INDIANA BATS, NORTHERN LONG-EARED BATS, AND PRESCRIBED FIRE IN THE APPALACHIANS: CHALLENGES AND CONSIDERATIONS

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Abstract—The Indiana bat (*Myotis sodalis*) is an endangered species and the northern long-eared bat (*M. septentrionalis*) has been proposed for listing as endangered. Both species are found throughout the Appalachians, and they commonly inhabit fire-dependent ecosystems such as pine and pine-oak forests. Due to their legal status, prescribed burns in areas where these species occur must be conducted to avoid harming or harassing the animals, and managers must consider the effects of their prescribed burning programs on these species. We review what is known about the potential positive and negative impacts of prescribed fire on Indiana and northern long-eared bats throughout their life cycles. Prescribed fire may affect Indiana bats and northern long-eared bats by causing short-term disturbance while they are in their roosts, and this may impact them more during critical points of their life cycle such as post-hibernation and the early pup-rearing phase. Prescribed fires may destroy roosts, although they may also create some. However, several studies suggest that both Indiana bats and northern long-eared bats select areas that have been burned for both roosting and foraging, indicating that prescribed fire may be beneficial for both species. Further, prescribed fire may be critical for the long-term restoration of their preferred habitats. Thus, managers and policymakers must balance the short-term impacts with the long-term benefits of prescribed fire within the range of these species.

INTRODUCTION

Indiana bats (*Myotis sodalis*) and northern long-eared bats (*M. septentrionalis*) are small (~7–10 g) insectivorous bats distributed throughout much of the Eastern United States, including the Appalachian region (fig. 1). The Indiana bat was listed as an endangered species in 1967, primarily due to disturbance to and destruction of their hibernacula. Despite protection and rehabilitation of many of their hibernacula since being listed as endangered, Indiana bat populations continued to decline throughout the latter half of the 20th century (USFWS 2007). The number of Indiana bats appeared to be increasing from 2000–2007, but White-Nose Syndrome (WNS), a newly emerging infectious disease that has resulted in massive deaths of hibernating bats (Blehert and others 2009), has caused renewed declines (Langwig and others 2012, Turner and others 2011). WNS is now found throughout the Appalachian region (Turner and others 2011), and Indiana bat populations are projected to experience severe declines or extirpation throughout their range as a result of it (Thogmartin and others 2013). In contrast, northern long-eared bat populations were considered secure until the introduction of WNS. However, due to high mortality rates associated with WNS (Langwig and others 2012, Turner and others 2011), the northern long-eared bat was proposed for listing as an endangered species in October 2013 (Federal Register 2013). The final decision regarding the status of the northern long-eared bat will be made in late 2014.

The distributions of Indiana bats and northern long-eared bats in the Eastern United States overlap much of the range of fire-dependent pine (*Pinus*) and oak (*Quercus*) forests, and both species roost in pine and oak trees (Lacki and others 2009a). Historically, fires in the Appalachians occurred during the dormant season but at fairly frequent (2–13 years) intervals over large extents (Flatley and others 2013). The close association of Indiana bats and northern long-eared bats with fire-adapted and fire-dependent habitats throughout the Appalachians presents problems for many managers. Due to their legal status, prescribed burns in areas where these species occur must be conducted to avoid "take"—take includes any action that may result in the harassment, harm, pursuit, wounding, or collection of an endangered species, where harm can include habitat modification (Bean 2009). Because prescribed burning may be critical for ensuring future habitat, managers and policymakers must balance the long-term needs for habitat restoration with the potential for short-term negative impacts. Our objective is to review what is known about the potential positive and negative effects of prescribed fire on Indiana and northern long-eared bats throughout their life cycles. We hope that this information can be used to develop science-based habitat management strategies that include prescribed fire and will allow managers to meet their habitat restoration goals and protect these endangered bats.

