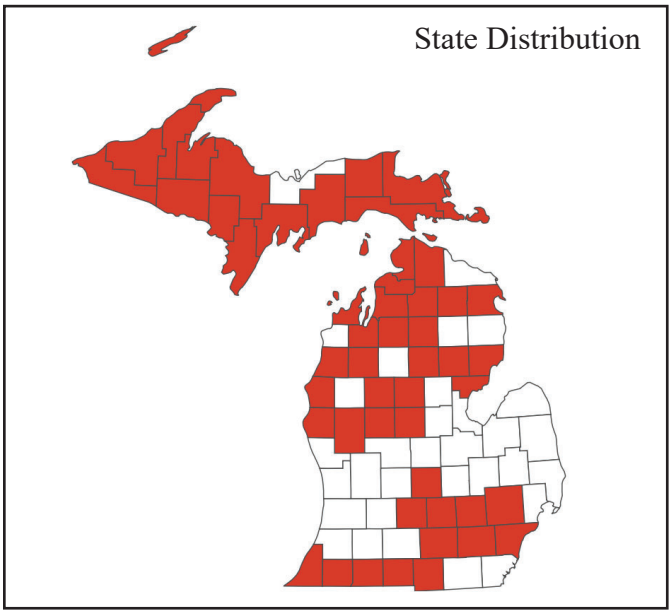
Myotis lucifugus Le Conte, 1831 — Little Brown Bat


Photo by Nicolette Sexton



Best Survey Period

State Status: Threatened (legally protected)

Global and State Rank: G3G4/S1

Family: Vespertilionidae (Evening bats)

Total Range: The little brown bat range extends from boreal forest in Canada and Alaska south through a large swath of the United States (NatureServe, 2023). There are five currently described subspecies (Wilson and Mittermeier, 2019):

- *M. lucifugus lucifugus* Le Conte, 1831: Found in the Northwest Territories (Canada) throughout the eastern United States to northern Florida.
- *M. lucifugus alascensis* G.S. Miller, 1897: Found in Alaska through British Columbia and south throughout the northwestern United States.
- *M. lucifugus carissimus* Thomas, 1904: Found throughout central and western United States, but absent from coastal regions.
- *M. lucifugus pernox* Hollistor, 1911: Restricted to the central border between British Columbia and Alberta, Canada.
- *M. lucifugus relictus* A.H. Harris, 1974: Found only in the mountains of California, United States.

State Distribution: The little brown bat was the most common bat species in the Upper Peninsula of Michigan and the northern half of the Lower Peninsula and had previously been found on more of the Great Lakes islands than any other bat species. Before white-nose syndrome was detected in Michigan (first discovered in 2014), this species made up 62% of bats caught in mist nets in these areas, however, it was less common in the southern Lower Peninsula where it only made up 4% of mist net captures (Kurta, 2008). Their range in Michigan is likely due to the location of suitable hibernacula locations (e.g., caves and mines). Most hibernacula sites were found in the Upper Peninsula in Baraga, Dickinson, Gogebic, Houghton, Keweenaw, Marquette, and Ontonagon counties, however there were also hibernacula in the Lower Peninsula in a hydroelectric dam facility and a quarry and in a

Michigan Natural Features Inventory
Phone: (517) 284-6200 Email: mnfi@msu.edu
Website: mnfi.anr.msu.edu

cave in Berrien County (MNFI, 2023). Studies conducted across Michigan in 2012 by the Michigan Natural Features Inventory reported that the little brown bat was the most recorded bat at coastal study sites along Lake Michigan and Lake Huron (53% of calls), that they are more abundant in the northern portion of the state, and that there is a decrease in little brown bat activity with increasing distance from riparian habitat (Klatt and Gehring, 2013a,b). In recent acoustic bat monitoring programs across the Lower Peninsula, little brown bats were the most common of the rare bat species (i.e., little brown bats, evening bats, and tri-colored bats) to be detected, potentially revealing remnant populations across the state (Auteri, 2022). There are currently 103 element occurrences (EOs) within the Michigan Natural Heritage Database, 61 of which are historical and 42 are extant. Of the 20 extant EOs for which viability has been assessed, 13 have excellent or good viability and 7 have fair or poor viability (MNFI, 2023). Most of the data used in these assessments was collected before white-nose syndrome was detected in Michigan. Therefore, more research is needed to better understand the viability of these EOs in the face of this novel disease.

