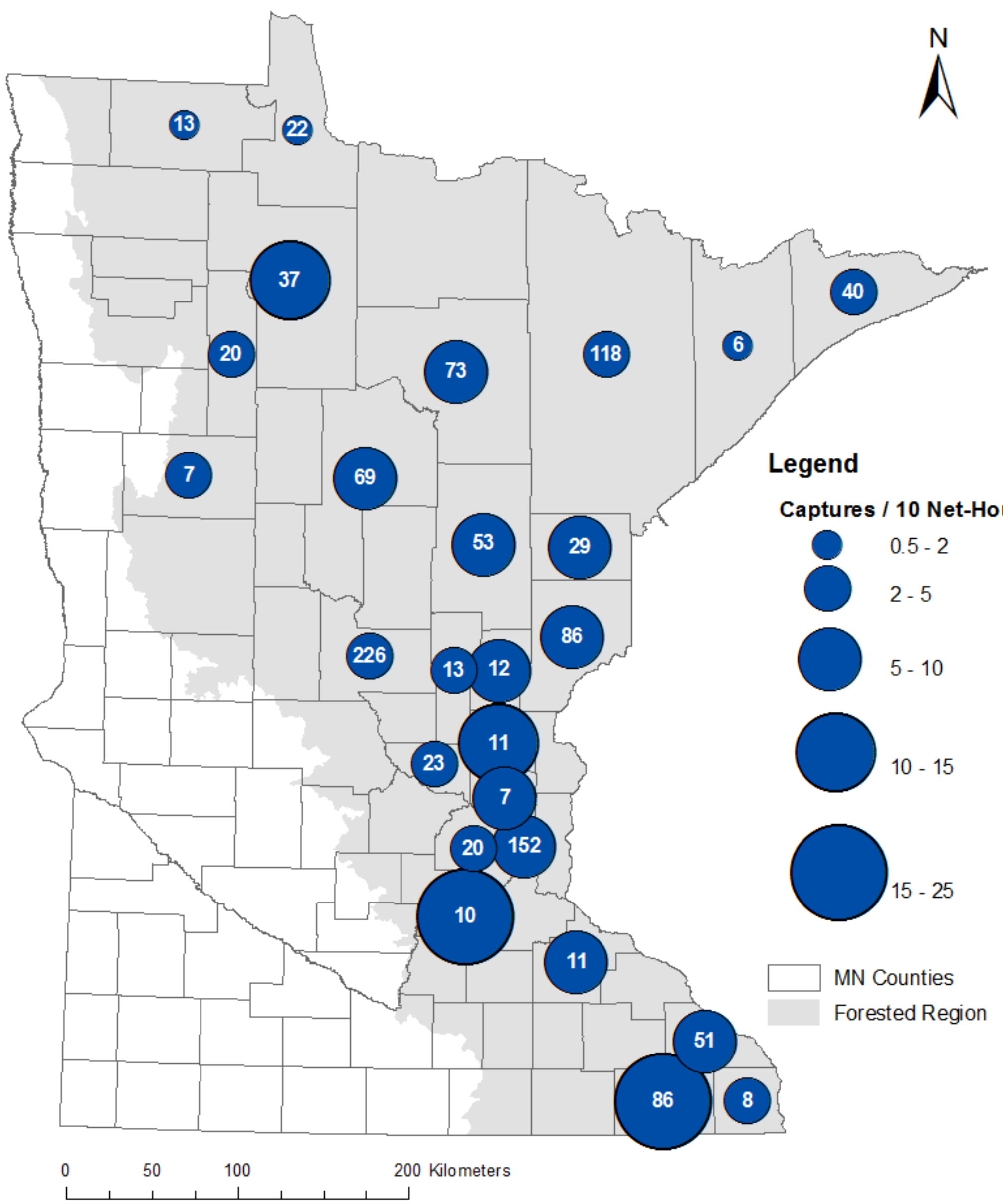
Table 6. Count of adult bats captured and processed during each field season by species and sex (MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat, NYHU – evening bat, PESU – tricolored bat).

Year	Sex	MYSE	MYLU	EPFU	LABO	LACI	LANO	NYHU	PESU	Total
2015	F	34	19	12	6	11	5	0	0	87
	M	35	42	18	4	0	2	0	0	101
2016	F	57	167	64	21	5	12	1	0	327
	M	36	102	96	27	1	7	0	1	270
2017	F	24	26	68	17	1	23	0	0	159
	M	8	46	76	9	2	4	0	0	145
Total		**194**	**402**	**334**	**84**	**20**	**53**	**1**	**1**	**1089**

Capture Rates / Distribution

Capture rates were slightly lower in the northeast part of the state compared to the central and southeast counties (Figure 5). However, perhaps the most important feature of Figure 5 is that capture rates were relatively consistent and above 0 in all parts of Minnesota where mist-netting was attempted.

Figure 5. Map of bat mist-netting capture results for all species and all years combined, grouped by county. The size of the symbol in each county indicates the overall capture rate (bats/10 net-hours), and the label indicates the total number of bats captured in that county during the project.



Throughout the project the average capture rate for all species combined was about 5 adult bats/10 net-hours (Table 7). Weekly capture rates were consistent with the overall average, except for the last two weeks of July when netting effort was lower. Many female bats would have been lactating in late July, and energy needs for lactation should have resulted in foraging every night, which is why a decline in the capture rate would not be expected. The number of juveniles captured increased in the last week of July.

Table 7. Total number of bats captured and effort (net-hours) by week, years combined (2015 – 2017).

Week	Total Bats	Net-Hours	Bats / 10 Net-Hours	Adults / 10 Net-Hours
6/1 – 6/7	75	172	4.36	4.36
6/8 – 6/14	220	398	5.53	5.53
6/16 – 6/21	260	430	6.05	6.05
6/22 – 6/28	197	378	5.21	5.16
6/29 – 7/5	80	156	5.13	4.81
7/6 – 7/12	191	296	6.45	4.43
7/13 – 7/19	110	260	4.23	3.46
7/20 – 7/26	54	112	4.82	3.30
7/27 – 8/2	15	14	10.71	5.00
Total	1202	2216	5.42	4.92

State-wide distribution of species varied (Figs. 6 and 7). Northern long-eared bats were captured throughout the forested portion of the state, and the highest capture rates were in counties around and north of Minneapolis-St. Paul (Fig. 6). Historical records of northern long-eared bat distribution are also throughout the state (Nordquist and Birney 1985, Moen et al. 2018).

Little brown bat capture rates were highest in the southeast and the northwest (Fig. 6). However, little brown bat captures were also distributed throughout the state. Big brown bats are also distributed throughout the state, and capture rates were highest in the central portion of the state around Minneapolis-St. Paul (Fig. 6). Eastern red bat had a slightly higher capture rate in the center of the state compared to the north and the south, although capture rates were lower than for the northern long-eared bat, little brown bat, and big brown bat (Fig. 6).

Fewer hoary bats and silver-haired bats were captured in mist-nets, so it is hard to evaluate differences in capture rates, but distribution was scattered throughout the locations we mist-netted (Fig. 7). Hoary bats were only captured north of the Twin Cities, while silver-haired bats were captured throughout the forested area of the state. Finally, only one tricolored bat was captured in the south, and one evening bat was captured in the Twin Cities area.

Figure 6. Maps of bat mist-netting results (captures per 10 net-hours) by species for all years of data combined (2015 - 2017). Capture results are grouped by county to limit symbol overlap. See Table 2 for total captures by species.

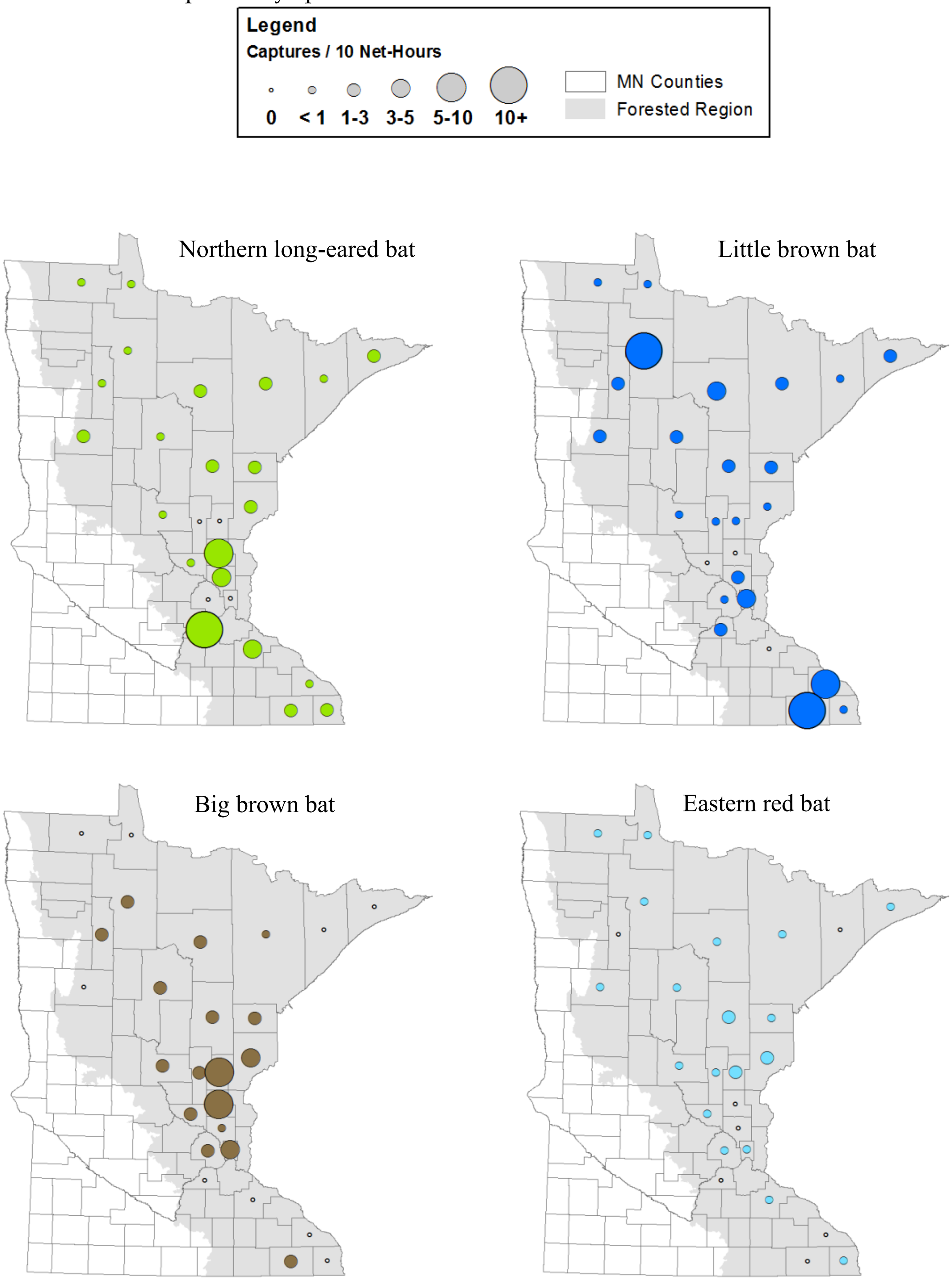
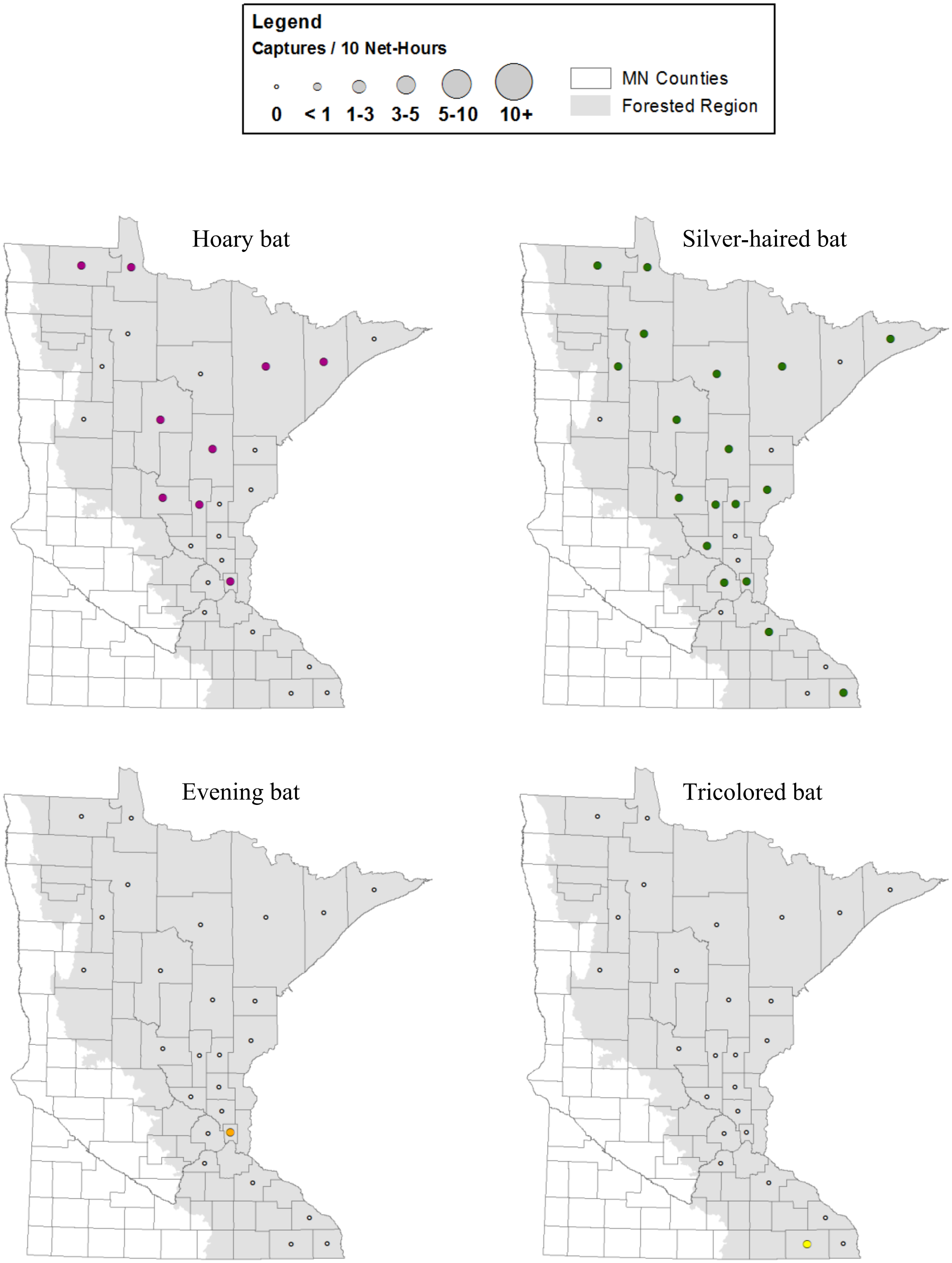


