

Myotis sodalis

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INTRODUCTORY

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AUTHORSHIP AND CITATION:

Luensmann, Peggy S. 2005. Myotis sodalis. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/> [2012, April 30].

FEIS ABBREVIATION:

MYSO

SYNONYMS:

None

COMMON NAMES:

Indiana bat

Indiana myotis

social myotis

TAXONOMY:

The scientific name of the Indiana bat is *Myotis sodalis* Miller & Allen [1,63].

ORDER:

Chiroptera

CLASS:

Mammal

FEDERAL LEGAL STATUS:

Endangered [96]

The Indiana bat was one of the 1st species in the United States that was listed as endangered and has been protected by law since March 11, 1967 [96].

OTHER STATUS:

The Indiana bat is considered endangered in every state in which the species is found [95]. It is possible that the Indiana bat is extirpated from some states that were part of its historical range. These states may include Massachusetts, where there have been no confirmed sightings of the Indiana bat since 1939 [61].

WILDLIFE DISTRIBUTION AND OCCURRENCE

SPECIES: *Myotis sodalis*

- GENERAL DISTRIBUTION
- ECOSYSTEMS
- STATES/PROVINCES
- BLM PHYSIOGRAPHIC REGIONS
- KUCHLER PLANT ASSOCIATIONS
- SAF COVER TYPES
- SRM (RANGELAND) COVER TYPES
- PLANT COMMUNITIES

GENERAL DISTRIBUTION:

The Indiana bat occurs in the eastern half of the United States. It is found east to the Appalachian Mountains, south to Alabama and Arkansas, west to eastern Kansas and Oklahoma, and north to southern Michigan and Vermont, with disjunct hibernation records from northwest Florida and northwest Michigan [87].

ECOSYSTEMS [37]:

FRES14 Oak-pine

FRES15 Oak-hickory

FRES16 Oak-gum-cypress

FRES17 Elm-ash-cottonwood

FRES18 Maple-beech-birch

STATES/PROVINCES: (key to state/province abbreviations)

UNITED STATES

AL	AR	FL	GA	IL	IN	IA	KS	KY	MD
MI	MS	MO	NJ	NY	NC	OH	OK	PA	SC
TN	VT	VA	WV						

BLM PHYSIOGRAPHIC REGIONS [6]:

None

KUCHLER [49] PLANT ASSOCIATIONS:

K082 Mosaic of K074 and K100

K099 Maple-basswood forest

K100 Oak-hickory forest

K101 Elm-ash forest

K102 Beech-maple forest

K103 Mixed mesophytic forest

K104 Appalachian oak forest

K106 Northern hardwoods

K108 Northern hardwoods-spruce forest

K111 Oak-hickory-pine

K113 Southern floodplain forest

SAF COVER TYPES [32]:

22 White pine-hemlock

23 Eastern hemlock

25 Sugar maple-beech-yellow birch

26 Sugar maple-basswood

27 Sugar maple

28 Black cherry-maple

39 Black ash-American elm-red maple

40 Post oak-blackjack oak

42 Bur oak

43 Bear oak

44 Chestnut oak

45 Pitch pine

46 Eastern redcedar

50 Black locust

51 White pine-chestnut oak

52 White oak-black oak-northern red oak

53 White oak

55 Northern red oak

57 Yellow-poplar

58 Yellow-poplar-eastern hemlock

59 Yellow-poplar-white oak-northern red oak

60 Beech-sugar maple

61 River birch-sycamore

62 Silver maple-American elm

63 Cottonwood

64 Sassafras-persimmon

65 Pin oak-sweetgum

76 Shortleaf pine-oak
 78 Virginia pine-oak
 87 Sweetgum-yellow-poplar
 93 Sugarberry-American elm-green ash
 94 Sycamore-sweetgum-American elm
 95 Black willow
 108 Red maple
 109 Hawthorn
 110 Black oak

SRM (RANGELAND) COVER TYPES [82]:

801 Savanna
 804 Tall fescue
 805 Riparian

PLANT COMMUNITIES:

Common dominant trees utilized by Indiana bat throughout its range include oaks (*Quercus* spp.), hickories (*Carya* spp.), ashes (*Fraxinus* spp.), elms (*Ulmus* spp.), eastern cottonwoods (*Populus deltoides*), locusts (*Robinia* spp.), and maples (*Acer* spp.). The understory may include hawthorns (*Crataegus* spp.), dogwoods (*Cornus* spp.), fragrant sumac (*Rhus aromatica*), giant ragweed (*Ambrosia trifida*), sedges (*Carex* spp.), Virginia creeper (*Parthenocissus quinquefolia*), wood nettle (*Laportea canadensis*), goldenrod (*Solidago* spp.), poison-ivy (*Toxicodendron radicans*), and wild grape (*Vitis* spp.) [35].

Indiana bats were found in a variety of plant associations in a southern Iowa study. Riparian areas were dominated by eastern cottonwood, hackberry (*Celtis occidentalis*), and silver maple (*Acer saccharinum*). In the forested floodplains, the dominant plants included black walnut (*Juglans nigra*), silver maple, American elm (*Ulmus americana*), and eastern cottonwood. In undisturbed upland forest, the most common plants were black oak (*Quercus velutina*), bur oak (*Q. macrocarpa*), shagbark hickory (*Carya ovata*), and bitternut hickory (*C. cordiformis*). Black walnut, American basswood, American elm, and bur oak dominated other upland Indiana bat sites [23].

