BATS OF THE HARDWOOD ECOSYSTEM EXPERIMENT BEFORE TIMBER HARVEST: ASSESSMENT AND PROGNOSIS

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Abstract.—Before experimental harvest of the Yellowwood (YW) and Morgan-Monroe (MM) State Forests (Indiana) as part of the Hardwood Ecosystem Experiment, bats were sampled using mist nets at four locations in MM and five locations in YW during each summer 2006 through 2008. Netting locations were adjacent to forest stands scheduled for experimental manipulations following conclusion of netting in 2008. This effort produced 342 bats (in order of abundance): northern myotis (*Myotis septentrionalis*), eastern red bat (*Lasiurus borealis*), big brown bat (*Eptesicus fuscus*), Indiana myotis (*M. sodalis*), little brown myotis (*M. lucifugus*), tri-colored bat (*Perimyotis subflavus*), hoary bat (*L. cinereus*), and silver-haired bat (*Lasionycteris noctivagans*). These data provide a baseline to understand how bats are affected by short- and long-term forest manipulations initiated in summer 2008.

INTRODUCTION

Many bats rely on forested habitats for foraging and roosting (Barclay and Brigham 1991, Barclay and Kurta 2007). Although bats are a critical element of forests, an understanding of how bats are affected by many forest management practices remains elusive (Lacki et al. 2007). Most research has addressed short-term responses of bats to common management techniques, such as thinning (Fisher and Wilkinson 2005, Kurta and Kennedy 2002, Miller 2003, Tibbels and Kurta 2003), prescribed burning (Boyles and Aubrey 2006, Boyles et al. 2005, Carter et al. 2002), and clearcutting (Hogburg et al. 2002, Owen et al. 2004, Patriquin and Barclay 2003). However, effects of other commonly used techniques on bats, especially single-tree selection and patch cutting, remain relatively unknown. Further, little is known about long-term effects of forest management practices on bats. Finally, past research involving bats typically considered only one management activity at a time, even when conducted within forest ecosystems receiving manipulations across multiple temporal and spatial scales.

To better understand impacts of forest management techniques, the Indiana Department of Natural Resources (IDNR)-Division of Forestry (DoF) and Purdue University designed a series of forest manipulations within the context of the Hardwood Ecosystem Experiment (HEE), a 100-year multi-agency, multi-university experiment at Morgan-Monroe (MM) and Yellowwood (YW) State Forests (Kalb and Mycroft, this publication). Provided herein is an overview of the bat community at HEE research sites before timber harvest, and hypotheses on how each species will respond to these manipulations.

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STUDY AREA

MM and YW state forests are in Morgan, Monroe, and Brown Counties in south-central Indiana (Fig. 1). The forests are similar in composition and are managed as one unit by DoF. Both state forests consist mainly of high ridges with steep runoff streams and upland forests. YW has 9,459 ha and MM has >9,720 ha of forest subject to harvest.

MATERIALS AND METHODS

Bats were captured using four multi-tiered mist-net sets (Avinet, Inc., Dryden, NY) placed at two sites in each of the nine management units (see Kalb and Mycroft, this publication). Sites were netted twice per summer (15 May to 15 August) during 2006, 2007, and 2008 on nonconsecutive nights, resulting in 144 net-nights of sampling each year, for a total