Recognition: The little brown bat is a small-bodied bat (average head-body length of 32-53 mm; Wilson and Mittermeier, 2019). The weight of individual bats varies seasonally from 5-12 g, weighing the least in the spring when emerging from hibernation (Kurta, 2008; Wilson and Mittermeier, 2019). Its fur is long, silky, and glossy (especially on the dorsal surface) and ranges from dark or golden brown, to reddish or olive brown (Fenton and Barclay 1980; Morgan et al. 2019; Wilson and Mittermeier, 2019). The base of each hair is darker than the tip (Kurta, 2008). Ventral hairs are lighter than those on the dorsal surface and generally have pale yellowish tips and darker brown bases. Their ears are usually short (11-15 mm) compared to other *Myotis* spp. found in Michigan and extend forward halfway between the eye and the nostril. The tragus is medium in height (7-9 mm), slightly curved, and is bluntly rounded at the tip. The membranes of the wings, nose, and ears are dark brown/black in color. The length of the forearm ranges from 36-40 mm and the wingspan ranges from 229-269 mm (Kurta, 2008). The length of the tibia is short relative to that of the hindfoot (8-10 mm) and the toes are covered in long hairs that extend past the tip of the claws (Fenton and Barclay, 1980; Wilson and Mittermeier, 2019).

Similar Species: Both the northern long-eared bat (*Myotis septentrionalis*) and Indiana bat (*M. sodalis*) are commonly confused with little brown bats. These species are best distinguished by close, in-hand inspection. Northern long-eared bats generally have longer ears than little brown bats and have a pointed, spear-like tragus in contrast to the blunt-tipped tragus of the little brown bat. When the ears are folded down alongside the head, northern long-eared bat ears will extend 3 mm or more past the nose when folded, while those of the little brown bat will extend no more than 3 mm beyond the end of the nose when folded. Ear length in this species, however, is highly variable and tragus shape and length are generally more reliable for identification between these species (Kurta, 2008; Morgan et al., 2019). Unlike Indiana bats, little brown bats have long toe hairs that extend beyond the toenails and have non-keeled calcars (a cartilaginous spur that extends from the ankle that is used to support the wing membrane; Fenton and Barclay, 1980; Kurta, 2008; Morgan et al., 2019). From a distance, little brown bat fur is often glossier in appearance and lighter in color than that of the Indiana bat, which often appears more gray in color (Fenton and Barclay, 1980; Morgan et al., 2019).

Little brown bats can also be identified using acoustic monitoring of echolocation calls; however, other *Myotis* spp. share similar call characteristics and it can be very difficult to differentiate between them. Little brown bats produce frequency modulated (FM) calls around 45 kHz that last 1-5 milliseconds and sweep from 80 to 40 kHz (Fenton and Bell, 1979; see Figure 1). In Michigan, little brown bat calls are rarely distinguishable from Indiana bat (*M. sodalis*) calls.

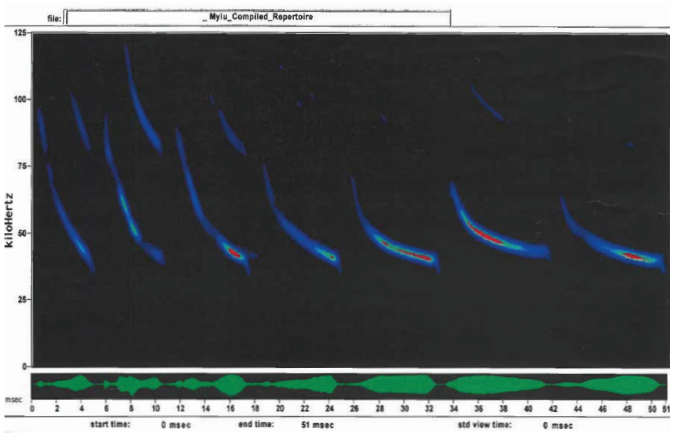


Figure 1. Compiled spectrograph of a little brown bat echolocation call repertoire (compiled by Brian Klatt).