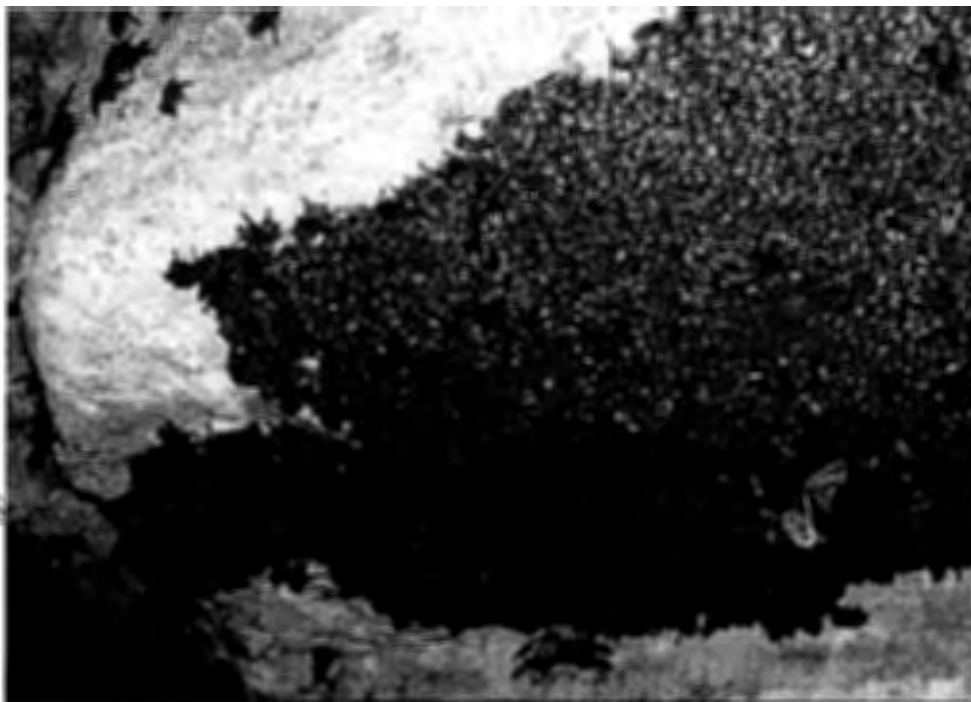
Studies have identified at least 29 tree species that Indiana bats use during the summer. The greatest number of utilized tree species are found in the central portion of Indiana bats's range (primarily Missouri, southern Illinois, southern Indiana, and Kentucky), but this is likely because the majority of research conducted on the species has occurred in this region. Roost trees from these central states, which are mainly in the oak-hickory cover type, include silver maple, red maple (*Acer rubrum*), sugar maple (*A. saccharum*), white oak (*Q. alba*), red oak (*Q. rubra*), pin oak (*Q. palustris*), scarlet oak (*Q. coccinea*), post oak (*Q. stellata*), shingle oak (*Q. imbricaria*), eastern cottonwood, shagbark hickory, bitternut hickory, mockernut hickory (*C. alba*), pignut hickory (*C. glabra*), American elm, slippery elm (*Ulmus rubra*), honey locust (*Gleditsia triacanthos*), sourwood (*Oxydendrum arboreum*), green ash (*Fraxinus pennsylvanica*), white ash (*F. americana*), Virginia pine (*Pinus virginiana*), American sycamore (*Platanus occidentalis*), and sassafras (*Sassafras albidum*) [17,18,20,35,36,38,44,47,50,59,89]. In southern Michigan and northern Indiana, which are mainly in the oak-hickory and elm-ash-cottonwood cover types, trees utilized as roosts include green, white, and black ash (*Fraxinus nigra*), silver maple, shagbark hickory, and American elm [22,46,51,56]. And finally, in the southern areas of the Indiana bat's range (primarily Tennessee, Arkansas, and northern Alabama), which include the oak-hickory and oak-pine cover types, Indiana bats utilize shagbark hickory, white oak, red oak, pitch pine (*P. rigida*), shortleaf pine (*P. echinata*), loblolly pine (*P. taeda*), sweet birch (*Betula lenta*), and eastern hemlock (*Tsuga canadensis*) [14,85]. Virtually no information exists for Indiana bats roosting in the Northeast (such as Pennsylvania, New York, and

Vermont) or for the eastern sections of the range (including Virginia, West Virginia, and Maryland). In these areas, Indiana bats likely utilize the some of the same species listed here and also take advantage of other tree species that are available.

BIOLOGICAL DATA AND HABITAT REQUIREMENTS

SPECIES: *Myotis sodalis*

- TIMING OF MAJOR LIFE HISTORY EVENTS
- PREFERRED HABITAT COVER
- REQUIREMENTS
- FOOD HABITS
- PREDATORS
- MANAGEMENT CONSIDERATIONS



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TIMING OF MAJOR LIFE HISTORY EVENTS:

Indiana bats begin to arrive at hibernacula (caves and mines in which they spend the winter) from their summer roosting sites in late August, with most returning in September [2]. Females enter hibernation shortly after arriving at hibernacula, but males remain active until late autumn to breed with females arriving late. Most Indiana bats hibernate from October through April, but many at the northern extent of their range hibernate from September to May. Occasionally, Indiana bats are found hibernating singly, but almost all are found hibernating in dense clusters of 3,230 bats/m² to 5,215 bats/m² [93].

Spring migration can begin as early as late March, but most Indiana bats do not leave their winter hibernacula until late April to early May [2]. Females emerge from hibernacula first, usually between late March and early May. Most males do not begin to emerge until mid- to late April [58,93]. Females arrive at summer locations beginning in mid-April. Females form summer nursery colonies of up to 100 adult females during summer [47,93]. Males typically roost alone or in small bachelor groups during the summer. Many males spend the summer near their winter hibernacula, while others migrate to other areas, similar to areas used by females [93].

Females can mate during their 1st fall, but some do not breed until their 2nd year [81,93]. Males become reproductively active during their 2nd year [93]. Breeding occurs in and around hibernacula in fall [29,93]. During the breeding season, Indiana bats undergo a phenomenon known as swarming. During this activity, large numbers of bats fly in and out of caves from sunset to sunrise [93]. Swarming mainly occurs during August to September [29] and is thought to be an integral part of mating [93]. Bats have been observed copulating in caves until early October [2]. During the swarming/breeding period, very few bats are found roosting within the hibernacula during the day [29]. Limited mating may also occur at the end of hibernation [93].

Fertilization does not occur until the end of hibernation [81,87,93], and gestation takes approximately 60 days [4]. Parturition occurs in late May to early July [81,93]. Female Indiana bats typically give birth to 1 pup [81,87,93]. Juveniles are weaned after 25 to 37 days [44] and become volant (able to fly) at about the same time [93]. Most young can fly by early to late July [44,62], but sometimes do not fly until early August [81]. Humphrey and others [44] reported an 8% mortality rate by the time young were weaned. However, they assumed that all females mate in the autumn [81], which is not the case, so not all the females would give birth. Thus, mortality of young may be even lower than 8%.

Indiana bats are relatively long lived. One Indiana bat was captured 20 years after being banded as an adult [58]. Data from other recaptured individuals show that females live at least 14 years 9 months [43], while males may live for at least 13 years 10 months [73].