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BIOLOGY AND ECOLOGY OF INDIANA AND NORTHERN LONG-EARED BATS

Like many temperate bat species, Indiana bats and northern long-eared bats have four distinct phases of their annual life cycle that are important to understand when considering the effects of prescribed fire on their populations. These phases are: 1) the winter hibernation period, 2) spring emergence and migration, 3) the summer maternity period, and 4) fall migration and swarming.

During winter (October or November to March or April), both species hibernate in cold caves and mines, and bats lower their body temperatures to reduce energy expenditures. Indiana bats form large clusters in hibernacula, usually on the cave or mine walls and ceilings. Population sizes of Indiana bats in hibernacula range between 1 and >50,000 (USFWS 2007) with 80 percent of the population residing in just 16 hibernacula (Thogmartin and others 2012). In contrast, northern long-eared bats form small clusters in cracks and crevices, and hibernating populations tend to be small (<300 bats; Caceres and Barclay 2000). However, due to their habit of roosting in inaccessible parts of hibernacula, our knowledge of winter populations of northern long-eared bats is limited.

In spring, Indiana bats and northern long-eared bats emerge from hibernation and migrate various distances to their summer ranges. Depending on sex and possibly geographic region, emergence generally occurs from mid-March to the beginning of May, with females leaving earlier than males (Cacares and Barclay 2000, Hall 1962). In West Virginia, Indiana bats do not leave hibernacula until late April or early May (Hobson and Holland 1995), whereas northern long-eared bats in Indiana emerge in March and early April, somewhat earlier than little brown bats (*M. lucifugus*) and tri-colored bats (*Perimyotis subflavus*; Whitaker and Rissler 1992). Female Indiana bats have been documented to migrate as far as 575 km from their hibernacula to their maternity range (Winhold and Kurta 2006), whereas northern long-eared bats stay within about 60–90 km of their hibernacula (Nagorsen and Brigham 1993).

Once on the summer range, female Indiana bats form maternity colonies that usually contain 30–200 adults (USFWS 2007), whereas northern long-eared bats form maternity colonies that are usually 30–90 adults (Caceres and Barclay 2000). Both species roost in snags and live trees, often between a piece of shedding bark and the bole of snags; however, northern long-eared bats are more likely to use crevices and cavities than Indiana bats (Lacki and others 2009a). In the southern Appalachians, optimal roosting habitat for Indiana bats is dead pine trees near a ridge top in a south-facing mixed pine-hardwood forest (Hammond 2013). In other parts of the Appalachians, Indiana bats use a variety of roosts, which are primarily hardwoods such as oak, hickory (*Carya*), and maple (*Acer*) species (Brack 2006, Ford and others 2002, Johnson and others 2010). Although northern long-eared bats have broader roosting niches than Indiana bats, they show roosting preferences for a variety of tree species across their range including shortleaf pine (*P. echinata*), oaks, and hickories (Carter and Feldhamer 2005, Foster and Kurta 1999, Perry and Thill 2007). In the southern Appalachians, northern long-eared bats select a variety of oak species as roosts but also roost in dead white pines (*P. strobus*; O'Keefe 2009).

The summer maternity period is a critical period for raising young, restoring fat reserves, and molting, all of which require large amounts of energy. Thus, foraging resources during this period are an important consideration. Indiana bats forage primarily by hawking insects from the air, whereas northern long-eared bats typically glean insects from vegetation (Faure and others 1993). Both species forage in interior or closed canopy forests in the Appalachians and elsewhere (Ford and others 2005, Jantzen and Fenton 2013, Loeb and O'Keefe 2006, Schirmacher and others 2007), although they will also use openings (O'Keefe and others 2013, Sparks and others 2005). They are opportunistic feeders, but Lepidoptera, Diptera, and Coleoptera are prominent orders of insects in their diets in most areas (e.g., Carter and others 2003, Feldhamer and others 2009, Lacki and others 2009b, Tuttle and others 2006, Whitaker 2004).