Best Survey Time: Little brown bats are sensitive to human disturbance during breeding and hibernation periods, so special precautions should be taken to not disturb them during these times (NatureServe, 2023). Disturbances during hibernation may cause bats to use their fat reserves that are needed to survive the winter and the disturbance of breeding colonies can cause young bat pups to lose their grip and fall to their deaths (NatureServe, 2023). Common survey techniques include the use of harp traps and mist nests from late May to early September to safely survey populations without disturbing them during these sensitive time periods. Mist nets should be set up perpendicular to travel corridors such as streams, rivers, and logging trails, and surveys should be conducted for four nights and in at least two different locations within a site. Nets should be checked every 10 minutes from sunset to sunrise (USFWS, 2023). They are most active between 25 minutes to 4 hours after sundown.

Like with any other wild mammals, bats should not be handled casually or without protective equipment. When bats are handled, they will often bite in self-defense, and sick individuals are more likely to be caught while surveying. In addition, there are various measures that we must take to protect bats from pathogens that we can transmit to them (e.g., white-nose syndrome [*Pseudogymnoascus destructans*]). Following established protocol of pre-exposure vaccinations, handling techniques, protective equipment, and decontamination will reduce the danger of disease transmission to and from humans (Aguilar-Setién et al., 2022). Acoustic surveys eliminate the need for many of these safety protocols and can be an efficient and cost-effective way to survey for bats.

Habitat: Habitat and roosting behaviors vary seasonally. Most little brown bats are associated with forested areas near water; however, they can be found in all the following habitat types: temperate coniferous forests, lowland temperate grasslands, savannas and shrublands, deserts, tundra, boreal forests, taiga, and temperate broadleaf forests (Wilson and Mittermeier, 2019). In Michigan, it is associated with cave, floodplain forest, northern hardwood swamp, southern hardwood swamp, and wet-mesic flatwoods natural communities (MNFI, 2023). Three types of roosts are used by these bats throughout the year: day roosts, night roosts, and hibernacula (winter roosting sites). Day and night roosts are used in the spring, summer, and fall when bats are active. These roosts are usually found in buildings, trees, under rocks, in piles of wood, and occasionally in caves (Fenton and Barclay, 1980). Day roosts have little light and are generally exposed to the southwest, providing heat for arousal from daily torpor (Fenton and Barclay, 1980). Night roosts are confined spaces in which large groups can cluster together, increasing the temperature of the roost during breaks from feeding on cool nights. Day roosts are generally used when temperatures are above 15 degrees Celsius, whereas hibernacula are used in the winter when temperatures dip below this. Little brown bats select hibernacula in which ambient temperatures remain above freezing and that have high humidity levels (Fenton and Barclay, 1980). The structures generally used as hibernacula include caves and abandoned mines. Most hibernacula in Michigan are found in abandoned mines in the Upper Peninsula, however, there are a few located in the Lower Peninsula in caves, a quarry, and a hydroelectric dam facility. After hibernation, females gather in maternity colonies which are most often found in buildings (e.g., barns, sheds, houses, cabins). Due to their tendency to use buildings as roosting sites, they are often

encountered and disturbed by humans. Female little brown bats tend to select warmer roost sites than males and big brown bats (*Eptesicus fuscus*) (Kurta, 2008).

Biology: Generally, this species migrates less than 300 km to and from winter roosting sites (Kurta, 2008), however, longer migrations of up to 1000 km have been described (Wilson and Mittermeier, 2019). Once bats have arrived at their summer roosting sites, females cluster into maternity colonies while males are more solitary. Maternity colonies typically contain 100-300 adults; however, colonies as large as 1000 individuals have been reported in Michigan (Kurta, 2008). Adult male bats sometimes roost in the same structures used by females, but generally occupy separate, cooler sites (Kurta, 2008).