PREFERRED HABITAT:

Landscape: Habitat requirements for the Indiana bat are not completely understood. Bottomland and floodplain forests were once thought to be the most important habitats during the summer, but subsequent study has shown that upland forest habitats may be equally important, especially in the southern portions of the species's range [17,23,35]. Indiana bats are found in hardwood forests throughout most of their range [35,44,56] and mixed hardwood-pine forests in the southeastern United States [14,59]. Stone and Battle [85] found a significantly greater proportion ($p < 0.05$) of old-growth forest (greater than 100 years), more hardwoods, and fewer conifers in stands occupied by Indiana bats than in random stands in Alabama.

In an Illinois study by Gardner and others [35], the study area where Indiana bats were found was estimated as approximately 67% agricultural land including cropland and old fields; 30% was upland forest; while 2.2% was floodplain forest. Finally, only 0.1% of the area was covered with water. Kurta and others [53] found that in southern Michigan, the general landscape occupied by Indiana bats consisted of open fields and agricultural lands (55%), wetlands and lowland forest (19%), other forested habitats (17%), developed areas (6%), and perennial water sources such as ponds and streams (3%). In southern Illinois, Carter and others [18] reported that all roosts were located in bottomland, swamp, and floodplain areas. Miller and others [64] determined the predominant habitat types near areas where Indiana bats were captured in Missouri were forest, crop fields, and grasslands. Indiana bats did not show any preference for early successional habitats, such as old fields, shrublands, and early successional forests, showing 71% to 75% of activity occurring in other habitats [34]. Although much of the landscape throughout the distributional range of the Indiana bat is dominated by agricultural lands and other open areas, these areas are typically not utilized by Indiana bats [44,67].

Indiana bats typically spend the winter months in caves or mines. However, a few bats have been found hibernating on a dam in northern Michigan [88]. Indiana bats need very specific conditions in order to survive the winter hibernation period, which lasts approximately 6 months. As the microclimate in a hibernaculum fluctuates throughout the winter, Indiana bats sometimes fly to different areas within the hibernaculum to find optimal conditions [28,40], but this does not appear

necessary for every hibernaculum [39]. Indiana bats may even switch between nearby hibernacula in search of the most appropriate hibernating conditions [58]. Indiana bats are generally loyal to specific hibernacula or to the general area near hibernacula that they have occupied previously [58]. Critical winter habitats of Indiana bats have been designated by the U.S. Fish and Wildlife Service and include 13 hibernacula distributed across Illinois, Indiana, Kentucky, Missouri, Tennessee, and West Virginia [92].

Three types of hibernacula have been designated depending on the amount of use each receives from year to year. Priority One hibernacula are those that consistently have greater than 30,000 Indiana bats hibernating inside each winter. Priority Two hibernacula contain 500 to 30,000 bats, and Priority 3 hibernacula are any with fewer than 500 bats. At least 50% of Indiana bats are thought to hibernate in the 8 Priority One hibernacula, which can be found in Indiana (3 hibernacula), Missouri (3), and Kentucky (2). Estimates of hibernating populations in 2001 suggest that Priority One hibernacula have experienced a 48% decline since 1983. Overall, populations have fallen approximately 57% since 1960 across all hibernacula. Evidence suggests that Priority Two hibernacula are becoming more important to Indiana bat survival [27].

Site Characteristics: Studies have identified at least 29 tree species (see Plant Communities) used by Indiana bats during the summer and during spring and fall migrations. Since so many tree species are utilized as roosts, tree species is likely not a limiting habitat requirement. In addition to trees, Indiana bats have used a Pennsylvania church attic [16], a utility pole [85], and bat boxes [79] as roosts. However, use of man-made structures appears to be rare. Roost selection by females may be related to environmental factors, especially weather. Cool temperatures can slow fetal development [44,75], so choosing roosts with appropriate conditions is essential for reproductive success [93] and probably influences roost choice.

Two types of day roosts utilized by Indiana bats have been identified as primary and alternate roosts. Primary roosts typically support more than 30 bats at a time [64] and are used most often by a maternity colony. Trees that support smaller numbers of Indiana bats from the same maternity colony are designated as alternate roosts. In cases where smaller maternity colonies are present in an area, primary roosts may be defined as those used for more than 2 days at a time by each bat, while alternate roosts are generally used less than 2 consecutive days [14]. Maternity colonies may use up to 3 primary roosts and up to 33 alternate roosts [36,64] in a single season. Reproductively active females frequently switch roosts to find optimal roosting conditions. When switching between day roosts, Indiana bats may travel as little as 23 feet (7 m) or as far as 3.6 miles (5.8 km) [53,54,56]. In general, moves are relatively short and typically less than 0.6 mile (1 km) [102].

Primary roosts are most often found at forest edges or in canopy gaps [17,64]. Alternate roosts are generally located in a shaded portion of the interior forest and occasionally at the forest edge [17]. Most roost trees in a Kentucky study occurred in canopy gaps in oak, oak-hickory, oak-pine, and oak-poplar community types [47]. Roosts found by Kurta and others [53] in an elm-ash-maple forest in Michigan were in a woodland/marsh edge, a lowland hardwood forest, small wetlands, a shrub wetland/cornfield edge, and a small woodlot. Around hibernacula in autumn, Indiana bats tended to choose roost trees on upper slopes and ridges that were exposed to direct sunlight throughout the day [47].

The preferred amount of canopy cover at the roost is unclear. Many studies have reported the need for low cover, while others have documented use of trees with moderate to high canopy cover, occasionally up to complete canopy closure. Canopy cover ranges from 0% at the forest edge to 100% in the interior of the stand [17,35,59]. A general trend is that primary roosts are found in low cover, while alternate roosts tend to be more shaded. Few data directly compare the differences between

roost types. In Alabama, canopy cover at the roost tended to be low at an average of 35.5%, but at the stand level, canopy cover was higher with a mean of 65.8% [85]. In a habitat suitability model, Romme and others [78] recommended the ideal canopy cover for roosting Indiana bats as 60% to 80%. Actual roost sites in eastern Tennessee were very high in the tree, and Indiana bats were able to exit the roost above the surrounding canopy. Thus, canopy cover measurements taken from the bases of roost trees may overestimate the actual amount of cover required by roosting Indiana bats [14].

A great deal of difference exists between stands occupied by Indiana bats. A Virginia pine roost was in a stand with a density of only 367 trees/ha [41] while in Kentucky, a shagbark hickory roost was in a closed canopy stand with 1,210 trees/ha [47]. Overall tree density in Great Smoky Mountain National Park was higher around primary roosts than at alternate roosts [14]. At the landscape level, the basal area for stands with roosts was 30% lower than basal area of random stands in Alabama [85]. Tree density in southern Iowa varied between different habitats. In a forested floodplain, tree density was lowest at 229 trees/ha, while a riparian strip had the highest tree density at 493 trees/ha [23].