Starting in mid-August and continuing to October or November, bats migrate to their swarming sites and hibernacula. Swarming is a behavior in which bats gather at hibernacula entrances to familiarize juveniles with hibernacula and to mate (Davis and Hitchcock 1965, Thomas and others 1979). During this period, many bats still roost in trees in the area surrounding the swarming sites (Brack 2006, Gumbert 2001). Bats may either enter the hibernaculum at which they swarm or move to another hibernaculum for the winter.

EFFECTS OF FIRE DURING HIBERNATION

Little is known about the effects of fire on bats during the hibernation period (Perry 2012). Smoke entering the cave is a potential concern because this could cause bats to arouse (Dickinson and others 2009). Bats typically arouse every 2–3 weeks during the hibernation period, but each arousal is energetically costly, and the amount of fat reserves they have at the beginning of the hibernation period is often just sufficient to allow them to make it through the hibernation period (Thomas and others 1990). Because WNS results in frequent arousals during hibernation (Reeder and others 2012), smoke inundation may have a significant impact on bats if it causes additional arousals and energy expenditure. Fire may also alter the vegetation near hibernacula openings which could change airflow and, thus, positively or negatively affect microclimates within the hibernacula (e.g., Richter and others 1993). Only one study has examined the effects of smoke on hibernating bats, finding no response by bats despite slight increases in noxious gases (Caviness 2003). To reduce the risk of impacting bats during the hibernation period, many forests restrict prescribed fires close to hibernacula (e.g., USDA Forest Service 2004). However, more data are needed to determine if these restrictions are needed.

EFFECTS OF FIRE DURING THE SPRING EMERGENCE PERIOD

Late winter-early spring (March through mid-April) is an important period for prescribed fires in the Appalachian region (Brose and others 2013). However, this is also the period when Indiana and northern long-eared bats emerge from hibernation and begin using tree roosts. Thus, there is potential for conflict between conducting prescribed fires during the optimal burn periods and protecting Indiana bats and northern long-eared bats during the emergence period.

Prescribed fire during the emergence period may impact Indiana bats and northern long-eared bats in several ways. When bats emerge from hibernation, they must restore their fat reserves for migration and reproduction. For WNS-affected bats, restoration of fat reserves is even more critical as they may have even fewer fat reserves than non-affected bats (Warnecke and others 2012), and disruption of bats in their tree roosts during this period may add additional stress. Further, bats commonly use torpor as a means for conserving energy even after leaving hibernacula (Willis 2006). In the southern Appalachians, female Indiana bats use daily torpor in June and July, particularly in the morning when air temperatures are lowest (Hammond 2013). Torpor length and depth are negatively correlated with temperature and positively correlated with precipitation (Dzal and Brigham 2013). Thus, torpor bouts during spring will likely be more frequent, deeper, and longer than in the summer months. For example, hoary bats (*Lasiurus cinereus*) use deep, prolonged torpor bouts lasting ~ 4 days/bout during spring rain/snow storms in Saskatchewan, Canada (Willis and others 2006). Indiana bats that have recently emerged from hibernacula in Vermont switch roosts every 4.8 days and only emerge from roosts about 1/3 of the nights (Britzke and others 2006). However, during the summer maternity season, female Indiana bats in the same area switch roosts approximately every day (Watrous and others 2006). This suggests that Indiana bats enter deep torpor for energy conservation during the spring. If torpor bouts are deep and long during the spring emergence period due to cold snaps, Indiana and northern long-eared bats may not be able to respond as quickly to the presence of fire. Therefore, conducting prescribed fires on warmer days or during warmer periods of the day may allow bats to respond more quickly to the sound and smell of smoke, and to escape the fire (Layne 2009). For example, northern long-eared bats left their tree roosts within 10 minutes of ignition when a fire was lit late in the day (1640 and 1650 EST; Dickinson and others 2009). In contrast, red bats (*Lasiurus borealis*) require >20 minutes to respond when temperatures drop below 50 °F (Layne 2009).