In late summer or early fall, prior to hibernation, little brown bats swarm at the entrances of hibernacula sites. During the swarming period, females generally mate with more than one male and males will mate with multiple females (Thomas et al., 1979; Wai-Ping and Fenton, 1988). All bats found in Michigan use delayed fertilization, meaning they mate in the fall, store sperm through the winter, and ovulate after hibernation (around seven months after mating in little brown bats; Thomas et al., 1979; Wai-Ping and Fenton, 1988; Kurta, 2008). Most females arrive at the maternity colony during early pregnancy and gestation lasts for 50-60 days (shorter in warm years and potentially longer when the spring is constantly wet and cool; Kurta, 2008; Wilson and Mittermeier, 2019). Females give birth to one pup each year, primarily in June, but sometimes later in northern Michigan. These pups are 25% of their mother's body weight (2.3 g) and are born flesh-colored, with closed eyes and droopy ears (Fenton and Barclay, 1980; Burnette and Kunz, 1982; Kurta, 2008). For the first 18 days of life pups only feed on milk and after this, insects are ingested (Wilson and Mittermeier, 2019). Even after they are weaned, young bats can be distinguished from adults by the darker color of their fur (Kurta, 2008). Pups can fly at about three weeks after they are born and reach independence at four weeks of age when they reach their adult body weight (Fenton and Barclay, 1980; Wilson and Mittermeier, 2019).

Little brown bats are primarily nocturnal, spending most of the daylight hours in a day roost. At night, bats feed and rest at night roosts. In the summer little brown bats generally eat 50% percent of their body weight in insects each night; however, lactating females with large young can consume up to 110-125% of their body mass in a night (Kurta, 2008; Wilson and Mittermeier, 2019). They catch free-flying insects via aerial hawking in wooded areas, fields, and over water bodies and catch sedentary prey via gleaning from objects/surfaces such as plants and water bodies (Fenton and Barclay, 1980; Wilson and Mittermeier, 2019). They generally forage on swarms of insects in which they will concentrate on just one or two insect species; however, when insects are dispersed and fewer are available, they are less selective and will consume multiple different species (Wilson and Mittermeier, 2019). Midges (Diptera) are their primary prey, but a large portion of their diet is also made up of caddisflies (Trichoptera), and mayflies (Ephemeroptera) (Kurta, 2008; Wilson and Mittermeier, 2019). When they are available, beetles (Coleoptera), moths (Lepidoptera), and lacewings (Neuroptera) are eaten as well (Kurta, 2008; Wilson and Mittermeier, 2019). Many of these prey items are very small (3-10 mm long), therefore these bats consume hundreds to thousands of them each night to obtain the amount of energy they require (Kurta, 2008). Night roosts are utilized to rest, stay warm, and digest their meals before they head back out to forage within the same night. Bats acquire water from moisture within their prey, and by dipping their mouth into a water body as they fly above the surface (Kurta, 2008).

After their young are weaned in late August or early September, maternity colonies disband and the bats travel to hibernacula (Kurta, 2008). Swarming at hibernacula can be seen 4-5 hours after sunset and during this time mating begins. Little brown

bats do not store fat before migration to hibernacula sites to avoid being weighed down. Therefore, bats that arrive and swarm at hibernacula sites are very thin. As the temperature begins to cool and the breeding season slows, bats begin to stay in the hibernaculum throughout the day. Adults are the first to begin their hibernation; juveniles require more time to accumulate their fat reserves due to their inexperience in foraging. Generally, little brown bats form clusters containing a few individuals within hibernacula but can form larger clusters that can reach as high as 500 bats in cooler locations (Kurta, 2008). They tend to hibernate on the walls and ceilings of mines/caves, crevices in the rock, and within bore holes in abandoned mines. Hibernacula can be shared with other bat species, such as big brown bats (*Eptesicus fuscus*) and Yuma myotis (*M. yumanensis)* in the western portion of their range). In spring, females begin leaving the hibernaculum in mid/late-April, while males remain until mid/late-May (Kurta, 2008).