The number of roosts used and home range occupied by a maternity colony can vary widely. In Missouri, Callahan and others [17] found that the highest density of roosts being used in a oak-hickory stand was 0.25 tree/ha. In Michigan, the number of trees utilized by a colony was 4.6 trees/ha, with as many as 13.2 potential roosts/ha in the green ash-silver maple stand [56]. Clark and others [23] estimated that the density of potential roosts in southern Iowa in areas where Indiana bats were caught was 10 to 26/ha in riparian, floodplain, and upland areas dominated by eastern cottonwood-silver maple, oak-hickory, and black walnut-silver maple-American elm, respectively. In Illinois, the suggested optimal number of potential roost trees in an upland oak-hickory habitat was 64/ha; the optimal number for riparian and floodplain forest, dominated by silver maple and eastern cottonwood, was proposed to be 41/ha [35]. Salyers and others [79] suggested a potential roost density of 15 trees/ha was needed, or 30 roosts/ha if artificial roost boxes are erected in a stand with American elm and shagbark hickory. The roosting home range used by any single Indiana bat was as large as 568 hectares in a oak-pine community in Kentucky [59]. Roosts of 2 maternity colonies in southern Illinois were located in roosting areas estimated at 11.72 hectares and 146.5 hectares and included green ash, American elm, silver maple, pin oak, and shagbark hickory [18]. The extent of the maternity home range may depend on the availability of suitable roosts in the area [94].

Most habitat attributes measured for the Indiana bat were insignificant as well as inconsistent from one location to another. In Missouri, oak-hickory stands with maternity colonies had significantly ($p=0.01$) more medium trees (12-22 inches (30-57 cm) dbh) and significantly ($p=0.01$) more large sized trees (>22 inches (57 cm) dbh) than areas where Indiana bats were not found. No other major landscape differences were detected [64].

Distances seen between roosts and other habitat features may be influenced by the age, sex, and reproductive condition of the Indiana bats. Distances between roosts and paved roads is greater than the distances between roosts and unpaved roads in some locales, although overlap between the two situations has been documented. In Illinois, most roosts used by adult females and juveniles were about 2,300 feet (700 m) or more from a paved highway, while adult males roosted less than 790 feet (240 m) from the road [35,36]. In Michigan, roosts were only slightly closer to paved roads: 2,000 feet (600 m) on average for all roosts located [51]. In general, roosts were located 1,600 feet (500 m) to 2,600 feet (800 m) from unpaved roads in Illinois and Michigan [36,51]. Roost trees used during autumn in Kentucky were very close to unpaved roads at an average of 160 feet (50 m) [47].

Roost proximity to water is highly variable and therefore probably not as important as once thought. In Indiana, roost trees were discovered less than 660 feet (200 m) from a creek [44], while roosts in

another part of Indiana were 1.2 miles (2 km) from the nearest permanent water source [36,51]. To the other extreme, roosts of a maternity colony from Michigan were all found in a 12-acre (5 ha) wetland that was inundated for most of the year [51]. In Virginia, foraging areas near a stream were utilized [41]. Intermittent streams may be located closer to roosts than more permanent sources of water [35,51]. Ponds, streams, and road ruts appear to be important water sources, especially in upland habitats [60].

Foraging habitat: Studies on the foraging needs for Indiana bats are inconclusive. Callahan and others [17] reported that bats foraged in a landscape composed of pasture, corn fields, woodlots, and a strip of riparian woodland, although Indiana bat activity was not necessarily recorded in all these habitat types. Murray and Kurta [67] made some qualitative assessments of Indiana bat foraging habitat in Michigan: the majority of bats were found foraging in forested wetlands and other woodlands, while 1 bat foraged in an area around a small lake and another in an area with 50% woodland and 50% open fields. Another Indiana bat foraged over a river, while 10 others foraged in areas greater than 0.6 mile (1 km) from the same river [67]. Bat activity was centered around small canopy gaps or closed forest canopy along small 2nd-order streams in West Virginia [33]. Indiana bats foraged under the dense oak-hickory forest canopy along ridges and hillsides in eastern Missouri, but rarely over streams [57]. Indiana bats have been detected foraging in upland forest [11,23,47,93] in addition to riparian areas such as floodplain forest edges [11,23,44,55,69,72,93]. Romme and others [78] also suggested that foraging habitat would ideally have 50% to 70% canopy closure. Indiana bats rarely utilize open agricultural fields and pastures, upland hedgerows, open water, and deforested creeks for traveling or foraging [36,44,67]. Boyles and others [9] concluded that most activity occurred under the canopy as opposed to above the canopy.

Hibernacula: During hibernation, Indiana bats occupy open areas of hibernacula ceilings and generally avoid crevices and other enclosed areas [76]. Indiana bats were associated with hibernacula that were long ($\mu=2,817$ feet (858 m)), had high ceilings ($\mu=15$ feet (4.5 m)), and had large entrances ($\mu=104.4$ feet² (9.7 m²)). The preferred hibernacula often had multiple entrances promoting airflow. Hibernacula choice may be influenced by the ability of the outside landscape to provide adequate forage upon arrival at the hibernacula as well as the specific microclimate inside. Having forested areas around the hibernacula entrance and low amounts of open farmland may be important factors influencing the suitability of hibernacula [76]. This is the only comprehensive habitat assessment of Indiana bat hibernacula known to date (2005).

COVER REQUIREMENTS:

Primary roosts used by Indiana bats are typically snags in canopy gaps and forest edges that receive direct sunlight throughout the day [17]. Alternate roosts live or dead trees, generally located in the forest interior, that usually receive little or no direct sunlight [17,44]. Weather, such as very warm temperatures and precipitation, appears to influence the use of interior alternate roost trees over primary roosts, as alternate roosts generally offer more shade and protection during inclement weather and extreme heat [17,44,64]. However, this preference may fluctuate from season to season. Indiana bats moved to the alternate roost during periods of heavy rain and colder ambient temperatures during fall in Missouri, but chose to roost in the primary snag during inclement weather in the spring. These differences may be attributed to variation in the heat retention capabilities of the trees at different times of the year [44]. Gumbert and others [38] discovered bats from a maternity colony switched roosts more frequently in summer and autumn than they did in spring in an oak-pine forest in Kentucky. Indiana bats exhibit strong fidelity to individual roost trees from year to year if they are still suitable roost sites [26,38,44,52,56]. Many trees are no longer usable after just a few years [17,26,35,44,51,56,93], while others may last as long as 20 years [81].