Figure 7. Maps of bat mist-netting results (captures per 10 net-hours) by species for all years of data combined (2015 - 2017). Capture results are displayed by county to limit symbol overlap. See Table 2 for total captures by species.



Age Class and Reproductive Status of Captured Bats

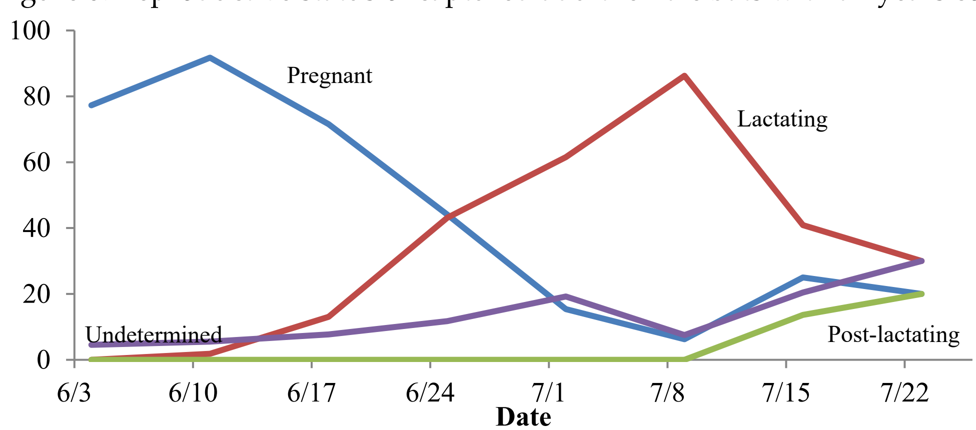
More than 90% of bats captured were adults and about 10% of bats captured were juveniles (Table 8). Juveniles were first captured on June 22nd (big brown bat) and June 23rd (little brown bat). The first juvenile northern long-eared bat was captured on July 14th. Most (85%) captured adult female bats were pregnant or lactating, with the first lactating bats captured on June 13th (big brown bat and hoary bat) and the first lactating northern long-eared bat captured on June 28th. The latest we captured pregnant bats was July 21st (little brown bat and northern long-eared bat); we also captured pregnant big brown bats, eastern red bats, and hoary bats in July.

Table 8. Number of individual bats captured of all species by age and reproductive condition by week, 2015 – 2017. P – Pregnant, L – Lactating, PL – Post-lactating, TD – Testes descended, NR – Non-reproductive, U – Undetermined.

	Adult Female					Adult Male			Juvenile	Total
Week of Capture	**P**	**L**	**PL**	**NR**	**U**	**TD**	**NR**	**U**	**NR**	
6/1 – 6/7	17	0	0	1	12	4	38	3	0	**75**
6/8 – 6/14	100	2	0	6	19	10	55	28	0	**220**
6/16 – 6/21	93	17	0	10	22	17	86	15	0	**260**
6/22 – 6/28	44	44	0	12	5	13	74	3	2	**197**
6/29 – 7/5	4	16	0	5	4	4	41	1	5	**80**
7/6 – 7/12	5	69	0	6	3	12	33	3	60	**191**
7/13 – 7/19	11	18	6	9	2	8	30	6	20	**110**
7/20 – 7/26	2	3	2	3	0	13	14	0	17	**54**
7/27 – 8/2	0	1	0	0	0	3	2	1	8	**15**
Total	**276**	**170**	**8**	**52**	**67**	**84**	**373**	**60**	**112**	**1202**

The highest proportion of pregnant bats captured was in early June, and the highest proportion of lactating bats captured was in early July (Fig. 8). We could not determine the reproductive status of some bats, especially early in the summer, when pregnancy can be difficult to determine.

Figure 8. Reproductive status of captured adult female bats with all years combined.



Weights and Measurements of Captured Bats

Weights of captured bats were consistent with those reported in the literature (Jackson 1961, Hazard 1982). Female bats weighed more on average than male bats for each species (Table 9). Weights did not differ between years for most groups with the exception of female little brown bats (ANOVA, $F_{2,209} = 4.3$, $P < 0.02$), and male and female northern long-eared bats (ANOVA, $F_{2,76} = 4.8$, $P < 0.02$; $F_{2,112} = 10.8$, $P < 0.0001$, respectively). The single male tricolored bat caught weighed 8.0 g and the single female evening bat caught weighed 12.0 g.

Table 9. Weights of 1,087 adult bats captured (Mean ± SE). For female hoary bats in 2017 and male hoary bats in 2016, only one individual was captured, so the weight of that individual is shown. No male hoary bats were captured in 2015. (MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat).

	Sex	MYSE	MYLU	EPFU	LABO	LACI	LANO
2015	Female	8.3 ± 0.2	10.4 ± 0.3	25.8 ± 1.7	15.6 ± 1.0	29.1 ± 1.5	17.9 ± 1.7
2016	Female	9.4 ± 0.2	10.4 ± 0.2	24.0 ± 0.5	14.7 ± 0.5	33.8 ± 3.2	17.1 ± 0.6
2017	Female	7.8 ± 0.3	9.2 ± 0.3	23.9 ± 0.5	15.3 ± 0.5	33.2	17.4 ± 0.5
Total	Female	8.7 ± 0.2	10.3 ± 0.1	24.1 ± 0.4	15.1 ± 0.3	30.7 ± 1.4	17.4 ± 0.4
2015	Male	6.9 ± 0.1	8.5 ± 0.2	20.2 ± 0.4	12.1 ± 0.4	-	12.3 ± 0.3
2016	Male	8.1 ± 0.4	8.9 ± 0.1	19.8 ± 0.3	13.0 ± 0.4	21.5	12.3 ± 0.6
2017	Male	8.2 ± 0.9	8.7 ± 0.1	20.0 ± 0.2	13.0 ± 0.4	26.0 ± 0.5	13.6 ± 0.5
Total	Male	7.6 ± 0.2	8.8 ± 0.1	19.9 ± 0.2	12.9 ± 0.3	24.5 ± 1.5	12.7 ± 0.4

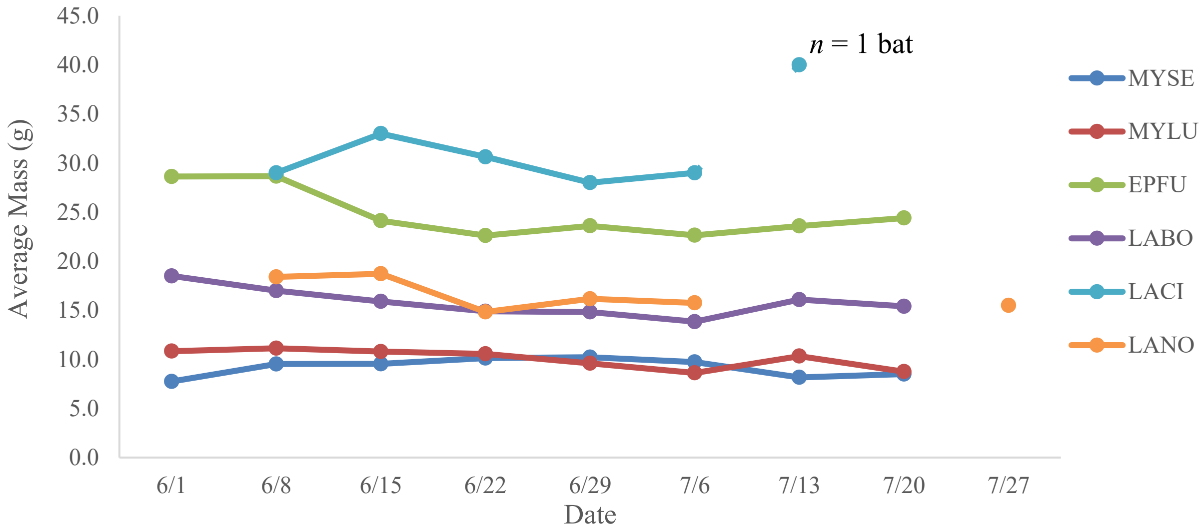
There were some differences in body mass among adult reproductive categories, but the clearest difference was that, as would be expected, juvenile bats weighed less than adult bats (Table 10).