Prescribed fire may also impact the availability of roosts during the emergence period. Although a great deal has been learned about roost site selection of Indiana bats and northern long-eared bats during the summer maternity season (see below), we are not aware of any studies that have examined roost site use or selection by northern long-eared bats in spring, and only a few studies that have examined Indiana bat roost use and selection in spring (Britkze and others 2006, Gumbert 2001, Hobson and Holland 1995). Britzke and others (2006) tracked female Indiana bats from hibernacula in New York to 39 roost trees in New York and Vermont, and noted that bats favored live trees such as shagbark hickories (*C. ovata*) more than is typically observed in summer. In Kentucky, male Indiana bats primarily roost in oaks and hickories during spring, many of which are alive, whereas pines snags are used much more in summer (Gumbert 2001). Further, the number of crevice roosts increases by 20 percent in spring compared to summer and fall. The greater use of live trees in Vermont and Kentucky during spring and the seasonal variation in roost use in Kentucky suggests that basing management actions in spring and fall on our knowledge of roost selection during summer may be misguided. Thus, until more information is gained regarding roost site use and selection by these bats during the spring emergence period, it will be difficult to develop burn programs that avoid disturbing or destroying Indiana bat and northern long-eared bat roosts during spring.

Similar to roosting behavior, little is known about foraging habitat use during the spring emergence period. In particular, it is important to understand how prescribed fires affect prey availability and its distribution during this period. However, we are not aware of any studies that have examined the immediate effect of prescribed fire on spring nocturnal insect abundance and composition. Further, although several studies have examined foraging habitat use during summer, no studies have examined foraging habitat use during spring. Bats may use different habitats during spring in response to either changes in structure (i.e., leaf-off) or insect availability. Thus, bats may respond differently to prescribed fire in spring foraging habitats than to those in summer foraging habitats. More data are needed to determine what habitats these bats use during the spring emergence period and how prescribed fire may affect use of those habitats.

EFFECTS OF PRESCRIBED FIRE DURING THE SUMMER MATERNITY PERIOD

Growing season burns are usually restricted in areas that contain Indiana bats during the maternity season, and they may be restricted in areas with northern long-eared bats in the future. However, prescribed fire conducted during other seasons may still have impacts, both positive and negative on summer habitat use by Indiana and northern long-eared bats. Fire will most likely have its greatest impacts on foraging and roosting habitats.

Prescribed fire may affect foraging habitat by affecting insect prey availability and forest structure. The results of studies that have examined the effects of prescribed fire on nighttime flying insects are equivocal. For example, overall insect abundance and abundance of Coleopterans and Dipterans increased in the 5 months after prescribed fires in Kentucky (Lacki and others 2009b), whereas insect availability is not related to burn history in Missouri (Womack 2011). In Idaho, a high-severity wildfire led to a pulse of nutrients in streams, thereby increasing aquatic insects and bat activity up to 5 years post fire (Malison and Baxter 2010).

Several studies in forested habitats across the world have examined foraging habitat use of bats in response to prescribed fire. In general, bat activity increases in areas that have been burned, particularly for large-bodied species that are less clutter-adapted than smaller, more agile species (e.g., Armitage and Ober 2012, Inkster-Draper and others 2013, Loeb and Waldrop 2008, Smith and Gehrt 2010). Most authors have attributed these changes to a reduction in forest clutter. Unfortunately, only a few studies have been conducted in areas with Indiana bats or northern long-eared bats. Northern long-eared bat occupancy of sites in Missouri is negatively related to saplings/ac, sawlogs/ac, and conifer basal area and positively related to the number of fires within the past 10 years, although these relationships are not statistically significant (Starbuck 2013). In Kentucky, northern long-eared bat forage closer to burned areas than to nonburned areas in the 4 months following a prescribed burn which may be due to reduced clutter in these areas or increased insect availability (Lacki and others 2009b). Five of six Indiana bats with home ranges overlapping low-severity burns selected the burned areas during their foraging bouts; this finding was attributed to more open understories in burned areas (Womack and others 2013). Prescribed fire may also generate early successional conditions in forests; bats that are ecologically similar to Indiana and northern long-eared bats show neutral or positive responses to moderate- or high-severity fires that created these conditions in California (Buchalski and others 2013). Thus, based on a small number of studies, it appears that prescribed fire has a positive or neutral effect on Indiana and northern long-eared bat foraging habitat. However, far more data are needed to fully understand how prescribed fire affects foraging habitat use of Indiana and northern long-eared bats, particularly in relation to such factors as fire intensity and fire frequency.