Another important factor relating to roost suitability is tree condition. Indiana bats prefer dead or dying trees with exfoliating bark [51]. The amount of exfoliating bark present on a tree seems to be insignificant [47]. Indiana bats show an affinity for very large trees that receive lots of sunlight [54]. Typically, Indiana bats roost in snags, but a few species of live trees are also utilized. Live roost trees are usually shagbark hickory, silver maple, and white oak [17,35,89]. Shagbark hickories make excellent alternate roosts throughout the Indiana bats's range due to their naturally exfoliating bark [93]. Although Indiana bats primarily roost under loose bark, a small fraction roost in tree cavities [14,35,50,51,53,89].

Primary roosts are generally larger than alternate roosts [14], but both show a lot of variability. Females typically use large roost trees averaging 10.8 inches (27.4 cm) to 25.7 inches (65.3 cm) as maternity roosts [17,35,41,47,50,51,56,83,85]. Males are more flexible, roosting in trees as small as 3 inches (8 cm) dbh [35,41,47,59]. In a review, Romme and others [78] determined that Indiana bats required tree roosts greater than 8 inches (22 cm) dbh, while Clawson [26] suggested that roosts of 12 inches (30 cm) dbh or larger were preferred. The heights of roost trees vary, but they tend to be tall, with average heights ranging from 62.7 feet (19.1 m) to 100 feet (30 m). The heights of the actual roosting sites are variable as well, ranging from 4.6 feet (1.4 m) to 59 feet (18 m) [41,51,56,85]. There is evidence that roost height is influenced by the extent of canopy closure. Specifically, more open canopies tend to be correlated with into lower roost heights [35]. However, this rule does not appear to hold true in all localities [51,85].

In addition to day roosts, Indiana bats use temporary roosts throughout the night to rest between foraging bouts. Limited research has examined the use of night roosts by Indiana bats, and thus their use and importance are poorly understood. Males, lactating and postlactating females, and juveniles have been found roosting under bridges at night [48,65]. Some Indiana bats were tracked to 3 different night roosts within the same night [67]. Night roosts are often found within the bats's foraging area. Indiana bats using night roosts are thought to roost alone and only and for short periods, typically 10 minutes or less. Lactating bats may return to the day roost several times each night, presumably to nurse their young. Pregnant bats have not been tracked back to the day roost during the night except during heavy rain. Because Indiana bats are difficult to track during their nightly movements and usually rest for such short periods of time, the specific requirements that Indiana bats need in a night roost, and reasons why night roosts are needed, are still unknown.

During spring and fall, Indiana bats migrate between hibernacula and summer roosting sites. In New York and Vermont, bats traveled up to 25 miles (40 km) between hibernacula and summer roosting sites in spring [15]. This is a considerably shorter distance than what is seen in the Midwest, where bats may travel up to 300 miles (500 km) [52]. Many males remain close to hibernacula during the spring and summer [2,102] rather than migrating long distances like females. Occasionally, they even roost within hibernacula during the summer [102]. Males also roost in caves and trees during fall swarming [26,102]. Few data exist for the roosting requirements of Indiana bats during spring and fall migrations; data indicate that requirements during these times are similar to summer needs in that the bats chose large trees with direct sunlight and exfoliating bark [15,41].

The ability for Indiana bats to find suitable hibernating conditions is critical for their survival. A hibernaculum that remained too warm during one winter caused a 45% mortality rate in hibernating Indiana bats [77]. Bats generally hibernate in warmer portions of the hibernacula in fall, then move to cooler areas as winter progresses. During October and November, temperatures at roosting sites within major hibernacula in 6 states averaged 43.5 °F to 53.2 °F (6.4-11.8 °C). Roost temperatures at the same hibernacula ranged from 34.5 °F to 48.6 °F (1.4-9.2 °C) from December to February. Temperatures in March and April were slightly lower than in autumn at 39.6 °F to 51.3 °F (4.2-10.7 °C) [90]. The Indiana Bat Recovery Team [93] discovered that Indiana bat populations increased over

time in hibernacula that had stable mid-winter temperatures averaging 37.4 °F to 45.0 °F (3.0-7.2 °C), and declined in hibernacula with temperatures outside this range [90,93]. Temperatures slightly above freezing during hibernation allow Indiana bats to slow their metabolic rates as much as possible without the risk of freezing to death or using up fat too quickly [42,77]. Hibernating Indiana bats may also survive low temperatures by sharing body heat within the tight clusters they typically form [28]. Bats awaken periodically throughout the hibernation period, presumably to eliminate waste or to move to more appropriate microclimates [39,40]. This periodic waking does not seem to affect the survival of Indiana bats, but waking caused by disturbance can cause Indiana bats to use up large amounts of energy, which can cause them to run out of fat reserves before the end of winter, possibly leading to death [86].

One way in which caves retain low temperatures is through a constant input of cold air from outside the cave circulating in. Typically, the caves supporting the largest Indiana bat populations have multiple entrances that allow cool air from outside the cave to come in, creating a circulation of fresh cooled air [91]. Gates that are meant to keep vandals out of caves have altered the temperature and airflow of hibernacula, resulting in population declines of Indiana bats at many major hibernacula throughout their range. Removing or modifying gates at some of these have given these populations a chance to rebound [30]. Also, the bats seem to prefer a relative humidity of 74% to 100%, although it is uncommon for the air to be saturated [2,26,28,39,42]. Relative humidities of only 50.4% have also been recorded [76]. More research is needed to identify other specific environmental conditions that bats require at hibernacula.

FOOD HABITS:

Indiana bats feed exclusively on terrestrial and aquatic flying insects [69]. The most common prey items taken by Indiana bats are moths (Lepidoptera), beetles (Coleoptera), and mosquitoes and midges (Diptera) [10,58]. Selection of prey depends largely on availability in the foraging habitat with diet varying seasonally, by reproductive status of females, and from night to night. In southern Michigan, Indiana bats primarily ate caddisflies (Trichoptera) and bees, wasps, and ants (Hymenoptera), in addition to the more common prey previously listed [55,68,69]. In the Ozarks of southern Missouri, the bats also primarily ate bees, wasps, ants, moths, and beetles as well as leafhoppers (Homoptera), although diet did vary throughout the summer [10]. Bats in Indiana were found to prefer beetles, moths, mosquitoes, midges, leafhoppers, and wasps [100,101]. Other arthropod groups which are consumed by Indiana bats in very limited quantities are lacewings (Neuroptera), spiders (Araneae), stoneflies (Plecoptera), mayflies (Ephemeroptera), mites and ticks (Acari), and lice (Phthiraptera) [10,47,55,69].