Table 10. Weights of bats captured by species, age, and reproductive condition. P – Pregnant, L – Lactating, PL – Post-lactating, TD – Testes descended, NR – Non-reproductive, U – Undetermined. (MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat).

Age/Sex	Status	MYSE	MYLU	EPFU	LABO	LACI	LANO
Adult Female	P	9.5	10.9	26.7	16.9	33.6	18.5
	L	9.2	9.0	22.1	14.6	28.3	15.3
	PL	7.6		24.2	16.5	-	-
	NR	7.5	8.3	19.4	13.5	34.4	11.5
	U	7.2	9.6	14.8	16.8	26.3	-
Adult Male	TD	8.3	8.4	20.4	12.3	-	-
	NR	7.5	8.8	19.8	12.9	24.5	12.6
	U	7.3	8.8	18.0	14.0	-	12.9
Juvenile	NR	6.6	7.9	15.5	11.4	21.0	9.3

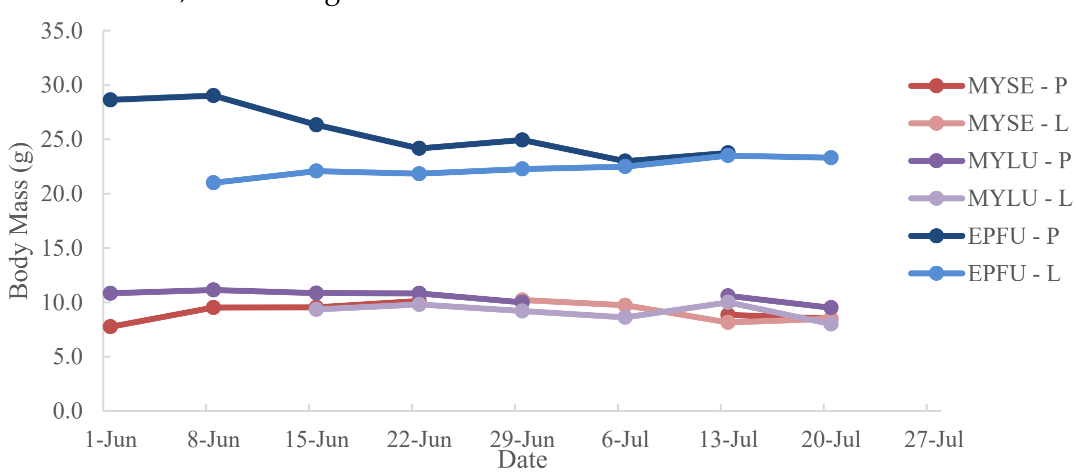
Body mass patterns of female bats were level across the summer (Fig. 9). Only one hoary bat was caught on 7/13; the apparent increase in body mass is an effect of this bat. This figure also shows relative weights of Minnesota bat species. The *Myotis* species and the tri-colored bat are the smallest bats in Minnesota.

Figure 9. Body mass of captured adult female bats over time. Species codes: MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat.



Body mass of pregnant and lactating bats appeared to be relatively consistent over the summer, except that body mass of pregnant big brown bats seemed to decline (Fig. 10). It is possible that pregnant females captured later in the summer were in poorer physical condition than those captured earlier.

Figure 10. Body mass of pregnant (P) and lactating (L) northern long-eared bats, little brown bats, and big brown bats over time. Species codes: MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat.



Forearm length of captured bats was also consistent with measurements reported in the literature (Jackson 1961, Hazard 1982). The only unusual pattern was in female northern long-eared bats, which had a smaller average forearm length in 2016 than in the other years (Table 11). Average body mass of female northern long-eared bats was heaviest in 2016, and we are not sure why the two measurements contradict each other—we expected forearm length and body mass to be correlated. The single tricolored bat caught had a forearm length of 31.7 mm and the single evening bat caught had a forearm length of 37.0 mm.

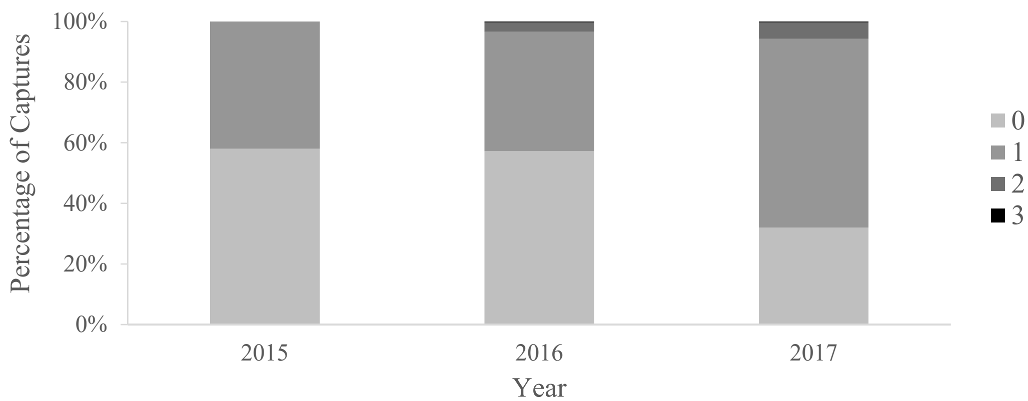
Table 11. Forearm length (mm) of adult bats captured. Species codes: MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat.

	Sex	MYSE	MYLU	EPFU	LABO	LACI	LANO
2015	F	36.6 ± 0.2	38.5 ± 0.2	48.7 ± 0.4	40.9 ± 0.4	55.2 ± 0.3	41.5 ± 0.5
2016	F	33.4 ± 0.7	37.6 ± 0.2	47.6 ± 0.4	40.7 ± 0.5	55.0 ± 0.7	40.8 ± 1.0
2017	F	36.3 ± 0.4	38.0 ± 0.2	47.8 ± 0.3	41.3 ± 0.6	56.0	40.4 ± 1.1
Total	F	34.9 ± 0.4	37.8 ± 0.1	47.8 ± 0.2	41.0 ± 0.3	55.2 ± 0.2	40.7 ± 0.7
2015	M	36.5 ± 0.2	38.1 ± 0.3	47.6 ± 0.5	39.2 ± 0.5		41.9 ± 1.1
2016	M	36.4 ± 0.4	37.0 ± 0.2	45.1 ± 0.4	38.7 ± 0.5	52.9	40.7 ± 0.3
2017	M	36.3 ± 0.5	38.0 ± 0.2	46.2 ± 0.4	39.6 ± 0.7	54.2 ± 1.4	40.0 ± 0.8
Total	M	36.4 ± 0.2	37.5 ± 0.2	45.8 ± 0.3	39.0 ± 0.4	53.7 ± 0.9	40.7 ± 0.4

Wing Damage of Captured Bats

Wing damage index (WDI) scores ≥ 1 were recorded for 593 of the 1204 bats captured, including individuals of all eight bat species captured. The proportion of captured bats with wing damage increased over the three years of the project, with 38% of captures in 2015 and 68% of captures in 2017 showing wing damage (Fig. 11). The proportion of northern long-eared bats with WDI scores ≥ 1 increased from 32% in 2015 to 69% in 2017. Moderate (WDI = 2) damage was recorded for 3.5% of all cave-hibernating bats (big brown bat, little brown bat, northern long-eared bat, and tricolored bat) captured, but only three bats showed WDI scores of 3, indicating severe wing damage. The moderate and severe wing damage was likely caused by WNS, although wing damage may occur for reasons other than WNS.

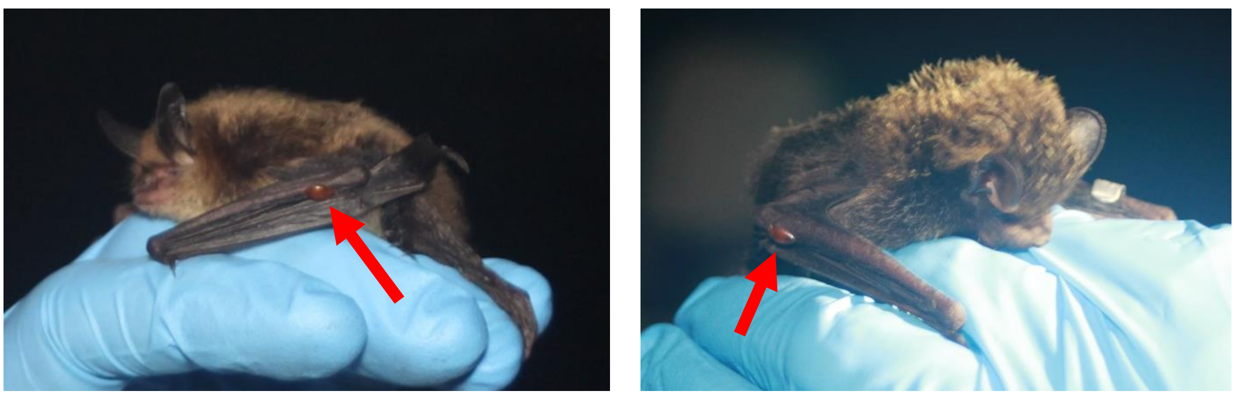
Figure 11. Chart showing the proportion of bats captured by year assigned to each level of the Wing Damage Index (WDI, Reichard and Kunz 2009), where 0 = no damage and 3 = severe damage.