Little brown bats typically live between 6-7 years in the wild, but can live much longer (Walker, 1994). Keen and Hitchcock (1980) reported recapturing two *M. lucifugus* specimens in southeastern Ontario that were banded 29 and 30 years prior. The record for maximum longevity is currently 34 years (Davis and Hitchcock, 1995).

Conservation/Management: An introduced fungal pathogen, turbine collisions, contaminants, predation, poaching, and deforestation are all contributing to the drastic decline in little brown bat populations across their range. Their primary threat in recent years is a fungal pathogen, *Pseudogymnoascus destructans*, the causative agent of white-nose syndrome (WNS). WNS is an often-fatal disease that attacks hibernating bats, causing them to arouse more frequently, using up their limited fat reserves that are required to survive hibernation (Warnecke et al., 2012; NatureServe, 2023). Within the first four years after WNS was introduced to the United States at least 1 million bats succumbed to the disease (Kunz and Reichard, 2010). WNS has been spreading rapidly at an average rate of 200-900 km/year and, at this rate, the entire species is likely to be affected within 12-18 years (Wilson and Mittermeier, 2019; Hoyt et al., 2021). There is no apparent containment of the northern or western spread of WNS as proper growing conditions for *P. destructans* are present throughout the entire range of the little brown bat. If not controlled, the total number of mature little brown bats are predicted to decline by more than 50% over the next three generations (Wilson and Mittermeier, 2019).

Wind energy facilities are also a significant cause of mortality among little brown bats, although less frequently than hoary, eastern red, and silver-haired bats (Arnett et al., 2008; NatureServe, 2023). Arnett and Baerwald (2013) estimated that approximately 51,600-107,000 little brown bats were killed at these facilities in the United States and Canada between 2000-2011. Wind energy is expected to expand substantially by 2030 and the impacts of this expansion need to be studied further (NatureServe, 2023). In a Michigan study that was conducted at high wind energy coastal sites across the state, the little brown bat was the most commonly recorded species (53% of all 22,909 recorded calls) and was more frequently recorded near the shore than inland (Klatt and Gehring, 2013a). Most of Michigan's bat species were detected in the coastal areas of this study; therefore, careful consideration must be given when placing wind farms in coastal areas within the site to minimize bat fatalities.

While predation is generally not a problem as predators take bats opportunistically, domestic cats have developed the ability to capture many bats due to their proximity to human structures (Fenton and Barclay, 1980). Cats and many other predators (e.g., mice, owls, weasels, snakes, raccoons) utilize the high concentrations of bats in the roosts and some will wait at the entrance of roosts to capture bats that are entering/leaving (Gillette and Kimbrough, 1970; Fenton and Barclay, 1980). Other predator species such as martens and fishers take advantage of helpless pups or hibernating individuals that fall from the roost ceiling or walls (Fenton and Barclay, 1980). In addition, little brown bats

are killed each year by exterminators and other humans that find bats roosting in their homes. This is unnecessary, as sealing access sites after bats have left for the night is a much cheaper, safe, and effective option (Barclay et al., 1980).

Gates or other barriers can be used to allow for bats to enter and exit abandoned mines or caves without human interference. Maintenance of adequate habitat for all life stages should be monitored every year or two depending on pattern of decline or impacts. Forest management should increase roosting and foraging habitat. Forest managers are encouraged to promote mixed-species, mixed-aged plots as the little brown bat chooses trees based on suitability of crevices and bark as roosts, rather than on tree species. (Kurta, 2008). Land managers should also try to reduce or eliminate burdock (*Arctium minus*), an invasive plant that produces seed heads that can trap bats and cause death from exposure (Norquay et al., 2010). Vernal pools are often considered important food and water sources for bats in forested habitats (Francl, 2008). Special care is required while studying bats to protect both the bat and the researcher. Do not touch a bat unless you are properly permitted to do so, have the proper personal protection equipment, are fully vaccinated against rabies, and are able to perform the proper decontamination protocol. Everything that touches a bat, or its hibernacula must be decontaminated to prevent the spread of white-nose syndrome to other bats/colonies. Cave and mine tours should also take special care and provide decontamination stations for visitors as they can transport *P. destructans* spores on their clothing from one hibernacula site to another (Zhelyazkova et al., 2020; Shapiro et al., 2021).