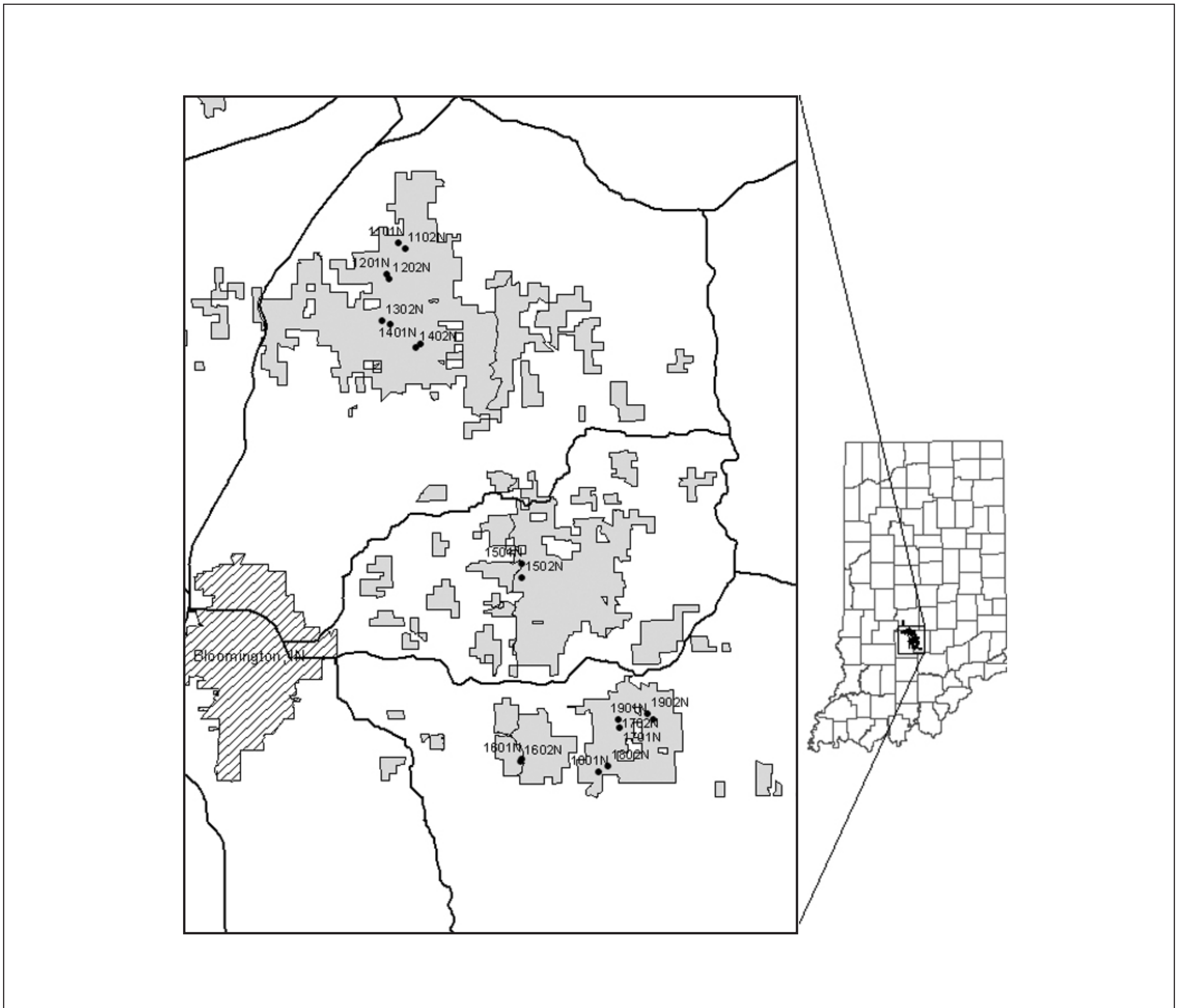

Figure 1.—Location of Morgan-Monroe (MM) and Yellowwood (YW) State Forests (gray areas) in relation to Bloomington, IN (hash mark). Solid circles denote net sites.

of 432 net-nights. At each site mist-net sets were arranged to maximize bat captures with most placed across logging roads. At each site we recorded habitat descriptions, including tree species, potential roost trees, undergrowth species, and distance to water sources. Weather conditions were monitored, including temperature (°C), estimated cloud cover, and wind speed. Mist nets were set by nightfall and left in place for 5 hours. Nets were checked at least every 10 minutes. Data collected on captured bats included species, sex, reproductive condition, right forearm length, body mass, and an estimate of age (juvenile or adult). Numbered metal bands (Prozana Ltd., Icklesham, East Sussex, UK) were fitted to the right (males) or left (females) forearm to allow identification of individual bats. Statistical analyses were conducted with SPSS 11.0 for Windows (SPSS Inc., Chicago, IL) with a rejection level of $\alpha = 0.05$ used throughout. A Kruskal-Wallis one-way analysis of variance test for non-parametric data was used to compare the capture rates of each species among years and MacArthur's (1972) diversity index across all years.