Ectoparasites Found on Bats

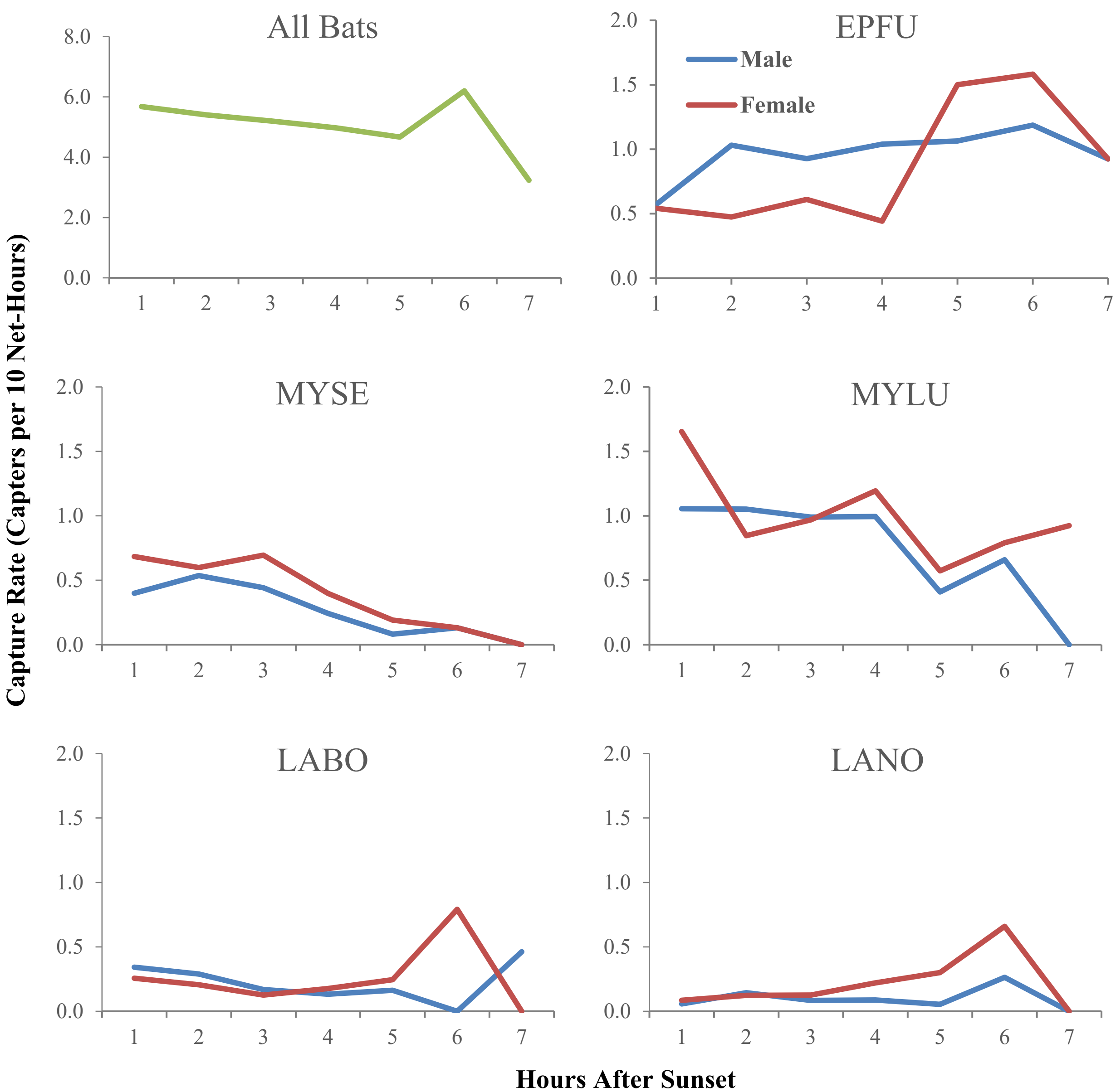
Ectoparasites were seen on 44 bats (3.7%) during processing. The parasites we observed were most likely bat bugs (*Cimex adjunctus*) and mites (Jackson 1961). We observed parasites most often on the ears and wings of captured bats (Fig. 12). Notes were made when any parasites were observed incidentally during handling, but a full examination for parasites was not made for each bat and no ectoparasites were collected or identified microscopically. We found parasites on a larger proportion of the northern long-eared bats captured than other species (n = 24, 13.4%), probably because most radiotransmitters were deployed on northern long-eared bats, and the longer handling times for bats receiving radiotransmitters provided more opportunity to observe parasites incidentally.

Figure 12. Photos showing ectoparasites (bat bugs – *Cimex adjunctus*; indicated by red arrows) on the wings of captured bats. Left: female northern long-eared bat; Right: female silver-haired bat.



We generally attempted to capture bats from sunset to 2:00 a.m., which meant nets were open for about five hours. However, nets were sometimes closed earlier or later based on weather conditions and capture rates. Bat captures / hour declined slightly from sunset to 2:00 a.m., although bats were captured from 0 to 7 hours after sunset (Fig. 13). Differences among species and between males and females were obvious. *Myotis* spp. (northern long-eared bat and little brown bat) were captured at higher rates earlier in the night, and capture rates were similar between the sexes. For big brown bats, eastern red bats, and silver-haired bats, capture rates were higher later in the night, especially for females of those species.

Figure 13. Capture rates (# captures / 10 net-hours) by hour past sunset. Species codes: MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat, LABO – eastern red bat, LACI – hoary bat, LANO – silver-haired bat.



Radiotransmittered Bats

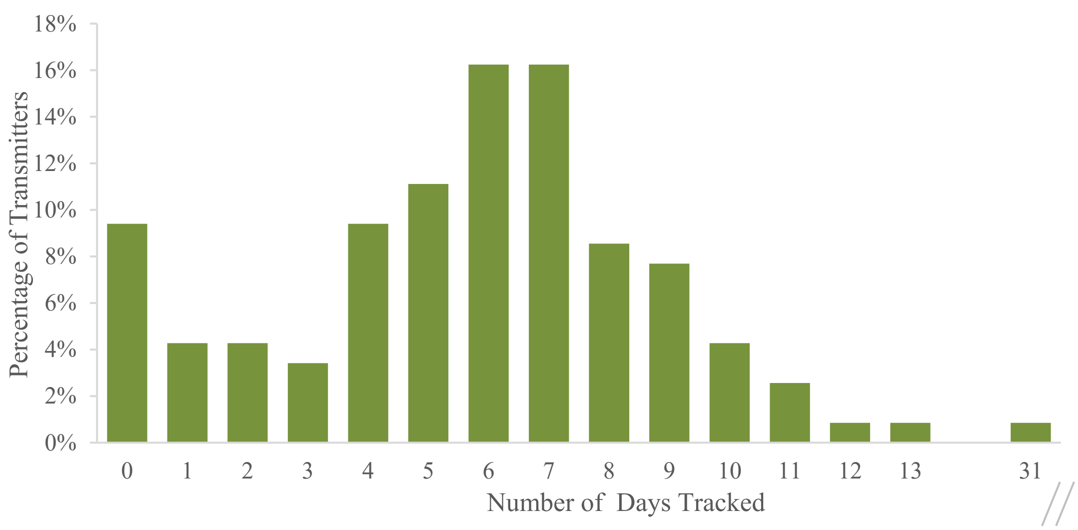
We attached transmitters to 117 bats, including 89 female northern long-eared bats (Table 12). Our original plan was to deploy transmitters only on reproductive female northern long-eared bats, but due to reductions in capture rates (especially in 2017), we attached transmitters to adult male northern long-eared bats, little brown bats, and big brown bats. We tracked 84 northern long-eared bats, 13 little brown bats, and 8 big brown bats to roosts in 262 trees and 12 buildings (Table 12). Twelve bats given transmitters could not be located after release.

Table 12. Transmitters deployed, bats successfully tracked, and roosts identified by bat species and sex. Species codes: MYSE – northern long-eared bat, MYLU – little brown bat, EPFU – big brown bat.

		Transmitters Deployed					
Species	**Sex**	**2015**	**2016**	**2017**	**Total**	**Bats Tracked**	**Roosts Identified**
MYSE	F	24	45	20	89	83	238
MYSE	M	0	0	2	2	1	3
MYLU	F	1	3	11	15	11	11
MYLU	M	0	0	2	2	2	7
EPFU	F	0	0	8	8	7	14
EPFU	M	0	0	1	1	1	1
Total		**25**	**48**	**44**	**117**	**105**	**274**

The bats with transmitters were tracked until the transmitters failed or fell off, which was between 1 – 31 days (median = 6). About 80% of bats wearing transmitters were tracked for ≥ 4 days (Fig. 14). The average tracking duration for female northern long-eared bats was 6.3 days (range 1 – 13).

Figure 14. Frequency distribution of the length of tracking. Tracking ended when the transmitter could no longer be found, when the transmitter reached end of life, or when the transmitter was no longer attached to the bat.



Female northern long-eared bats with radiotransmitters used from 1 to 7 unique roosts (Table 13). With a mean and median of about six days of tracking per bat, sample size is large enough to show that northern long-eared bat females are switching roost trees frequently.

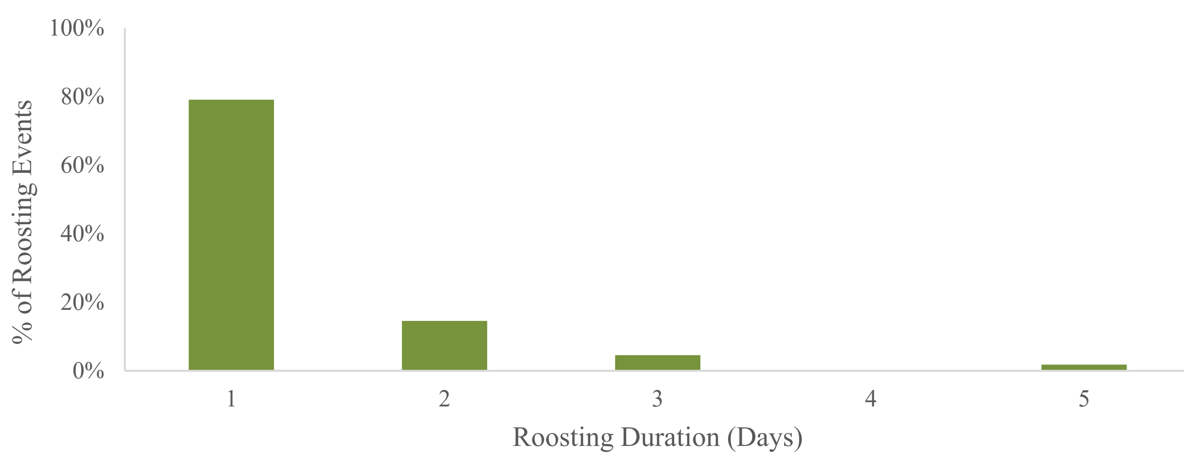
Table 13. Number of bats tracked, by species, sex and number of unique roosts.

Species	Sex	Number of Unique Roosts							# Bats Tracked
		1	**2**	**3**	**4**	**5**	**6**	**7**	
MYSE	Female	12	14	19	15	14	8	1	83
MYSE	Male	0	0	1	0	0	0	0	1
MYLU	Female	9	2	0	0	0	0	0	11
MYLU	Male	1	0	0	0	0	1	0	2
EPFU	Female	4	0	1	1	1	0	0	7
EPFU	Male	1	0	0	0	0	0	0	1
Total		**27**	**16**	**21**	**16**	**15**	**9**	**1**	**105**

Movements between roosts

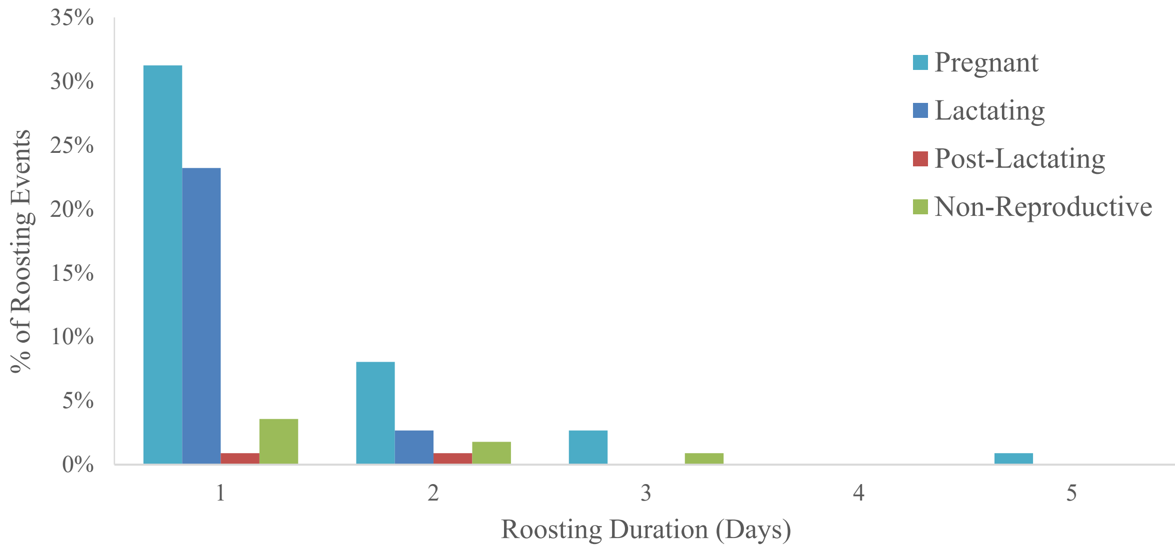
The number of days spent in a roost could be determined if we knew when a bat started using a roost, and we also knew when a bat switched to a new roost. The first roost a bat with a radiotransmitter used could not be included because we did not know the roost the bat had used the day before being captured. The 79 female northern long-eared bats that were tracked to roosts in trees spent an average of 1.3 days (median = 1 day, range of 1 to 5 days) in each roost for the 110 roosting events with known start and end dates. Most of the time female northern long-eared bats only spent one day in a roost (Fig. 15). Female big brown bats that roosted in trees spent an average of 1.4 days in each roost (n = 5 roosting events of known length), and the one male little brown bat tracked spent an average of 1.6 days in each roost (n = 17 roosting events of known length). There were < 5 roosting events of known length in trees for male big brown bats, female little brown bats, and male northern long-eared bats.