Prescribed fire may also affect summer roosting habitat by creating or destroying roost structures and changing the fine-scale structure of the habitat around the roosts that make them more or less desirable to bats (Perry 2012). Most of the data on the effects of prescribed and wildland fire on snag dynamics are from the Western United States. In general, more snags are lost than are created, particularly larger diameter snags (e.g., Bagne and others 2008, Horton and Mannan 1988, Randall-Parker and Miller 2002), although small diameter snags may increase in abundance (Stephens and Moghaddas 2005). In the southern Appalachians, snag basal area is significantly higher in areas that receive high-severity burns compared to areas that have not been burned or have received low- or medium-severity burns (Rush and others 2012). However, the size distribution of these snags is not known. Boyles and Aubrey (2006) also found that snag availability was greater in a burned area compared to an adjacent nonburned area in Missouri. Thus, it appears that prescribed fire may destroy existing snags, but in some cases new snags are created. However, before conclusions can be drawn about the short-term effects of prescribed fire on roost structures, more information is needed on how snag creation and loss varies with factors such as fire frequency, time since burning, species, topography, and fire intensity. Further, if prescribed fire is necessary to create the types of habitat that bats prefer for roosting (see below), then the short-term effects must be balanced against the long-term habitat needs of these animals.

Although only a few studies have examined the effects of prescribed fire on roost use and selection by Indiana bats, these studies suggest that they respond positively to prescribed fire in terms of roosting behavior. For example, Indiana bats (mostly males) use burned areas in proportion to their availability in Kentucky (Gumbert 2001), and male Indiana bats in West Virginia roost in fire killed trees 1–3 years post fire (Johnson and others 2010). Most of the roost trees used in West Virginia are adjacent to canopy gaps, but the roosts in the burned areas are in larger gaps than those in the unburned areas. Bats often choose roosts near edges or canopy gaps because these trees get more solar exposure, allowing the bats to use the warmth of the sun for passive warming (Kalcounis-

Ruppell and others 2005). For example, in Missouri, evening bats (*Nycticeius humeralis*) show strong preference for roosts in burned areas where canopy light penetration is significantly greater (Boyles and Aubry 2006). It appears that changes in forest structure created by prescribed fire, such as the creation of more open canopies or canopy gaps, is beneficial for Indiana bats.

Two studies in the Appalachian region have examined the effects of prescribed fire on northern long-eared bat roosting behavior. In West Virginia, female northern long-eared bats respond positively to prescribed fire, possibly due to an increase in the amount of exfoliating bark on live and dead trees (Johnson and others 2009). Further, cavities in areas that were burned are significantly warmer than cavities in unburned areas, suggesting that roosts in the burned areas receive more solar radiation. Similarly, in Kentucky, female northern long-eared bats select roosts in burned areas over unburned areas within months of a spring prescribed fire (Lacki and others 2009b), and northern long-eared bats in Arkansas select roosts in stands that have been thinned and burned (Perry and others 2007, Perry and others 2008). Thus, although the data are limited, it appears prescribed fire in the Appalachians and surrounding areas results in good summer roosting habitat for both northern long-eared and Indiana bats. In addition to creating beneficial changes in forest structure around roosts, prescribed fire may be needed to promote the regeneration of fire-adapted species such as pines and oaks, both of which are important roosts for Indiana and northern long-eared bats. Pines may be ideal roosts due to their faster growth rates and tendency for exfoliating bark. Although slower growing, oaks can be quite large in diameter and also produce exfoliating bark both when alive and dead.