In addition to differences in diet, variation in foraging behaviors have been documented. For instance, the distance that an individual Indiana bat travels between a day roost and a nightly foraging range can vary. Garner and Gardner [36] discovered that Indiana bats traveled up to 1.6 miles (2.6 km) from their day roosts to their foraging sites in Illinois. Similarly, bats traveled up to 1.5 miles (2.4 km) to forage in Kentucky [47]. In Michigan, female bats traveled as far as 2.6 miles (4.2 km) to reach foraging areas with an average of 1.5 miles (2.4 km) [67].

Several studies have documented similarities in how foraging habitats are actually utilized by Indiana bats. Humphrey and others [44] found Indiana bats in Indiana were foraging around the canopy, which was 7 to 98 feet (2-30 m) above ground. LaVal and others [57], whose study was also conducted in Missouri, found that a female bat foraged 7 to 33 feet (2-10 m) above a river. In the same study, a male Indiana bat was observed flying in an elliptical pattern among trees at 10 to 33 feet (3-10 m) above the ground under the canopy of dense forests [57]. In addition, bats were observed foraging at canopy height in Virginia [41], which would likely provide foraging conditions similar to the studies previously mentioned.

Differences in the extent of foraging ranges have also been noted. Bats from the same colony foraged in different areas at least some of the time [67]. Humphrey and others [44] reported that the average foraging area for female bats in Indiana was 843 acres (341 ha), but the foraging area for males averaged 6,837 acres (2,767 ha). Hobson and Holland reported a male bat utilizing a foraging area of 1,544 acres (625 ha) in Virginia [41]. In Illinois, however, the foraging ranges were much smaller at an average of 625 acres (253 ha) for adult females, 141 acres (57 ha) for adult males, 91 acres (37 ha) for juvenile females, and only 69 acres (28 ha) for juvenile males [35,36,47]. Humphrey and others [44] found that foraging areas utilized by Indiana bats in Indiana increased throughout the summer season, but only averaged 11.2 acres (4.54 ha) in mid-summer.

PREDATORS:

During hibernation, predators of Indiana bats may include black rat snakes (*Elaphe obsoleta*) [21,99] and northern raccoons (*Procyon lotor*) [66,83,99]. During other times of the year northern raccoons have been observed trying to grab bats from the air when they attempt to fly away [83]. Skunks (Mephitidae), Virginia opossums (*Didelphis virginiana*), and feral cats (*Felis catus*) may pose a similar threat [4,99]. If Indiana bats fly from their day roosts during the day, they may be susceptible to predation by hawks (Accipitridae) [83,99]. Indiana bats foraging at night may also be susceptible to predation by owls (Strigidae) [44,99]. While not a predator, woodpeckers (Picidae) may disturb roosting bats through their foraging activities by peeling away sections of bark being utilized by Indiana bats, causing Indiana bats to fly from the roost during the day and making the tree unsuitable for future habitation [51,83]. It is possible that this disturbance could cause some indirect mortality of Indiana bats by destroying habitat and by causing nonvolant juveniles to fall to the ground or become exposed to predators.

The impact of natural predators on Indiana bats is minimal compared to the damage to habitat and mortality caused by humans, especially during hibernation. The presence of people in caves can cause Indiana bats to come out of hibernation, leading to a large increase in the energy used by the bats. By causing Indiana bats to wake up and use greater amounts of energy stores, humans can cause high mortality in a cave population of hibernating Indiana bats [86]. Human disturbance and the degradation of habitat are the primary causes for the decline of the Indiana bat [13].

MANAGEMENT CONSIDERATIONS:

Indiana bats may respond positively to some forest disturbance [93], but direct and indirect effects of land management on the Indiana bat are still unknown. Direct mortality, injury, or harassment of Indiana bats is possible from felling trees, especially if snags are felled [84]. Belwood [5] noted that a maple snag felled in a new residential area had been a maternity roost. A dead female and 33 nonvolant juveniles were found near the tree after felling. The juveniles were retrieved by their mothers shortly after being placed in a bat house for protection [5]. All juveniles appear to have survived the destruction of the tree, but it is unclear whether the female died as a result of tree felling or from other causes.

Harvesting trees within stands where Indiana bats are known to roost during the summer could result in the mortality or displacement of individual bats or possibly entire colonies [84]. Harvests would probably be safer in these areas during the hibernation period when the trees are not being utilized. However, felling trees at any time may result in the loss of unknown maternity roosts [8]. Cutting down a tree with roosting Indiana bats is assumed to be unlikely in most cases because of the rarity of the species, because many stands with suitable habitat have more potential roost trees than are likely utilized by Indiana bats, and because most maternity colonies are far apart across their range [103].

Since roost trees tend to be ephemeral, lasting for just a couple of seasons because of tree fall or loss of exfoliating bark from the bole, it may be more beneficial for Indiana bat conservation to protect

and manage stands rather than individual trees. Others go a step further by recommending that existing snags should be retained and new snags should be recruited [3]. This may be especially true for lands intensively managed for wood harvest where forests are not allowed to reach old age classes and very few snags are typically created [97]. Since Indiana bats need a variety of roosts to suit their roosting needs, trees of various species, size, and condition should be maintained to provide the maximum probability that the needs of the bats will be met [62] and to provide a continuous supply of roosts for when old roosts become unsuitable [26].