Figure 15. Frequency distribution of the number of consecutive nights a tree roost was used based on 110 female northern long-eared bat roosting events with known start and end dates.



Female northern long-eared bats spent only one night in a roost most of the time, whether they were pregnant or lactating (Fig. 16). It was somewhat surprising that even when lactating, female northern long-eared bats would spend only one night in a tree roost.

Figure 16. Frequency distribution of the number of consecutive nights a tree roost was used by reproductive condition, based on 86 roosting events with known start and end dates for female northern long-eared bats with known reproductive condition.



In contrast to bats that roosted in trees, bats that roosted in buildings did not switch roosts while radiotransmitters were active. This was true even for female northern long-eared bats, which switched tree roosts frequently (Fig. 16). The frequency of using buildings as roosts varies among bat species. Female northern long-eared bats roosted in buildings 4 times out of 83 bats tracked, which was 5% of northern long-eared bats that wore radiotransmitters. Fewer transmitters were deployed on female little brown bats, but eight of those bats were tracked to five different buildings, and only three were tracked to roosts in trees. This meant that 73% of female little brown bats roosted in buildings. Three of the eight big brown bats roosted in two different buildings, which meant that 38% of little brown bats roosted in buildings.

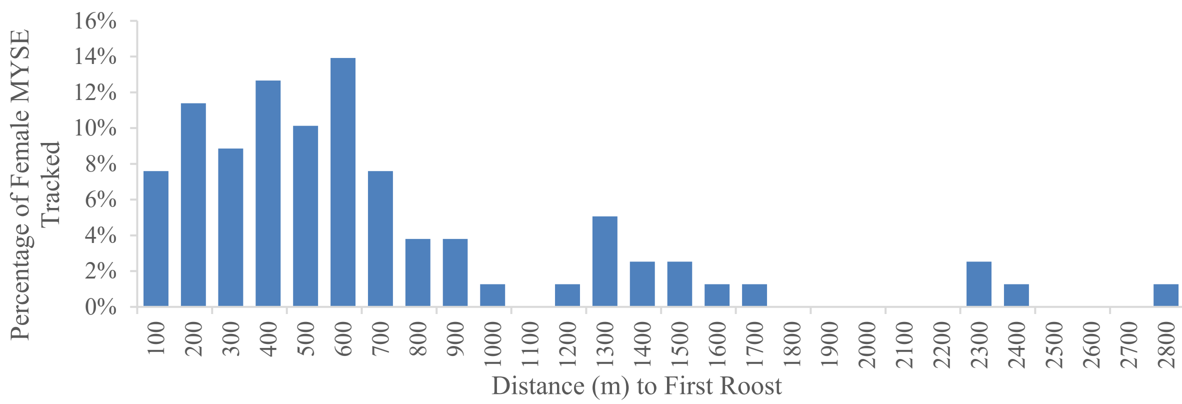
The average distance from the capture location to the first roost for northern long-eared bat females was about 700 m (Table 14). Female little brown bats and female big brown bats first roosted about twice as far away from the capture location at an average of 1.5 km, and the first roosts of the two male little brown bats with radiotransmitters were 230 m and 2.3 km from the capture location.

Table 14. Distances traveled (in meters) between the capture location and the first roost by bats with radiotransmitters 2015 - 2017. Each cell shows the average distance ± SE followed by the range in parentheses when n was > 2. Distances include roosts in either trees or buildings.

Sex	MYSE	MYLU	EPFU
Female	726 ± 64 (26 – 4197)	1662 ± 380 (259 – 4583)	1456 ± 387 (565 – 3234)
Male	59	1246 (232, 2261)	684

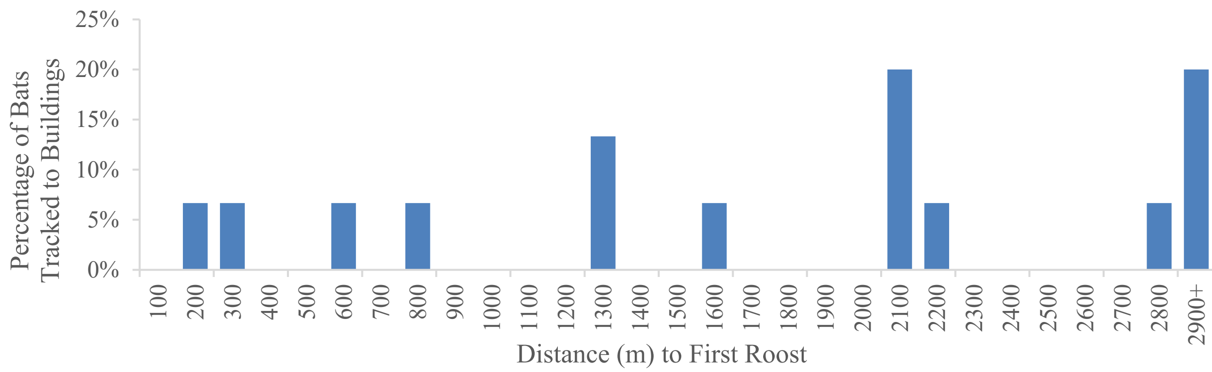
For female northern long-eared bats, about 61% of movements between the capture location and the first roost tree were < 700 m, about 75% of movements from the capture location to the first roost tree were < 1 km, and the longest distance between the capture location and the first roost tree was 2.8 km (Fig. 17).

Figure 17. Frequency distribution of the distance from capture location to first roost, for female northern long-eared bats using tree roosts.



Distances from capture location to the first roost were similar for other bat species, although sample size was too low to draw specific conclusions (Fig. 18). One little brown bat moved 4.5 km, a male northern long-eared bat moved 4 km, and the longest distance moved from capture site to roost site by big brown bats was 3 km. However, sample size of bats with radiotransmitters for male northern long-eared bats, male and female little brown bats, and big brown bats was ≤ 11.

Figure 18. Frequency distribution of the distance from capture location to first roost for all bats fitted with radiotransmitters except female northern long-eared bats. Because of low sample size, species are not identified.

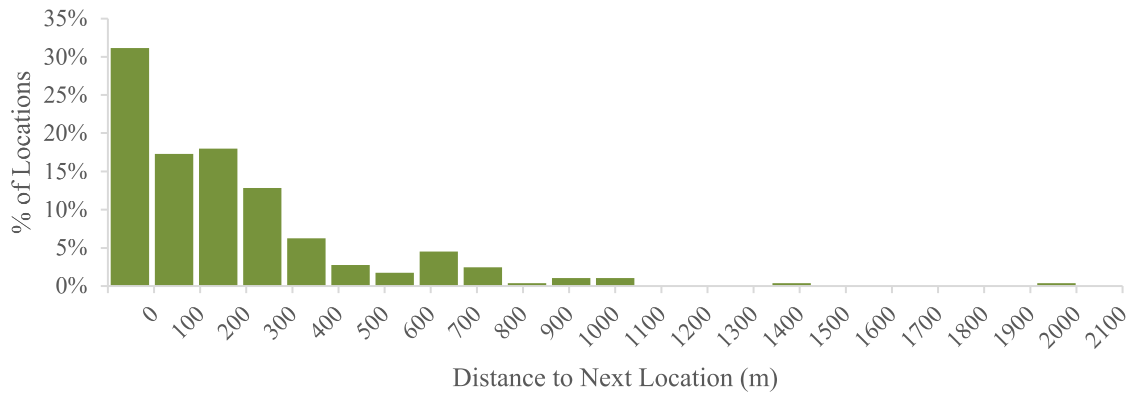


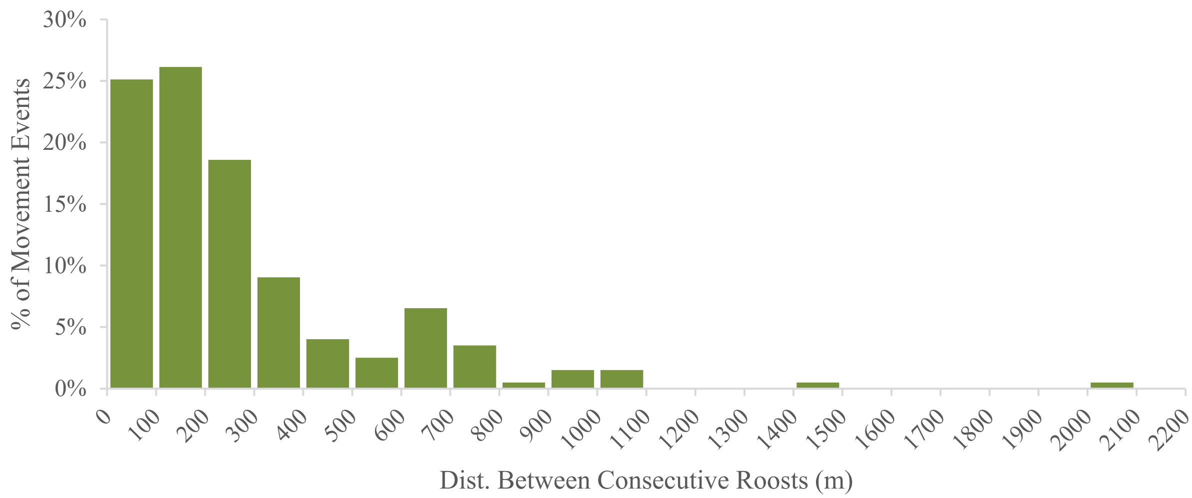
Distances moved between consecutive roosts were shorter than the distances moved from the mist-net site to the first roost, at 10% to 30% of distances moved from the capture site to the first roost (Table 15), except for male northern long-eared bats. A male northern long-eared bat had the farthest recorded distance between consecutive roosts at 2193 m. Distance traveled between consecutive roosts for all bats averaged 280 m, with 82% of consecutive roosts < 500 m apart, and 25% of consecutive roosts < 100 m apart (Fig. 19). About 30% of the time the female MYSE reused the same roost (Fig. 19a). When roosts were switched, 70% of the time the distance between roosts was < 300 m (Fig. 19b).