Research Needs: More research is needed to better understand current population sizes and the distribution of the little brown bat across its range as it continues to face disease, deforestation, and various other threats. Continued research on white-nose syndrome, its impact on the species, and potential solutions are crucial to the preservation of this species. In addition, further research is needed to locate summer roosting locations across Michigan and to understand the impacts of habitat destruction and fragmentation on their populations. Other research needs include the impact of expanding wind energy farms across their range and the impact of environmental contaminants such as pesticides on this species.

Related Abstracts: Cave, Floodplain Forest, Northern Hardwood Swamp, Southern Hardwood Swamp, Wet-Mesic Flatwoods, Indiana bat, northern long-eared bat, red-shouldered hawk, short-eared owl, long-eared owl

Selected References

Aguilar-Setién, A., N. Aréchiga-Ceballos, G. A. Balsamo, A. J. Behrman, H. K. Frank, G. R. Fuijimoto, E. G. Duane, H. T. Warner, S. M. Jones, L. A. O. Carrera, G. L. Powell, C. A. Smith, J. T. Van Sickle, and S. E. Vleck. 2022. Biosafety practices when working with bats: a guide to field research considerations. Applied Biosafety 27: 169-190.

Arnett, E. B. and E. F. Baerwald. 2013. Chapter 21: Impacts of wind energy development on bats: implications for conservation. In Adams, R. and S. Petersen (eds) Bat evolution, Ecology, and Conservation. Springer, New York, NY.

Arnett, E. B., W. K. Brown, W. P. Erickson, J. K. Fiedler, B. L. Hamilton, T. H. Henry, A. Jain, G. D. Johnson, J. Kerns, R. R. Koford, C. P. Nicholson, T. J. O'Connell, M. D. Piorkowski, and R. D. Tankersley. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management 72: 61-78.

Auteri, G. G. 2022. Michigan bat monitoring program: 2021 Report.

Barclay, R. M. R., D. W. Thomas, and M. B. Fenton. 1980. Comparison of methods used for controlling bats in buildings. The Journal of Wildlife Management 44: 502-506.

Burnette, C. D. and T. H. Kunz. 1982 Growth rates and age estimation in *Eptesicus fuscus* and comparison with *Myotis lucifugus*. Journal of Mammalogy 63: 33-41.

Davis, W. H. and H. B. Hitchcock. 1995. A new longevity record for the bat *Myotis lucifugus*. Bat Research News 1: 6.

Fenton, M. B. and G. P. Bell. 1979. Echolocation and feeding behaviour in four species of *Myotis* (Chiroptera). Canadian Journal of Zoology 57: 1271-1277.

Fenton, M. B. and M. R. Barclay. 1980. Myotis lucifugus. Mammalian Species 142: 1-8.

Francl, K. E. 2008. Summer bat activity at woodland seasonal pools in the northern Great Lakes region. Wetlands 28: 117-124.

Keen, R. and H. B. Hitchcock. 1980. Survival and longevity of the little brown bat (*Myotis lucifugus*) in Southeastern Ontario. Journal of Mammalogy 61:1-7.

Klatt, B. J. and J. L. Gehring. 2013a. Bat Activity in High Wind-Energy Coastal Areas of Michigan – A Preliminary Analysis. Michigan Natural Features Inventory, Michigan State University, Report Number 2013-06, Lansing, MI.