When harvesting trees in either green or salvage units, the U.S. Fish and Wildlife Service in Pennsylvania [94] recommends that all shagbark and shellbark hickories, living or dead, be retained in any area where Indiana bats could potentially occur. More than 16 live trees of at least 9 inches (23 cm) dbh should be left per acre in partial harvest units. Three of these live trees should be at least 20 inches (51 cm) dbh. For final harvest units and clearcuts, 8 to 15 live trees at least 9 inches (23 cm) dbh should be retained per acre with 1 tree being at least 20 inches dbh per acre. For partial to intermediate harvests in green stands, canopy cover should be reduced to 54%. Live residual trees surrounding approximately 1/3rd of the large (>12 inches (30 cm) dbh) snags with exfoliating bark should be saved in order to provide partial shade of the snags throughout the summer [94]. These live trees could potentially become suitable roosts in the future. Live hickories, oaks, elms, ashes, cottonwoods, and maples should be retained when possible since they are the types primarily used as roosts [78,94]. In partial and final harvests in salvage units as well as in clearcuts, 5 to 10 snags of at least 9 inches (23 cm) in diameter should be retained per acre. At least 1 snag 16 inches (41 cm) dbh should remain per 2 acres (0.8 ha). All known Indiana bat roosts should be protected until they are no longer suitable for use as roosts [94]. In other reports, even more harvest guidelines were presented. For instance, for every 5 acres (2 ha) harvested, a clump of trees 0.25 acre (0.1 ha) in size should be left and contain "den trees," snags, oaks and hickories, conifers, less common species, and/or mast species in a variety of sizes [81]. Additionally, large snags in open canopy should be preserved [26]. Due to the bats' preference for large snags, removal of any snag with exfoliating bark within Indiana bat habitat would potentially cause habitat degradation by the removal of current or potential roost sites.

Several studies document stand use by Indiana bats after tree harvest. Bats completely avoided sites in the study area that had been recently clearcut in Kentucky [59]. However, unmanaged forest stands received 1.5 to 2 times as much activity as expected based on habitat availability. Recent two-aged shelterwood harvests experienced 4 to 7 times the amount of activity expected. These two-aged shelterwood harvests followed guidelines that called for the retention of 40 live trees/ha as well as all snags, shagbark hickories, hollow trees, and trees with large dead limbs. More roosts and more bats utilizing those roosts were found within these harvested areas than in a similar Kentucky study where 40 live trees and just 5 snags/ha were retained [59]. In Illinois, a maternity colony remained in a selectively harvested area and utilized the same roosts that were previously occupied [35]. Indiana bats were occasionally observed foraging under intact canopies and forests with gaps that were created by diameter-limit harvests in West Virginia. Indiana bat activity was not recorded in clearcut areas or under complex canopies [72].

A project in eastern Texas proposed that thinning in pine forests will create more suitable habitats for the southeastern myotis (*Myotis austroriparius*) and Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) by promoting the growth of remaining pine trees to old-growth age class [74]. This condition is reportedly similar to what is preferred by the Indiana bat [85]. Thus, thinning understory may help to improve Indiana bat summer habitat. (See Site Characteristics for discussion on the preferred stand structure of Indiana bats.)

Further recommendations for improving and maintaining the landscape for the Indiana bat have been proposed by biologists in Missouri, Pennsylvania, and Ohio. Riparian corridors should be forested for 100 feet (30 m) or more on either side of a stream. In areas lacking wide forest corridors, reforestation should be a priority [26]. Reducing forest canopies from 100% cover to roughly 30% to 80% cover and clearing some understory is also recommended [8,26]. However, reducing canopy cover even more could be detrimental to the bats by causing the loss of current and future roosts as well as by altering the landscape and microhabitats. Creating new water sources, especially in upland habitats, may improve habitats in which other water sources are not readily available [26]. Sedimentation of stream corridors following logging could potentially affect the insect prey assemblage in a foraging area [8].

Greater threats to the survival of Indiana bats may exist during hibernation. Hibernating bats that are disturbed by human activity have faster weight loss than those not visited by people. Bats located in hibernacula that are visited by people during the hibernation period are more likely to die before spring [45]. The biggest threats to Indiana bat hibernacula are human disturbance, including researchers and spelunkers, and vandalism, poorly designed gates that disrupt airflow, natural hazards such as flooding or mine collapse, and microclimate changes [39,93]. Although gating cave and mine entrances can deter humans from entering hibernacula and disturbing hibernating bats, gates can severely change temperature and airflow within the cave causing it to fall below optimal conditions [42,77]. Management recommendations include protecting hibernacula with bat-friendly gates [30] and restoring abandoned hibernacula if possible [26,103]. Hibernacula should also be closed to visitation from September 1 to April 30 toward the southern extent of the species's range, and from September 1 to May 31 in the north. To minimize disturbance to hibernating populations, censuses of Indiana bats should only occur biennially [26]. Clawson [26] also recommended that a 0.25-mile (0.4 ha) buffer zone be established around hibernacula, in which no development, agricultural activities, logging, or mining should occur. Kiser and Elliott [47] suggested that any snags located within 1.4 miles (2.4 km) of a hibernaculum should be retained, and recruitment of new snags in the same area should also be a priority to ensure that a continuous supply of new roost trees will be available. In addition, any areas that have been altered through agricultural, mining, logging, and other activities should be reforested with trees that are commonly used by Indiana bats for roosting [47].

Pesticides commonly used in agriculture in the past and present, such as organochlorines, organophosphates, carbamates, and pyrethroids, have all been found in the feces and tissues of bats. Since the ban on organochlorines, pyrethroids may be the biggest threat to bat health because they are likely to persist in the environment [71]. Pesticides inhibit cholinesterase and may cause cancer, birth defects, and death in bats. These conclusions are based on preliminary results and thus are largely speculative [80]. Organochlorines, especially DDE, a long-lived product of DDT, build up in bat tissues but are not always found at lethal levels [24]. Products of DDT are highly soluble in fat, so when bats build up fat for hibernation, they run the risk of taking so much that it can be fatal. Pesticide residues concentrate in the brain as other fat in the body is metabolized [24]. There is evidence of Indiana bat mortality due to organochlorines found in the Indiana bat [25,71]. Organochlorine residues still exist in the environment even though their use has been banned for decades. Pesticide residues originate in the bats' prey and build up in tissues, including brain tissues, over time [71]. Pesticide toxicity may have contributed to many mass die-offs that have occurred in the Indiana bat as well as other species around the world [24]. Restricting pesticide use, especially within the vicinity of hibernacula, may help reduce the negative impacts that they can have on Indiana bats and other bat species.

In the northern regions of its range, Indiana bat populations have remained stable or increased slightly since surveys were first conducted in 1960, especially in Indiana, New York, Ohio, and West Virginia. However, Indiana bat populations have decreased drastically in the southern portion of its

range, especially in Kentucky, Missouri, Tennessee, and Arkansas [27,93]. What we have learned about their year-round habitat needs can give us direction on how land should be managed to ensure the survival of the Indiana bat.