During 2006-08 24 net-nights did not meet pre-specified weather conditions of rain or temperature (because of rain for >45 minutes or ambient temperature <10 °C). Bats captured on those nights were not included in the analysis of standardized data, and the site was netted again. This data set was included to provide a more complete survey.

RESULTS

Over 3 summers 342 bats were captured consisting of 8 species (Table 1). In 2006, we captured 140 bats representing 6 species: northern myotis (*Myotis septentrionalis*), eastern red bat (*Lasiurus borealis*), big brown bat (*Eptesicus fuscus*), little brown myotis (*M. lucifugus*), Indiana myotis (*M. sodalis*), and tri-colored bat (*Perimyotis subflavus*)[2]. In 2007, 87 bats were captured, including an additional species, the hoary bat (*L. cinereus*). In 2008, 115 bats were captured, including the migratory silver-haired bat (*Lasionycteris noctivagans*).

A total of 432 net-nights resulted in 0.79 bats per net-night. Capture rates (bats per net-night) for each species were similar across the 3 years ($p = 0.091$). The total capture rate of bats was 0.83 per net-night (192 net-nights) in MM State Forest and 0.77 bats per net-night (240 net-nights) in YW State Forest. The MacArthur diversity index for MM and YW forests combined for each year was 3.5 in 2006, 3.0 in 2007, and 4.0 in 2008. The supplemental netting in 2007 captured 5 bats and in 2008 captured 11 bats (Table 2).

[2] Formerly eastern pipistrelle (*Pipistrellus subflavus*)

Table 1.—Numbers (n) of bats captured in mist nets in 2006, 2007, and 2008 (each with 144 net-nights, NN), within Morgan-Monroe and Yellowwood State Forests in Indiana, and results of the Kruskal-Wallis test comparing capture rates (n/NN) of species among years, 2006-08.

	2006		2007		2008		Total		Kruskal-Wallis	
Species	n	n/NN	n	n/NN	n	n/NN	N	n/NN	χ^2	P
Northern myotis	53	0.37	37	0.26	41	0.28	131	0.30	0.85	0.65
Eastern red bat	46	0.32	26	0.18	32	0.22	104	0.24	5.29	0.07
Big brown bat	27	0.19	12	0.08	21	0.15	60	0.14	3.59	0.17
Indiana myotis	5	0.03	3	0.02	8	0.06	16	0.04	0.30	0.86
Tri-colored bat	4	0.03	3	0.02	10	0.07	17	0.04	0.89	0.64
Little brown myotis	5	0.03	4	0.03	2	0.01	11	0.03	1.12	0.57
Hoary bat	0	0.00	2	0.01	0	0.00	2	0.00	4.08	0.13
Silver-haired bat	0	0.00	0	0.00	1	0.01	1	0.00	2.00	0.37
Total	140	0.97	87	0.60	115	0.80	342	0.79	4.78	0.09

DISCUSSION

The eight species of bats currently found in the HEE study area are typical of the region's forested areas (Mumford and Whitaker 1982, Whitaker and Hamilton 1998). The MacArthur diversity index increased each year because a new species was caught each year. A ninth species, the evening bat (*Nycticeius humeralis*), also may inhabit these forests, but is most often caught in lowland areas (Whitaker et al. 2007), which were not well represented in the sample.

Bat species capture rates reflect the structure of the HEE study sites, which historically have been managed using mostly uneven-aged harvest methods. Northern myotis, a clutter-adapted species (Loeb and O'Keefe 2006), was most commonly caught in both state forests. "Clutter" refers to physical objects in the environment into which a bat can fly or that may disrupt echolocation. Clutter-adapted species have high-frequency echolocation calls that produce more details about an environment and allow a bat to fly through areas of dense foliage, and body/wind shapes that allow for rapid maneuverability (Brooks and Ford 2006). Single-tree and group-selection management results in a mosaic of wooded areas and small openings around which northern myotis typically forage (Patriquin and Barclay 2003).