Klatt, B. J. and J. L. Gehring. 2013b. Assessing bat Community Structure in Riparian and Agricultural Habitats in a High Wind Resource Area of Southeast Michigan – A Preliminary Analysis. Michigan Natural Features Inventory, Michigan State University, Report Number 2013-05, Lansing, MI.

Kurta, A. 2008. Bats of Michigan. Indiana State University Center for North American Bat Research and Conservation, Terre Haute, IN. pp. 38-40.

Kunz, T. H. and J. D. Reichard. 2010. Status review of the little brown myotis (*Myotis lucifugus*) and determination that immediate listing under the Endangered Species Act is scientifically and legally warranted. Boston University, Boston, MA. pp. 1-31.

Gillette, D. D. and J. D. Kimbrough. 1970. Chiropteran Mortality. Fondren Science Series 1: 262-283.

Hoyt, J. R., A. M. Kilpatrick, and K. E. Langwig. 2021. Ecology and impacts of white-nose syndrome on bats. Nature Reviews Microbiology 19: 196-210.

Morgan, C. N., L. K. Ammerman, K. D. Demere, J. B. Doty, Y. J. Nakazawa, and M. R. Mauldin. 2019. Field identification key and guide for bats of the United States of America. Occasional Papers of the Museum of Texas Tech University 360: 1-54.

Michigan Natural Features Inventory (MNFI). 2023. Michigan Natural Heritage Database. Lansing, MI.

NatureServe. 2023. NatureServe. Comprehensive Species Report: Little brown bat (*Myotis lucifugus*). NatureServe Explorer. Version 2.0. updated June 2023. Retrieved from: https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.100473/Myotis_lucifugus. Accessed 06/28/2023.

Norquay, K. J. O., A. K. Menzies, C. S. McKibbin, M. E. Timmonin, D. E. Baloun, and C. K. R. Willis. 2010. Silver-haired bats (*Lasionycteris noctivagans*) found ensnared on burdock (*Arctium minus*).

Shapiro, H. G., A. S. Willcox, M. L. Verant, and E. V. Willcox. 2021. How has white-nose syndrome changed cave management in national parks? Wildlife Society Bulletin 45: 422-429.

Thomas, D. W., M. B. Fenton, and R. M. R. Bar-

clay. 1979. Social behavior of the little brown bat, *Myotis lucifugus*. Behavioral Ecology and Sociobiology 6: 129-136.

U.S. Fish and Wildlife Service. 2023. Range-Wide Indiana Bat & Northern Long-Eared Bat Survey Guidelines.

Walker, R. M. 1994. Walker's Bats of the World. The Johns Hopkins University Press, Baltimore, MD. pp. 188-190.

Warnecke, L., J. M. Turner, T. K. Bollinger, J. M. Lorch, V. Misra, P. M. Cryan, G. Wibbelt, D. S. Blehert, and C. K. R. Willis. 2012. Inoculation of bats with European *Geomyces destructans* supports the novel pathogen hypothesis for the origin of white-nose syndrome. Proceedings of the National Academy of Sciences 109: 6999-7003.

Wai-Ping, V. and M. B. Fenton. 1988. Nonselective mating in little brown bats (*Myotis lucifugus*). Journal of Mammalogy 69: 641-645.

Wilson, D. E. and R. A. Mittermeier, editors. 2019. Handbook of the Mammals of the World Vol.9: Bats. Lynx Edicions, Barcelona, ES.

Zhelyazkova, V., A. Hubancheva, G. Radoslavov, N. Toshkova, and S. J. Puechmaille. 2020. Did you wash your caving suit? Cavers' role in the potential spread of *Pseudogymnoascus destructans*, the causative agent of White-nose disease. International Journal of Speleology 49:149-159.

Abstract Citation

Sexton, N. H. 2024. Special animal abstract for *Myotis lucifugus* (little brown bat). Michigan Natural Features Inventory. Lansing, MI.

Copyright 2024 Michigan State University Board of Trustees.

Michigan State University Extension is an affirmative-action, equal-opportunity organization.

Funding for abstract provided by Michigan Department of Transportation.