FIRE EFFECTS AND USE

SPECIES: *Myotis sodalis*

- DIRECT FIRE EFFECTS ON ANIMALS
- HABITAT-RELATED FIRE EFFECTS
- FIRE USE

DIRECT FIRE EFFECTS ON ANIMALS:

Indiana bats would likely not be harmed during a fire because they could fly away to avoid smoke and flames. In late spring and early summer, however, there is a possibility of direct mortality of nonvolant young [7,81], unless the mothers are able to carry their pups away from the fire [19]. Since there are generally no fuels within winter hibernacula, it is highly unlikely that fire would directly harm the bats in any way during this time. However, if bats are hibernating near the entrance to a cave or mine, they may be susceptible to asphyxiation from smoke that may be entering the hibernacula [7,77,81,91]. Thus, the timing of a fire in Indiana bat habitat may be critical for the survival of individual bats. Fire may displace individuals, but the likelihood of direct individual mortality is very low [74].

HABITAT-RELATED FIRE EFFECTS:

Fire could have mixed effects on Indiana bat habitat. On one hand, fire could burn down a suitable roost tree [81] or weaken it to such an extent that it would fall shortly after. Also, a fire could burn off bark peeling from a roost, taking away preferred roosting locations on the tree. This would also make a roost tree suddenly become unsuitable for Indiana bats. On the other hand, fire could kill some trees, creating new roosting habitat. Overall, fire may result in both the loss and the production of snags [97]. Carter and others [19] suggested that fire in any season that results in tree mortality may provide more benefit to southeastern bats through snag creation than any negative impacts that may occur. A crown fire in an occupied forest stand would likely increase the amount of solar radiation reaching a roost, which would be preferable to a completely closed canopy (see Preferred Habitat). In addition, opening the canopy via a crown fire, or causing tree fall, could improve foraging habitat. In the long term, fire may benefit Indiana bat habitat by reducing the threat of future severe fires. Removing fuel biomass will decrease the risk of major fire events within a stand, which would ensure the continued presence of suitable roosts and foraging habitat for the Indiana bat. In addition, the growth of remaining trees after prescribed fire may be promoted due to decreased competition with other vegetation [74]. Since Indiana bats evolved in habitats that were affected by fire in the past, fire is unlikely to have a strong, long-term negative impact on bat populations [4].

MacGregor and others [59] discovered Indiana bats utilizing roosts located within prescribed fire areas twice as much as expected during 1 year based on the amount of area available. Indiana bat utilization was equal to expected during the 2nd year of the Kentucky study [59]. Some individuals were discovered roosting in a partially burned post oak (*Quercus stellata*) in Illinois [35]. These studies show that fire-affected landscapes remain suitable for Indiana bat use over time.

A mathematical model suggested that closely related bat species in California would be affected differently by high-severity fires. The fringed myotis (*Myotis thysanodes*) and the Yuma myotis (*M.*

yumanensis) were both predicted to be adversely affected by postwildfire conditions due to a perceived decrease in habitat suitability. In contrast, the model suggested that the long-eared myotis (*M. evotis*) would benefit from a high severity wildfire through the production of more suitable habitat [7]. Based on the results of this model, it is unclear how a high severity fire may affect Indiana bat habitat.

The following table provides fire return intervals for plant communities and ecosystems where the Indiana bat is important. For further information, see the FEIS review of the dominant species listed below.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
maple-beech-birch	<i>Acer-Fagus-Betula</i> spp.	>1,000
silver maple-American elm	<i>Acer saccharinum-Ulmus americana</i>	<5 to 200
sugar maple	<i>A. saccharum</i>	>1,000
sugar maple-basswood	<i>A. saccharum-Tilia americana</i>	>1,000
sugarberry-America elm-green ash	<i>Celtis laevigata-Ulmus americana-Fraxinus pennsylvanica</i>	<35 to 200
beech-sugar maple	<i>Fagus</i> spp.- <i>Acer saccharum</i>	>1,000
black ash	<i>Fraxinus nigra</i>	<35 to 200
yellow-poplar	<i>Liriodendron tulipifera</i>	<35
shortleaf pine-oak	<i>Pinus echinata-Quercus</i> spp.	<10
slash pine-hardwood	<i>P. elliotii</i> -variable	<35
longleaf pine-scrub oak	<i>P. palustris-Quercus</i> spp.	6-10
Table Mountain pine	<i>P. pungens</i>	<35 to 200
eastern white pine	<i>P. strobus</i>	35-200
eastern white pine-eastern hemlock	<i>Pinus strobus-Tsuga canadensis</i>	35-200
Virginia pine-oak	<i>P. virginiana-Quercus</i> spp.	10 to <35
sycamore-sweetgum-American elm	<i>Platanus occidentalis-Liquidambar styraciflua-Ulmus americana</i>	<35 to 200
black cherry-sugar maple	<i>Prunus serotina-Acer saccharum</i>	>1,000
oak-hickory	<i>Quercus-Carya</i> spp.	<35 [98]
oak-gum-cypress	<i>Quercus-Nyssa</i> -spp.- <i>Taxodium distichum</i>	35 to >200 [70]
southeastern oak-pine	<i>Quercus-Pinus</i> spp.	<10
white oak-black oak-northern red oak	<i>Quercus alba-Q. velutina-Q. rubra</i>	<35
northern pin oak	<i>Q. ellipsoidalis</i>	<35
bear oak	<i>Q. ilicifolia</i>	<35
bur oak	<i>Q. macrocarpa</i>	<10
chestnut oak	<i>Q. prinus</i>	3-8
northern red oak	<i>Q. rubra</i>	10 to <35

post oak-blackjack oak	<i>Q. stellata-Q. marilandica</i>	<10
black oak	<i>Q. velutina</i>	<35
eastern hemlock-yellow birch	<i>Tsuga canadensis-Betula alleghaniensis</i>	>200 [98]
elm-ash-cottonwood	<i>Ulmus-Fraxinus-Populus</i> spp.	<35 to 200 [31,98]

FIRE USE:

Based on the limited literature on the potential effects of fire on the Indiana bat, it is likely that direct mortality of an individual is extremely low. However, threats could be minimized by conducting prescribed fires during late autumn, winter, and early spring in areas that are potentially used by summering Indiana bats. This would virtually eliminate the possibility of juvenile mortality. Prescribed fires near hibernacula would be most safely performed during the summer, when asphyxiation of hibernating bats would not be an issue. Furthermore, only adult males are typically found in and near hibernacula during summer, so any Indiana bats in the area would presumably be able to flee approaching flames and smoke in those areas.

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