Table 15. Distances traveled (in meters) between consecutive roosts by bats with radiotransmitters 2015 – 2017. Each cell shows the average distance ± SE followed by the range in parentheses.

Sex	MYSE	MYLU	EPFU
Female	278 ± 20 (2 – 2083)	36 ± 32 (4 – 101)	317 ± 65 (33 – 555)
Male	739 ± 727 (12 – 2193)	244 ± 31 (14 – 416)	-

Figure 19. Frequency distribution of distance between daily locations for northern long-eared bats roosting in trees. Top chart includes all days on which the transmitter was active, including days in which the bat did not move roosts. Bottom chart is the same data, with zero distances removed, and shows distances between consecutive unique roost trees.





Five bats with transmitters (one northern long-eared bat female, one little brown bat female, one little brown bat male, one northern long-eared bat male, and one big brown bat female) re-used roosts on non-consecutive days within the tracking period (e.g. moved from roost tree A on day 1 to roost tree B on day 2 and then back to roost tree A on day 3). This could be a low estimate of the frequency of roost re-use because of the short duration of transmitter life. For the bats that we had transmitters on, 12% of the bats tracked for ≥ 3 roosts re-used a roost over the duration of the transmitter life.

We did not have a large enough sample size to calculate a time interval for returning to re-use a roost. In general, it was one or two days before a bat returned to roost tree A after using roost tree B. In some cases we could not locate a bat on a night, which would have inflated the days before re-use. The one exception was a little brown bat male that moved back and forth between six trees over 30 days, spending one to five days in each tree. This transmitter deployment was unusual; no other transmitter remained attached to a bat for more than 13 days (Fig. 14).

Maternity Roost Home Ranges

We calculated MCP maternity roost home range sizes for 32 bats that had four or more roosting locations (Table 16). The average maternity roost home-range size for female northern long-eared bats (n = 29) was 7.2 hectares. Pregnant and lactating bats had similarly-sized roost home ranges, with an average of 6.7 and 6.8 ha, respectively (t_{17} = -0.028, p = 0.978). Some bats that were pregnant at the time of capture could have given birth during the tracking period.

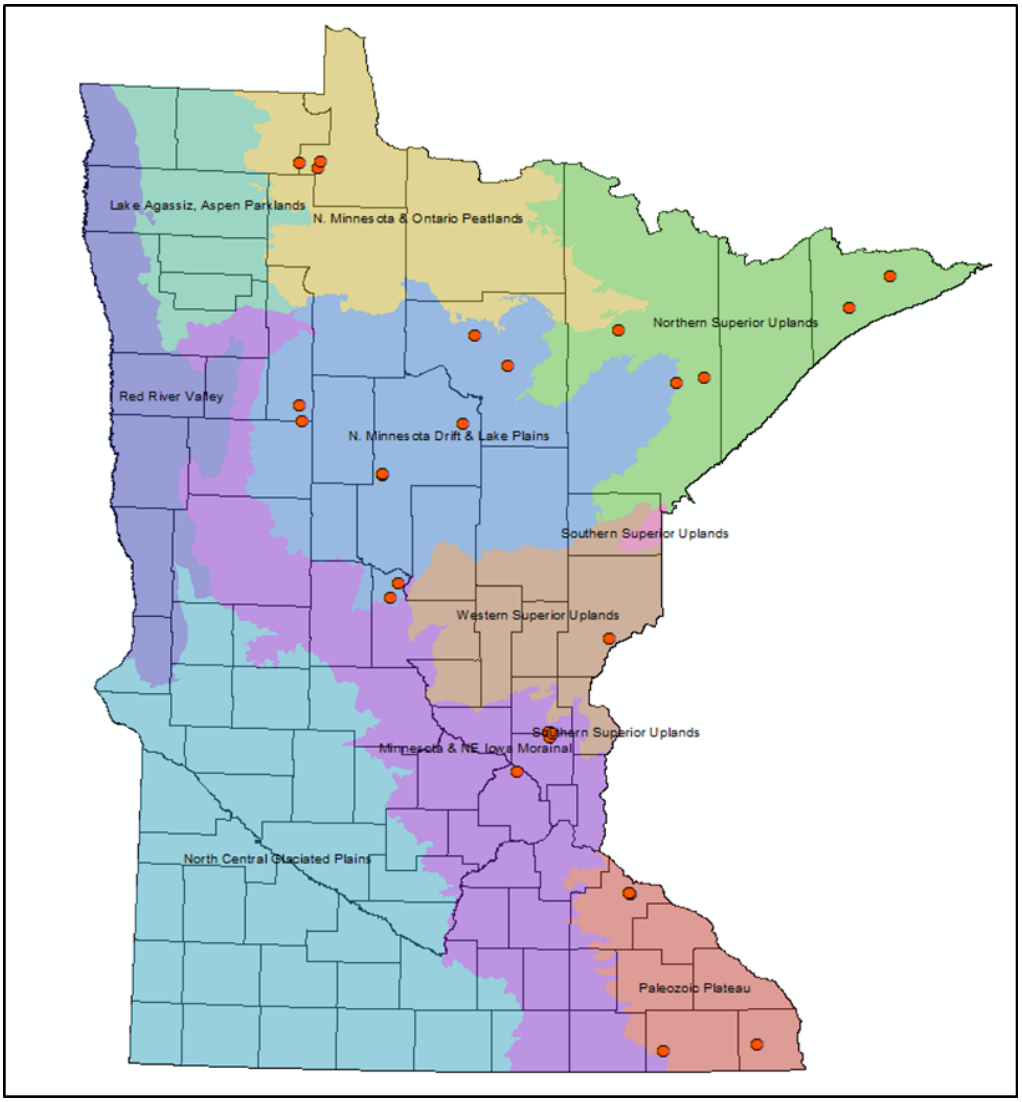
Table 16. Maternity roost home range sizes for female northern long-eared bats that had ≥ 4 roost sites.

Reproductive Status	Days	Roosts	Size(ha)
P	11	6	0.01
P	5	5	0.7
P	5	5	2.7
P	9	5	3.4
P	6	4	4.6
P	9	6	5.1
P	8	5	7.8
P	11	4	12.0
P	12	4	12.3
P	8	4	18.2
L	7	4	0.3
L	5	5	2.8
L	8	5	2.9
L	3	4	3.7
L	6	5	3.7
L	4	4	4.7
L	8	5	5.5
L	8	6	8.9
L	5	4	28.5
PL	10	4	1.5
U	10	6	0.6
U	10	4	0.7
U	10	5	0.8
U	5	4	1.1
U	8	4	7.1
U	9	6	12.6
U	10	6	26.6
U	9	4	30.8
NR	6	4	0.3

Roosting home ranges for two female big brown bats were 1.4 and 4.0 hectares. The roost home range for the male little brown bat with a radiotransmitter that lasted 31 days was 6.3 hectares. All of the female little brown bats we tracked roosted in < 4 locations, therefore we did not calculate maternity roost home ranges.

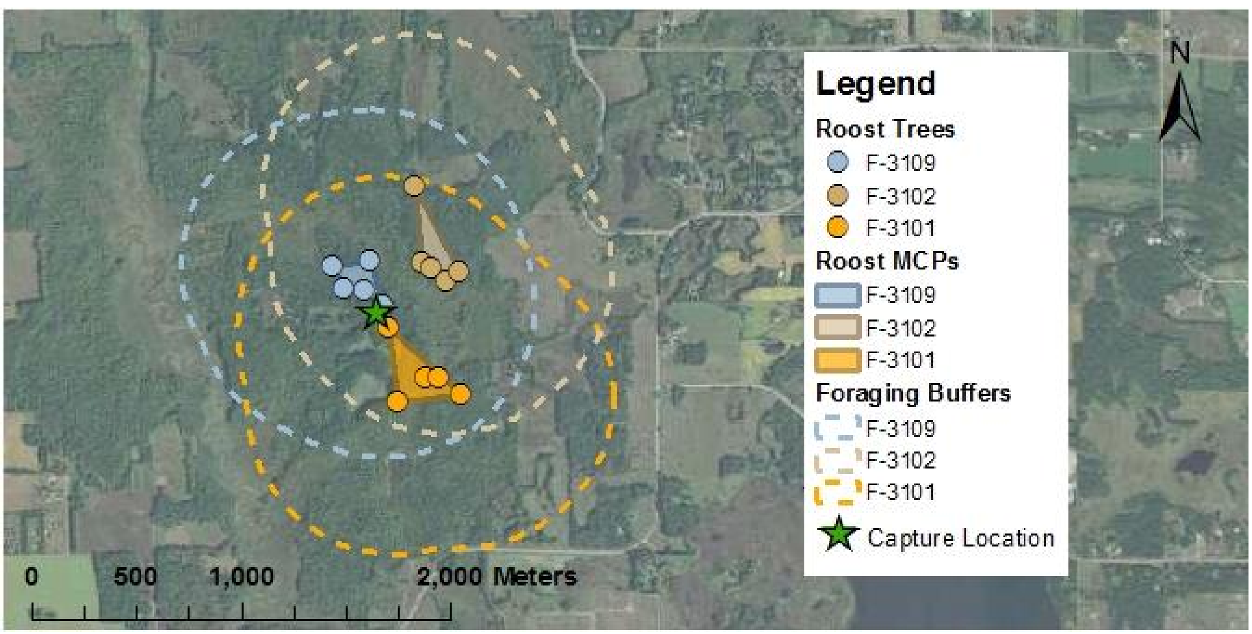
The calculated maternity roost home ranges were distributed throughout the forested portion of the state (Fig. 20). This also meant that there was not a large sample size of home ranges in any single location.

Figure 20. Spatial distribution of maternity roost home ranges calculated when > 4 roost trees were used by same bat.



It was also possible to make some preliminary estimates of foraging areas for bats with radiotransmitters, based on capture locations and identification of roost trees. We captured bats in mist-nets when they were foraging, or when they were flying to foraging areas. The maternity roost home range would be the central place from which female bats would forage each night. If we make a simplifying assumption that the foraging area is a circle, we can make a first approximation of the area that bats would forage in around the maternity roost home range (Fig. 21). This figure also shows how female northern long-eared bats caught in the same mist-net would be distributed around the capture location. When we deployed radiotransmitters on multiple bats caught in the same mist-net, they did not always roost together. Because of roost-switching, the bats would sometimes use the same roost tree, but more often than not different roost trees were used by each bat (Fig. 16). Roost tree characteristics and the number of bats emerging from a roost tree each night are analyzed in Moen et al. (2018b).

Figure 21. Example maternity roost home ranges. Colored circles show roost trees, shaded areas show MCP for "roost home ranges" and dotted lines show approximated foraging areas created by buffering the MCP home ranges by our mean "foraging distance" or distance from capture site to first roost for female northern long-eared bats of 726 m.