The tri-colored bat is an abundant species in other forests in southern Indiana (Brack et al. 2004, Brack and Whitaker 2004) but was rare in the HEE study area. Tri-colored bats are clutter-adapted but are known to forage in many types of forest habitats. The lack of diverse habitats in the HEE study area may explain why the tri-colored bat was rare. Indiana myotis use clutter-adapted echolocation calls, suggesting that they would be abundant in the HEE study area, but they were caught infrequently. Indiana myotis occur in more open woodland habitats with little or no understory and small openings (Menzel et al. 2001, Sparks et al. 2005a). Indiana myotis also roost in dead trees and require solar exposure for offspring (Kurta 2005), an attribute which might not be abundant under forest canopy. Little brown myotis were also infrequently captured and are less clutter-adapted than other myotis (Arita and Fenton 1997, Broders et al. 2004). Little brown myotis are known to forage over water, forest openings, and forest edges (Brack 2009), which were rare in the HEE study area.

Eastern red and big brown bats were commonly caught within the study area. Neither species is adapted to clutter, but most net sites were in uncluttered corridors where these bats can travel and forage. Hoary bats and silver-haired bats are not adapted to clutter and were not commonly captured. Hoary bats are rarely caught in mist nets, possibly because they are commonly active above the height sampled with mist nets. Silver-haired bats are usually caught in early spring during migration. Eastern red, hoary, silver-haired, and big brown bats are usually found foraging in low-clutter areas (i.e., old field, forest openings, and forest edges), which were rare in the HEE study area.

Our expectation is that all eight species will be present following timber harvest, but that the community composition may change at research sites as each species responds to changes in habitat. Over the short term, individual bats may be killed if they are roosting in a tree when it is harvested (Belwood 1979, Humphrey et al. 1977). To avoid mortality of bats, timber harvest should be conducted in the winter when bats are either hibernating or have migrated. In the long term, succession from dense forests (the current structure of the HEE study area) to more open forest (HEE study area after timber harvest) will benefit most species, especially the Indiana myotis. Below we summarize the foraging and roosting needs of the eight species captured at the study areas during the pre-treatment period, and based on these habitat needs, make predictions about how each species will respond to the various planned timber harvests in both the short term (i.e., immediately after harvest) and long term.

Northern Myotis

Northern myotis typically roost in tree cavities or under bark (Lacki and Schwierjohann 2001) and forage in forest interiors (Brack and Whitaker 2001, Owen et al. 2003, Patriquin and Barclay 2003). Northern myotis prefer interior forest (Owen et al. 2003, Patriquin and Barclay 2003) and so are less likely than other species to use recently clear-cut areas and other forest openings. For example northern myotis were captured less frequently following clearing of a large forest patch along Prairie Creek in Vigo County, IN (Sparks et al. 1998). Other types of timber harvest will not negatively impact this species as long as the availability of preferred roosts (hollow trees) remains unchanged in the surrounding landscape and the harvest protocol calls for the retention of snags. The species may be among the most tolerant of dense subcanopy (Owen et al. 2003), and thus as forest management practices create less cluttered forest, it may face competition with other species for foraging and roosting habitat within the HEE study area. Forest stands that are "solid walls" of vegetation provide little usable habitat for the northern myotis; however, single-tree selection and patch cuts can create a suitable matrix of habitats composed of different tree age classes over time.

Eastern Red Bat

Eastern red bats roost primarily in tree foliage (Mager and Nelson 2001) and forage in open habitats (Hutchinson and Lacki 1999, Walters et al. 2007). In the short term, timber harvests will remove potential roost trees but create open foraging habitat in a cluttered landscape (Elmore et al. 2004). We suspect that the overall availability of roost trees in the surrounding uncut blocks will provide a ready supply of suitable trees for roosting. As such, the greatest impact on eastern red bats may be the creation of uncluttered foraging habitat such as clearcuts, large patch cuts, logging corridors, and understory removal in shelterwoods. In the long term without continued timber harvests or management of past harvest areas, the openings will succeed to thick stands of saplings in which eastern red bats cannot forage.