EFFECTS OF PRESCRIBED FIRE DURING THE FALL MIGRATION AND SWARMING PERIOD

Little is known is about the behavior of Indiana bats and northern long-eared bats during the migration and swarming periods. However, in many respects the fall swarming period is very similar to the spring emergence period. Bats must increase their energy intake to put on fat to make it through the hibernation period as well as mate, both of which demand high levels of resources.

As in spring, there is some evidence that tree roosts used during the fall are somewhat different from those used during the summer. In West Virginia, male Indiana bats use primarily live roosts that have a greater amount of bark, in areas with greater stand basal area and smaller canopy gaps (Johnson and others 2010). In Kentucky, male Indiana bats use live white oaks (*Q. alba*) more in fall than in spring and summer, and use live trees with a greater amount of bark cover more in fall than in summer (Gumbert 2001). Live trees also comprise the majority of roost trees used by Indiana bats during the fall in Virginia (Brack 2006). Thus, the effects of prescribed fire on fall roost tree use and selection may be different than that observed during summer. At present, there are no data on roost use or selection by northern long-eared bats during the swarming period.

Only one study has examined foraging behavior of Indiana bats during the fall swarming period, and there are no studies on northern long-eared bats. In Virginia, Indiana bats use open deciduous forests which have experienced a disturbance such as harvesting within the past 10–20 years more than expected and more often as the season progresses; developed areas, closed deciduous forests, mixed hardwood-conifer stands are used less than expected in fall (Brack 2006). Due to reduced clutter, it may be more efficient for bats to forage in open versus closed forests, and thus, prescribed fire may have a positive effect on foraging behavior in fall if it creates more open forest conditions.

It is likely that Indiana bats and northern long-eared bats use torpor in fall as in spring, even while roosting in trees. Similar concerns regarding fires during cold periods of the day should be considered when developing burn plans. However, potential effects on bats from differences in day length, weather conditions, and fuel moisture should also be considered.

POTENTIAL EFFECTS OF NOT BURNING

One of the many goals of prescribed fire in the Appalachians is the reduction of fuel loads to prevent wildfire (Reilly and others 2012). Wildfires are not uncommon in areas that contain northern long-eared and Indiana bats, and if they occur during the maternity period, particularly before the pups are volant, they could have a large impact on the reproductive success of these species. For example, between 1998 and 2006 there were 16 lightning-caused fires in Great Smoky Mountains National Park (Cohen and other 2007), an area that contains both northern long-eared bats and Indiana bats (Harvey 2002). In August 2010, a wildfire that began from a lightning strike burned ~300 acres of pine and oak forests on the southwest side of this park. Fire managers adopted a “let it burn” approach to reduce fuel loading in the area, but monitored fire lines and protected potential Indiana bat roosts by clearing fuels and litter around dead pine snags. During wildfires, the probability that bats at roost will experience ear burns should increase (Dickinson and others 2010). Further, if roost trees are destroyed during wildfires or become unusable because of the loss of bark, then it may be difficult for bats to find alternate roost sites, particularly if the fire is large.

Surface fuels, which exacerbate wildfire effects, may increase as a result of drought, either through direct tree mortality or increased prevalence of pathogens and disease (Reilly and others 2012). Because drought is projected to increase in the South in future decades (Liu and others 2013), the probability of more severe wildfires is likely to increase due to heavier fuel loadings. Thus, to reduce the risk of wildfire during seasonally sensitive periods for Indiana bats and northern long-eared bats, it may be important to conduct prescribed fires that reduce fuel loads.

Another consequence of not burning or burning infrequently is the creation of highly cluttered habitats that are not suitable for Indiana bat or northern long-eared bat roosting and foraging habitat. More frequent prescribed fires result in forests with less clutter and greater bat activity (Armitage and Ober 2012). Thus, in the absence of other disturbances, frequent prescribed fires may be necessary to create and maintain suitable habitat for both Indiana and northern long-eared bats in the Appalachians.