Emergence Surveys

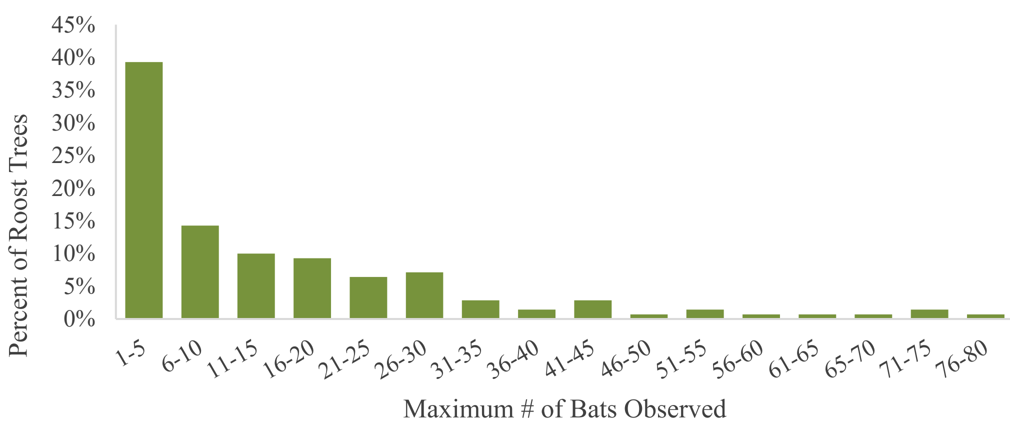
Field crews conducted 292 emergence surveys on 199 of the identified tree roosts. Bats were observed exiting the roost in 221 surveys at 160 tree roosts. Colony size (total count of bats emerging during one survey) at tree roosts ranged from 1 – 79 and averaged 14 bats (Table 17). Bats were not observed during some surveys, which was due to vegetation obstructing the view, misidentification of the roost tree, weather conditions affecting the emergence behavior of bats, or the bat/colony having moved to another tree. If a radiotransmitter had fallen off of a bat in a roost tree, we would not know the tree was no longer being used until the transmitter stayed in the tree for another night.

Table 17. Results of emergence surveys at tree roosts from 2015 – 2017. If a roost was surveyed more than once, the maximum number of bats exiting among all surveys was used to calculate the average colony size across trees. Colony sizes reported here are for roost trees at which bats were observed during emergence surveys. Roosts in buildings and associated emergence surveys are not included in the table.

Species	**Sex**	**Total Tree Roosts**	**Roosts with Bat Observations**	**Mean Colony Size**	**Minimum Colony Size**	**Maximum Colony Size**
MYSE	Female	234	140	15.2	1	79
MYSE	Male	3	2	2.0	1	3
MYLU	Female	5	4	5.5	2	13
MYLU	Male	7	7	1.6	1	5
EPFU	Female	12	7	16.1	2	34
EPFU	Male	1	0	-	-	-
Total		**262**	**160**	**14.2**	**1**	**79**

The average colony size at female northern long-eared bat tree roosts was 15.2, with ≤ 5 bats observed exiting at nearly 40% of roost trees (Fig. 22). About 70% of roost trees had 1 to 20 bats emerging on the night of observation.

Figure 22. Maximum number of bats observed exiting surveyed female northern long-eared bat roost trees 2015 – 2017. If a roost was surveyed more than once, the maximum number of bats exiting among all surveys is displayed in the figure so that each surveyed roost tree at which bats were observed appears once (n = 140). Building roosts are not included in this chart.



We conducted five surveys of the three buildings used as roosts by female northern long-eared bats. From 3 to 145 bats emerged from these buildings each night (average = 71). For these and other building roosts, we do not know the species of bats that emerged other than for the bat wearing the transmitter.

At the five buildings used as roosts by female little brown bats, we observed from 2 to 494 bats emerging (average = 196) in 17 surveys. The number of surveys varied from 1 – 7 per building, and three of the buildings had multiple transmitters in them. The average colony size per building was 178.

Sample size was small for big brown bats with only two building roosts. One of the building roosts had two big brown bats with radiotransmitters. At the two buildings used as roosts by big brown bats, we observed 44 and 96 bats emerging.

Discussion

We probably documented a decline in northern long-eared bats in Minnesota from 2015 to 2017 while mist-netting. Northern long-eared bats declined from almost 40% of captures in 2015 to less than 10% of captures in 2017. Captures per net hour of northern long-eared bat also declined, while captures per net hour did not decline for little brown bat or big brown bat. Coincidentally with the decline in northern long-eared bat captures we also recorded an increase in wing damage on both northern long-eared bat and little brown bat. Wing damage is not diagnostic of WNS but could be caused by it. The decline in northern long-eared bat after the appearance of WNS has also occurred in other states based on acoustic detection or mist-netting (Dzal et al. 2010, Brooks 2011, Ford et al. 2011, Francl et al. 2012, Reynolds 2016) and based on declines in the number of bats in hibernacula (Frick et al. 2010).

Species composition in captures. While species composition of bats in Minnesota may be in a state of flux because of large-scale mortality from WNS, we can identify patterns present in captures, whether scaled to captures / 10 net hours or as the percent of captures of bat species per year. These patterns in mist-net captures were sometimes consistent with the patterns of abundance in acoustic calls (Moen et al. 2018a).

About 15% of captures in mist-nets were northern long-eared bats, while less than 5% of acoustic calls were identified as the northern long-eared bat. We believe it is likely that some northern long-eared bat calls were classified as little brown bat calls, which is why the northern long-eared bat was under-represented in acoustic surveys relative to mist-netting. Calls of northern long-eared bats and little brown bats are known to be difficult to differentiate, and in many cases the species are lumped into the *Myotis* genus for analysis (e.g., Dixon 2011, see Moen and Swingen 2018 and Moen et al. 2018a for further discussion). About 40% of bats captured in mist-nets were little brown bats, while about 50% of acoustic calls were identified as little brown bats. Thus, little brown bats were over-represented in the acoustic surveys by about 10%, and northern long-eared bats were under-represented in acoustic surveys by about 10%, if mist-netting results, when bats are identified by physical characteristics, are more representative.

Another species that showed differences in capture rates was the big brown bat, which was about 30% of captures, but represented less than 10% of acoustic calls. The big brown bat may be less able to avoid mist-nets than the smaller *Myotis* species. One reason for this is that the big brown bat could be using the trail or path with the mist-net to commute to a foraging area, while *Myotis* species were foraging and traveling. Traveling (i.e., commuting) bats would be moving at a higher speed along the roads and trails that we mist-netted on, while a foraging bat would be moving at a lower speed and trying to detect insects, which would also increase the probability of detecting the mist-net.

In contrast, the smaller silver-haired bat was represented by 20% of calls in the acoustic surveys, but only about 5% of captures, perhaps because it was better able to avoid the mist-net. The eastern red bat had about 10% of captures and 10% of calls in acoustic surveys.

There was no trend in captures of little brown bats, while big brown bats increased in the captures from about 15% in 2016 to 45% of captures in 2017. The red bat, silver-haired bat, and hoary bat represented 10% or less of captures each year.

It is likely that there are also some random or unknown factors that affect capture rates. This was apparent from the changes in capture rates of both big brown bats and little brown bats. It would have been highly improbable or impossible for the population of big brown bats could not have doubled in three years. In addition, there was not a similar increase in big brown bat acoustic calls (Moen et al. 2018a). Another reason for the increase in big brown bats could be that we did not mist-net in the central part of Minnesota in 2015.

Another example is how little brown bat capture rate increased in 2016. One reason for this is the higher capture rates of little brown bats at four sites, as discussed above. We would have expected capture rate of little brown bats to decrease somewhat with the spread of WNS in Minnesota. Thus, the capture rates we observed can provide some information on relative abundance of bat species below the forest canopy, but additional sampling would be required to remove more variability in time and space.

Spatial patterns in species distribution. Bats were present wherever we mist-netted, although species composition and distribution varied. The only species that does not appear to be distributed throughout the forested region of the state is the tri-colored bat, which is the rarest bat in Minnesota (Nordquist et al. 2006). This distribution pattern is consistent with what had been assumed in the past, based on knowledge of bat behavior and the relatively few specimen records that exist (Hazard 1982, Norquist and Birney 1985).

About 75% of the bats caught in mist-nets were the northern long-eared bat, the little brown bat, and the big brown bat. These three species were present throughout the forested area of the state and historically have been considered the most common bats in Minnesota (Nordquist and Birney 1985). The percentage of northern long-eared bats captured in mist-nets declined from about 25% in northern Minnesota to about 12% in central and southern Minnesota.

In contrast, little brown bats were about 50% of mist-net captures in the northern and southern parts of Minnesota. In central Minnesota, the little brown bat declined to about 12% of mist-net captures. The big brown bat was the most common bat captured in the central part of Minnesota, with about 50% of captures.

The eastern red bat, hoary bat, and silver-haired bat were less frequently captured, with about 10% of captures for each species, but there may have been some spatial patterns also. The eastern red bat capture rate was 2 to 3 times higher in the central and northwestern parts of the state, with a peak capture rate of about 14%. The hoary bat was 37% of captures in the northwest and 2% or less of captures in other parts of the state. The silver-haired bat was most frequently captured in the central part of the state and in the northwest at about 9% of captures, with less than 1% of captures in the northeast and southeast. Even though capture rate varied, all three of these species were captured throughout the forested area of the state.

Out of 1,202 bats that were captured in mist-nets, only one tri-colored bat was captured in Fillmore county near the Minnesota-Iowa border. The tri-colored bat is the rarest of the 7 species of resident bats in Minnesota (Nordquist and Birney 1985). In part this is because the northwestern edge of the species distribution is in Minnesota (Hazard 1982).

At the start of the project it was thought there were seven species of bats in Minnesota (Hazard 1982, Nordquist and Birney 1985). We captured an evening bat in Ramsey County, the first documented record of an evening bat in Minnesota (MN DNR 2016). Wisconsin also documented its first evening bat in 2016 (WIDNR 2016). The evening bat is found in Iowa and Illinois, and other states to the south and east, and this may be an indication of a species range extending northward. Other mammal species that have had northern range extensions over the last few decades in the upper midwest include the opossum (*Didelphis virginianus*), the white-footed mouse (*Peromyscus leucopus*), and several other rodent species (Jannett et al. 2007, Myers et al. 2009).

Sex ratio of bats. The sex ratio of northern long-eared bats was biased towards females in 2016 and 2017 after WNS arrived. In a captive study on the effects of WNS on bat survival, female little brown bats had higher survival than male little brown bats (Johnson et al. 2014), which would be expected if female bats entered hibernation with higher energy reserves. In another captive study male little brown bats had higher survival after being infected with WNS than female little brown bats (Grieneisen et al. 2015), but those authors indicated that this was not expected given energy reserves. Sex ratio of big brown bats and silver-haired bats was not different from 1:1, while for the little brown bats sex ratio varied significantly among years. One possible explanation for the little brown bat sex ratio variation is spatial distribution of male and female little brown bats that was unexpectedly picked up with mist-netting. This explanation is possible because in 2016 the sex ratio was biased towards males, while in 2015 and 2017 the sex ratio was biased towards females. It is biologically impossible for sex ratios to change from 2:1 to 1:2 to 2:1 over 3 years in a population.

Timing of gestation and lactation. Female bats would be pregnant when we started mist-netting in early June, and this was confirmed by palpation. The first lactating bat we captured was on June 13, and the first lactating northern long-eared bat was caught on June 28. Pregnant bats were caught until July 21. More female bats were lactating than pregnant after about June 25, and one lactating bat was caught in early August. Based on the dates that we captured pregnant and lactating adult females, the period when pups are in maternity roosts could range from mid-June into early August.

It takes approximately 3 to 4 weeks before young are able to fly. The first juvenile northern long-eared bat was caught on July 14. In New York, the first volant northern long-eared bat juveniles were mist-netted on July 17 (First 2011). We caught juveniles of other bat species in mist-nets beginning June 22.