Big Brown Bat

Big brown bats use anthropogenic structures for roosting during both summer and winter (Whitaker et al. 2007); however, some individuals roost in tree cavities after maternity colonies break up in late summer (Whitaker 1996, Duchamp et al. 2004). Big brown bats forage in early successional and forest openings and forests with little subcanopy (Loeb and O'Keefe 2006) and a wide variety of other non-forested habitats (Duchamp et al. 2004). Openings created by clearcuts, large patch cuts, and shelterwoods will provide increased foraging opportunities for big brown bats in the short term. Smaller patch cuts and single-tree selection may not provide enough space and may be too scattered among cluttered areas for big browns to forage. In the long term, big browns will require more areas where the subcanopy is removed and new forest openings are created.

Tri-colored Bat

Tri-colored bats roost in leaf clusters in trees (Veilleux et al. 2003), tree cavities (Yates and Muzika 2006), and anthropogenic structures (Whitaker 1998). Tri-colored bats forage in forest openings and early successional areas in South Carolina (Loeb and O'Keefe 2006) and in cluttered forests (Menzel et al. 2005), but at Indianapolis International Airport, closer to our project area, this species uses a variety of land classes, such as open fields, the space above saplings in a regeneration opening, and mature closed canopy forest (Helms 2010). As such, tri-colored bats may be a habitat generalist and will forage in habitats in different successional stages. The different timber harvests should benefit the tri-colored bat by creating a mosaic of different habitats through the forest.

Indiana Myotis

Indiana myotis typically roost under tree bark (Humphrey et al. 1977) and forage at the air-vegetation interface (Sparks et al. 2005a), including along logging roads, riparian streams, above and below the canopy, and at the edge of clearings. Foraging Indiana myotis may make increased use of edge habitat created by harvests (Menzel et al. 2001). Further, regenerating clearcuts will closely resemble seedling plantations at Indianapolis International Airport, where Indiana myotis forage (Sparks et al. 2005a); if dominated by oak (*Quercus*) species (as planned), harvest areas may provide a source of Asiatic oak weevils (*Cyrtepistomus castaneus*), which are both an important consumer of young oaks and acorns and a common food item of several bat species including Indiana myotis (Brack 1983, Brack and LaVal 1985, Tuttle et al. 2006). As the understory removal stage of a three-stage shelterwood cut eliminates the subcanopy, the reduced clutter will allow movement through the forest. However, 30- to 80-year-old timber stands will be too cluttered for Indiana myotis.

A hypothetical comparison of high-quality Indiana myotis summer foraging habitat and successional stages of a forest is shown in Figure 2 (adapted from Sheets 2010). Through time, forest structure naturally increases in clutter during early successional stages and decreases in clutter in later successional stages. Timber harvests can simulate these natural stages. A disturbance event, such as a clearcut, provides uncluttered high-quality foraging habitat for Indiana myotis. Single-tree selection and patch cuts will also provide high-quality habitat because they can mimic a shifting mosaic. A shifting mosaic is a climax stage of forest succession before European settlement. The first cut of a shelterwood will decrease clutter under the canopy, and the overstory cut of the shelterwood will shift the successional stage to a clearcut-like condition that has seedlings already established (Sheets 2010).