CONCLUSIONS

The use of prescribed fire in the Appalachians is critical for fuels reduction as well as habitat restoration. Reconciling these needs with those of endangered bats and other species can be challenging. However, Indiana bats and northern long-eared bats have been part of the Appalachian ecosystem for thousands of years and have adapted to periodic fires on the landscape. In fact, although the data are limited, several studies suggest that prescribed fire may benefit Indiana bats and northern long-eared bats by improving both roosting and foraging habitat. Long-term benefits such as the creation of pine-oak habitats must also be considered and weighed against some short-term effects (e.g., loss of roost trees or disturbance of the roost). Conducting burns during time periods that will minimize disturbance to bats is one way to reduce risk. It is evident that far more research is needed on Indiana bats and northern long-eared bats during the spring, fall, and winter periods. Research should concentrate on potential effects of smoke during the hibernacula period, roosting and foraging behavior during spring and fall, and how prescribed fire during various seasons affects roosting and foraging habitats and behavior in spring and fall. This information will allow managers to develop effective management plans that will permit them to meet their vegetation restoration goals while reducing the risk to these sensitive bat species.

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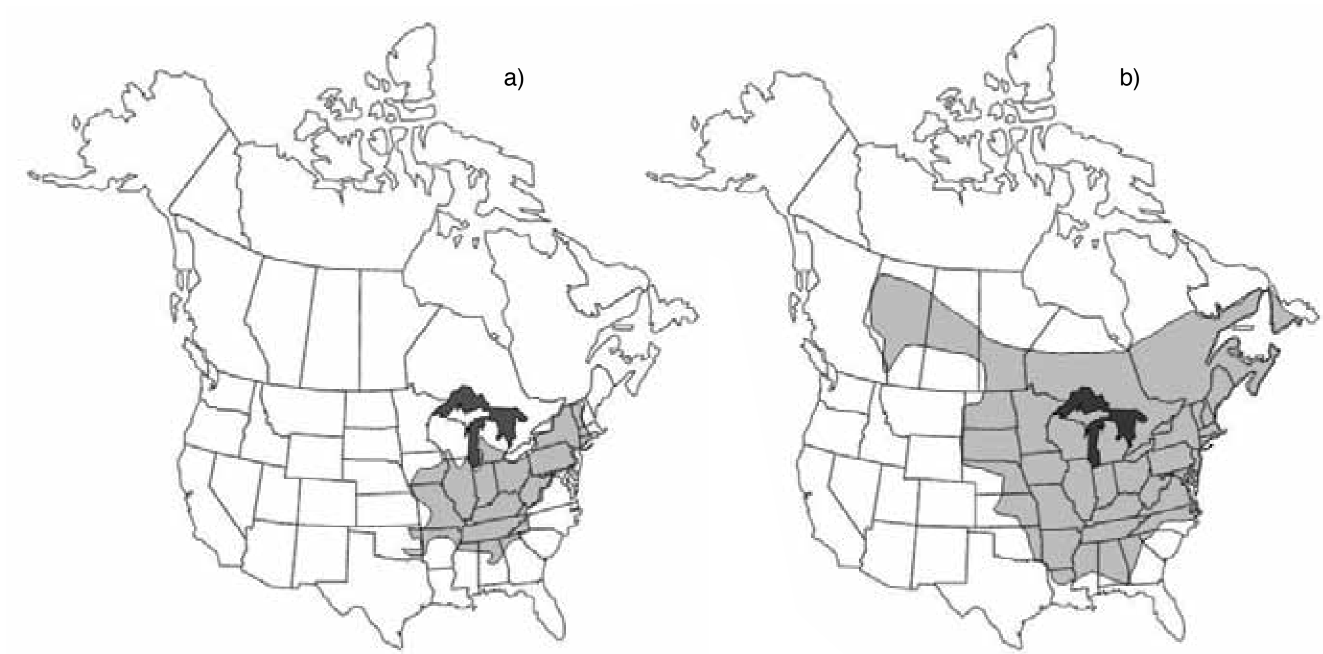

Figure 1—Approximate ranges of a) the Indiana bat and b) the northern long-eared bat.