Roosts during pregnancy and lactation. Maternity roost use was as expected in the northern long-eared bat, with females using different roosts while the VHF transmitter was active. Of the 83 northern long-eared bats that had radiotransmitters, over an average six day period they were tracked to one to seven unique roost trees. For female northern long-eared bats with known start and end days for use of a roost tree, almost 80% of the roost trees were used for only one day, about 10% were used for two days, and 3% were used for three days. The weighted average of 1.3 days / roost is less than measured in many other areas (Table 18), but is within the general range measured in research projects across the northern long-eared bat species range. Similarly, the range of one to seven roost trees used over an average of six days is consistent with the number of roost trees used in other locations. Because the number of roost trees used was similar whether the bats were pregnant or lactating, we have no explanation for why northern long-eared bats in Minnesota appear to switch roosts more frequently. One speculation we could make is that because roost trees are switched more frequently, either (1) roost trees are not limiting in Minnesota, or (2) the quality of the available roosts is lower, and bats are switching trees more frequently in an attempt to find a higher quality roost.

Although the number of days / roost was less for female northern long-eared bats in Minnesota compared to other locations, the number of bats using a roost was similar. The average of 15 bats emerging from a roost tree each night is consistent with results from other locations, where from 10 to 30 bats emerge from a maternity colony roost tree (Silvis et al. 2016). In addition, the observed range of from 1 to 79 bats that we measured is similar to the range of 1 to 100 individual northern long-eared bats in maternity colonies measured in other projects (Silvis et al. 2016).

The frequent roost tree switching of female northern long-eared bats even when lactating means that females must carry their pups to a new roost tree. It is unlikely that female bats carry the young with them while foraging (Fenton 1969, Davis 1970), but carrying of young has been documented in at least four species in *Myotis*, the little brown bat, the cave myotis (*M. velifer*), the Yuma myotis (*M. yumanensis*), and *M. bechsteinii* (Davis 1970, Milligan 1993, Kerth and Morf 2004).

Table 18. Length of time roost trees are used by northern long-eared bats. Days is the mean number of days tracked, Days per roost is the average days stayed in a roost, with Min and Max being the minimum and maximum days staying in a roost, and trees is the average number of trees used while the transmitter was active.

Days	Days/Roost	Min	Max	Trees	Loc	Reference	Notes
6.3	1.3	1	7	4.8	MN	This project	
5.3	1.4	1	5	3.7	IN	Badin 2014	
4.9	1.6	1	3	3.1	MO	Timpone et al. 2010	
5.9	1.7	2	6	3.2	WI	WI DNR 2014	
6.5	1.9	1	8	3.6	WI	WI DNR 2015	
3.0	1.9			2.3	WV	Ford et al. 2006	10 Males
5.6	2.0	1	6	3.0	MI	Foster and Kurta 1999	
3.9	2.8	1	5	1.9	IL	Carter and Feldhamer 2005	
8.0	3.6	1	5	2.2	NH	Sasse and Pekins 1996	
	3.0				WV	Owen et al. 2001	
4.8	3.1		6		ON	Jung et al. 2004	10 Males
6.8	3.3			2.3	SD	Cryan et al. 2001	
		1	5	2.6	OH	Krynak 2010	
		1	6	2.0	WV	Johnson et al. 2009	

Maternity roost home ranges. Female northern long-eared bats moved an average of 280 m between roost trees, with 80% of consecutive roosts < 500 apart. Minimum convex polygon home range size for females with ≥ 4 roosts was 7 ha, which would be a radius of about 110 m for an average maternity roost HR. A maternity roost home range size of 7 ha is consistent with results in other geographic areas (Table 19).

Table 19. Maternity roost MCP home range sizes of the northern long-eared bats. Radius assumes a circular home range. The home ranges calculated by Johnson et al. (2012) and Silvis et al. (2014) are for maternity colonies with locations from several individual bats.

Home range (ha)	Radius (m)	n	Loc	Reference
4.1	114	17	NB	Henderson and Broders 2008
5.2	129	18	NC	O'Keefe 2009
5.4	131	7	IN	Badin 2014
7.0	110	32	MN	This project
8.6	165	16	NB	Broders et al. 2006
13.1	204	54	WV	Johnson et al. 2012
47.5	389	54	KY	Silvis et al. 2014

One aspect of estimating maternity roost home ranges that should be considered is that the average duration of a radiotransmitter was about six days. It is likely that if transmitters lasted longer we would see an increase in the average maternity roost home range size. It is not possible to obtain radiotransmitters that last longer, so at this point the maternity roost home range size should be considered a minimum. It is also relevant that the range in maternity roost home range sizes that we measured was from 1 to 30 ha, even with a short transmitter life. When several bats are present in a colony, and colony home range size is calculated, the maternity colony home range size can increase to from 20 to 50 ha (Table 18), which is consistent with the largest home range size we measured of about 30 ha (Table 16).

The home range sizes of all projects in Table 18 are consistent with maternity roost distances < 300 m apart, but there have been some locations where roost-to-roost distances would indicate larger maternity roost home ranges. For example, in Missouri, the mean distance traveled between roost trees was 670 m (Timpone et al. 2010), more than twice as far as the average distance in Minnesota. Similarly, in New Hampshire, the mean distance moved between roost trees was 600 m (Sasse and Pekins 1996). Other locations have had shorter distances, e.g., 28 female northern long-eared bats moved an average of 298 m between 241 roost trees in Mississippi (Jackson 2004). For these projects, sample size was not large enough to calculate an MCP home range, but the distances are consistent with a larger maternity colony home range size.

Buildings as roosts. Buildings were rarely used by northern long-eared bat as roosts, with only 4 of the 89 female northern long-eared bats with transmitters using buildings. Unlike when female northern long-eared bats roost in trees almost every day, female northern long-eared bats roosting in buildings did not switch roosts frequently. Use of buildings as roosting sites by northern long-eared bats has been recorded (Caceres and Barclay 2000, Krochmal and Sparks 2007, Henderson and Broders 2008, Krynak 2010, Timpone et al. 2010) but occurs much less frequently than roosting in trees. For example, 2 of 39 roosts were in buildings (Timpone et al. 2010), 1 of 22 roosts (Krynak 2010), and 1 of 38 roosts were in buildings (Henderson and Broders 2008) in three studies that have reported buildings being used as roosts. One factor that would lower the number of roosts in buildings is that most research on northern long-eared bat has been in forested areas where buildings are less available.

A common aspect of when bats roost in buildings or other permanent structures seems to be that roost switching does not occur, or roost switching is much less frequent (Lewis 1985). Little brown bat females use buildings as maternity colonies more often than northern long-eared bats. All of the bats that we found roosting in buildings returned to the same building each day. We found this in the seven buildings that were used by little brown bats and big brown bats. However, some of the little brown bats and big brown bats we deployed transmitters on also used trees as roosts, indicating buildings are not the only roost type used by these species.

Foraging distances. Female northern long-eared bats forage each night using the maternity roost as a central location. The best indication of foraging distances is the distance from the capture site to the roost, although this would be a conservative estimate because bats could have gone further and be returning to the roost site. The average distance of about 700 m to the first roost would result in a circular foraging area of about 150 ha (380 acres). Average, minimum and maximum distances from the capture location to the first roost was within the range of variation in other projects (Table 20).

Table 20. Distance (m) from capture site to first roost of northern long-eared bats. Minimum and maximum distances are given if they were reported.

Mean	Min	Max	n	Reference	Loc	Sex	Notes
410			8	Keinath 2016	WY	M	7 M 1 F
463			10	Ford et al. 2006	WV	M	
602	60	1,719	26	Sasse and Pekins 1996	NH	F	
726	26	4,197	79	This project	MN	F	
770			15	Catton 2014	MN	F	14 F and 1 M
1,000	223	2,649	23	Badin 2014	IN	F	
1001			21	Broders et al. 2006	NB	F	
1,700	71	4,800		Timpone et al. 2010	MO	F	
2,200	100	5,900	9	Cryan et al. 2001	SD	F	

Foraging home range for northern long-eared bat has been measured at < 70 ha, which would result in a foraging radius of under 500 m (Table 21). This radius would be less than would be expected based on the distance from capture site to the first roost (Table 20). Other foraging home ranges in *Myotis* spp. range from 18 to about 450 ha, with radii of 240 m and 1.2 km, respectively (Table 21). For many *Myotis* species, the foraging home range will be less than 500 ha, with a radius for a circular area of 1.2 km or less. In reality, foraging home ranges may not be circular in shape, which would also account for the longer distances reported in Table 20.

Table 21. Home range sizes and circular radius for foraging home ranges of *Myotis* spp.

Species	ha	Radius	n	Loc	Reference	Notes
M. septentrionalis	60	440	9	WV	Owen 2003	
	68	465	14	KY	Lacki et al. 2009	
	46	383	17	NB	Broders et al. 2006	Females
M. lucifugus	143	675	7	AB	Coleman et al. 2014	
	30	309	22	QB	Henry et al. 2002	Pregnant
	18	239	22	QB	Henry et al. 2002	Lactating
	52	407	13	NB	Broders et al. 2006	Males
M. sodalis	335	1032	11	IN	Sparks et al. 2005	Females
	145	679	11	IL	Menzel et al. 2005	7 F 4 M
M. natterri	241	875	3	Germany	Siemers et al. 1999	
M. volans	448	1194	10	ID	Johnson et al. 2007	Pregnant
	304	984	10	ID	Johnson et al. 2007	Lactating

From a management perspective, at the scale of the individual female northern long-eared bat, pups would be in maternity roosts from mid-June to the end of July or early August. Females would likely be identifying maternity roost locations during late pregnancy, which could occur in early June in some females. Even when lactating, female northern long-eared bats would usually move to a different tree each night, with the pup being carried to the new roost as well. It was somewhat unexpected that almost 90% of the time a lactating female northern long-eared bat would switch roosts each night. However, this switching would occur within a relatively small area of about 7 ha (18 acres) for most bats, which would mean that the female would not be carrying the pup over long distances.

At the larger scale, an important management finding is that the northern long-eared bat population appeared to decline over the course of this project as WNS became established. The highest capture rate for northern long-eared bats was near the Twin Cities metropolitan area, which may be a reflection of the appearance of WNS in the northern hibernacula, which led to reduced capture rates in 2016 and 2017. A second important finding is that northern long-eared bats are still distributed throughout the forested region of the state. The estimated size of maternity roost home ranges can be used to design management actions to help the northern long-eared bat recover from population declines due to WNS.

This report summarized the mist-netting and telemetry parts of this project. Other reports summarize the roost tree characteristics and small and large scales (Moen et al. 2018), the acoustic detection work (Moen et al. 2018a), and the prior acoustic detection work related to northern long-eared bat (Moen and Swingen 2018). In general, our findings for northern long-eared bat mist-netting and roost tree use were consistent with findings reported elsewhere, but there are Minnesota-specific outcomes, such as species distributions, changes in abundance with effects of WNS, and distances travelled while foraging. Other Minnesota-specific outcomes are related to roost trees used and forest composition (Moen et al. 2018) and species distribution based on acoustic detection (Moen et al. 2018a).

The radiotelemetry portion of this project was focused on the northern long-eared bat because it is listed as a threatened species under the Endangered Species Act. Because both mist-nets and acoustic detectors result in captures or detections of other bat species that are present in an area, this became the largest project to date that can help determine distribution and relative abundance of bat species in the forested area of Minnesota. We didn't learn everything there is to know about bat populations in Minnesota, but collectively the different parts of this project have significantly advanced knowledge of bat ecology in Minnesota.

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