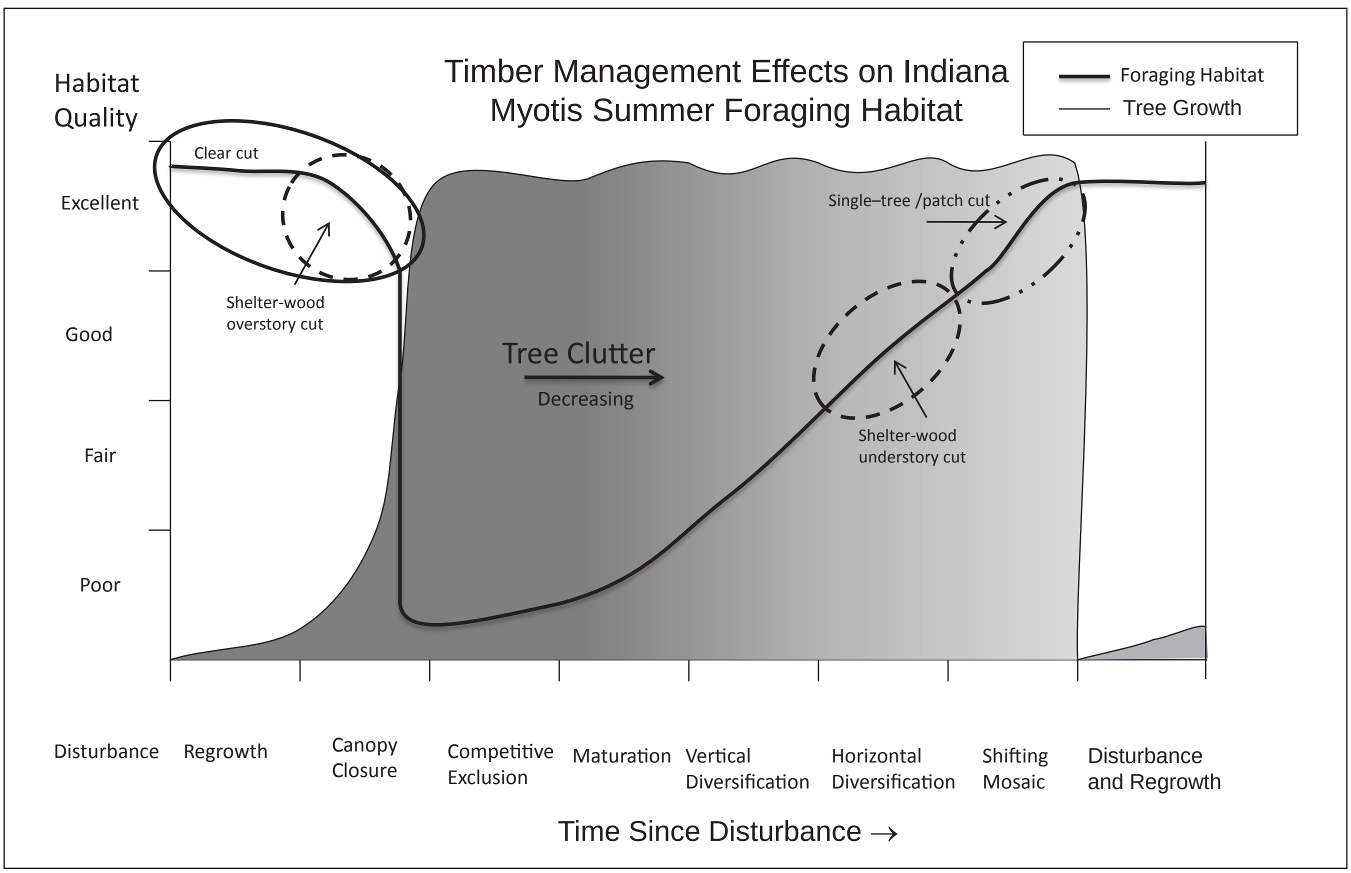

Figure 2.—Predicted changes in quality of summer foraging habitat for Indiana myotis as a function of time since disturbance and type of silvicultural treatment used. The horizontal axis depicts changes in forest structure over time. Ellipses represent harvest activity. The thin line bounding the upper portion of the shaded area mimics change in tree size following disturbance, whereas the thick line represents change in quality of foraging habitat associated with stand structure. The shaded area within the solid line denoting tree size depicts the decrease of clutter in a forest through time. Adapted from Sheets (2010).

It is possible that some Indiana myotis roost trees will be lost to harvest. Given the relatively small size of regeneration openings (≤ 4 ha), however, the availability of suitable roost trees in unharvested control units and buffer areas and retention/creation of snags in harvest areas (IDNR 2008), should ensure that much suitable roosting habitat will remain. Outside harvest areas, falling trees and logging equipment will damage some trees, which may help create suitable roosts for this species over the long term (Gumbert et al. 2002). Harvest methods that successfully yield mature oak-hickory (*Carya*) stands may benefit this species as it frequently roosts in shagbark (*C. ovata*) and shellbark (*C. lacinosa*) hickories and oaks (Callahan et al. 1997, Kurta 2005, Whitaker and Sparks 2008) during summer. Over the long term, the senescence and death of oaks and hickories during succession may provide valuable roost sites.

A hypothetical comparison of successional stages of a forest and high-quality Indiana myotis summer roosting habitat is shown in Figure 3 (adapted from Sheets 2010). Each type of timber cut, without additional girdling of trees, can provide a quality of roosting habitat different from the others. Clearcuts have the longest period of low-quality roosts because it takes time for the forest to produce large high-quality snags to serve as Indiana myotis roosts. Shelterwood cuts essentially resemble a clearcut harvest, but the effect is delayed because the overstory is cut later. Single-tree selection and patch cuts are likely to retain and have higher quality snags than the other timber harvests because trees will be damaged by the smaller cuts, thereby creating more snags; many snags may also be left standing (Sheets 2010).

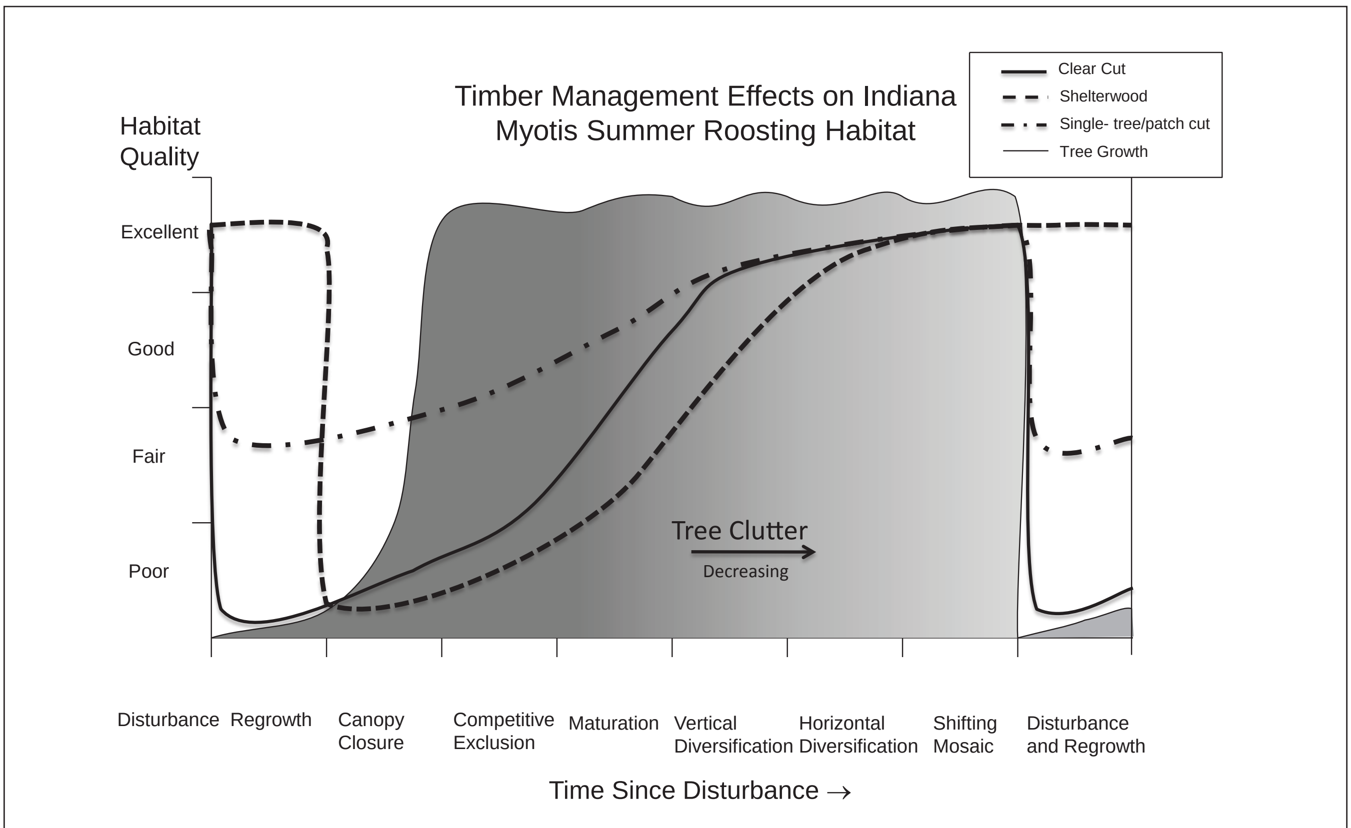

Figure 3.—Predicted changes in quality of summer roosting habitat for Indiana myotis as a function of time since disturbance and type of silvicultural treatment used. The horizontal axis depicts changes in forest structure over time. The thin line bounding the upper portion of the shaded area mimics change in tree size following disturbance and the shaded area within the solid line denoting tree size depicts the decrease of clutter in a forest through time. Adapted from Sheets (2010).

Little Brown Myotis

In Indiana, most documented summer roosts of little brown myotis have been in anthropogenic structures, especially attics of buildings and expansion cracks of bridges, although they occasionally roost under the exfoliating bark of dead trees (Whitaker et al. 2007). Little brown myotis forage along forest edges (Patriquin and Barclay 2003), in centers of clearcuts (Hogburg et al. 2002), and over aquatic habitats (Anthony and Kunz 1977). Being less clutter-adapted than other myotis, these bats are likely to benefit from larger clearcuts and shelterwoods, which have less clutter, but unlikely to benefit from smaller single-tree or patch cuts, which have more clutter in between openings. Corridors connecting water bodies or clearings around existing water sources will benefit little brown myotis. As harvest areas succeed, they are likely to become too cluttered for this species to use extensively.

Hoary Bat

Hoary bats roost mainly in tree canopies (Sparks et al. 2005b, Perry and Thill 2007) and based on wing size and call frequency, forage in open areas (Barclay et al. 1999, Elmore et al. 2004). Hoary bats will benefit from uncluttered foraging habitat in clearcut, large patch cut, and shelterwood harvest areas. Currently hoary bats are rarely encountered during mist-net surveys (we captured two during this study), but we suspect that the species roosts in these forests and forages outside the sampled area in surrounding unforested areas and above the canopy (Sparks et al. 2005b). Roosting habitat will remain abundant on the landscape as long as dominant mature trees are present (Perry and Thill 2007).

Silver-haired Bat

Silver-haired bats summer in the upper Midwest and provinces of Canada, where they roost in tree hollows (Parsons et al. 1986, Whitaker and Hamilton 1998) and forage in the interior of clearcuts (Hogburg et al. 2002). Silver-haired bats migrate through central Indiana during spring and autumn (Mumford and Whitaker 1982), although some hibernate in southern Indiana (Whitaker et al. 2007). Where bats, including the silver-haired bat, forage and roost during migration is not well known. As such, it is speculation that the silver-haired bats will forage in the HEE study area after harvest during migration. Silver-haired bats also feed extensively on caddisflies (Order Trichoptera), which live in streams and wetlands (Whitaker 1972), and may not typically forage in the upland areas of the HEE study area.

CONCLUSIONS

As the HEE progresses, the data presented herein will provide a valuable reference point to determine how the bat community responds to forest management techniques. With new openings created by timber harvest every 20 years, a mosaic of even-aged stands in varying successional states, uneven-aged stands, and unharvested control units will provide foraging habitats for species of bats throughout this 100-year project. Eventually, comparison of the bat community within these habitat types before and after timber harvests should provide substantial insight into ways to successfully manage bats and timber production on the same landscape.

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