ROOSTING BEHAVIOR AND HABITAT DYNAMICS OF MALE INDIANA BATS

(*MYOTIS SODALIS*) FOLLOWING A LARGE-SCALE NATURAL DISTURBANCE

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ROOSTING BEHAVIOR AND HABITAT DYNAMICS OF MALE INDIANA BATS (*MYOTIS SODALIS*) FOLLOWING A LARGE-SCALE NATURAL DISTURBANCE

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A Dissertation

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Doctor of Philosophy

Auburn, Alabama
August 8, 2005

VITA

Paul Roger Moosman, Jr. was born to Paul R. Moosman, Sr. and Jacqueline T. Moosman in London Derry, New Hampshire, 22 August 1976. While growing up in New Hampshire, he developed an early love of nature - spending many hours catching crayfishes, frogs, and snakes at the local swamp, or fishing with his father and uncles. It was here also, that the effects of urban sprawl and development left an early impression on Paul. At age 14, the Moosman family moved to the small town of Brookneal, Virginia, where there was little to do except fish, hunt, or spend the day scouting for Native American artifacts. After finishing high school at William Campbell, in Naruna, Paul attended the Virginia Military Institute (VMI) thanks to an academic scholarship. Life at VMI was a struggle to balance academics, duties to the rifle team, and the perpetual demands of a military system. However, Paul survived, and in 1998 left VMI with many close friends and a Bachelor of Science degree in biology. Immediately after graduating from VMI, Paul began working toward his M.S. degree in biology, at Eastern Kentucky University (EKU), in Richmond. While at EKU he conducted field research on bats and received his first formal training in subjects that he loved, such as aquatic, marine, and terrestrial ecology. Paul graduated from EKU in 2001 and went on to complete his Ph.D. dissertation at Auburn University, under the direction of Troy L. Best.

DISSERTATION ABSTRACT

ROOSTING BEHAVIOR AND HABITAT DYNAMICS OF MALE INDIANA BATS (*MYOTIS SODALIS*) FOLLOWING A LARGE-SCALE NATURAL DISTURBANCE

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Doctor of Philosophy, May 13, 2005
(M.S., Eastern Kentucky University, 2001)
(B.S., Virginia Military Institute, 1998)

95 Typed Pages

Directed by Troy L. Best

Indiana bats (*Myotis sodalis*) have been the subject of numerous ecological studies, partly because they are endangered. A majority of research has focused on maternity colonies and relatively less is known about males. Previous research identified habitat and described fidelity of a population of male Indiana bats at South Goldson Cave, Pulaski Co., Kentucky. Mortality of pine trees (*Pinus*) following a large infestation of southern pine beetles (*Dendroctonus frontalis*) at the site provided an opportunity to gain insight into ecological requirements of male Indiana bats, and determine if availability of dead trees influences fidelity. This dissertation 1) provides a summary of the conservation and life history of Indiana bats, 2) identifies microhabitat characteristics of male Indiana bats using natural roosts, and northern long-eared bats (*Myotis septentrionalis*) using bat boxes, 3) identifies macrohabitat variables that influenced selection by Indiana bats, 4) determines if fidelity changed following the infestation of southern pine beetles, and 5) estimates how long roosts may remain suitable for use by bats. Most roosts were under exfoliating bark of dead pine trees, ca. 9 m from the ground, with sunny or partially shaded conditions. Bat boxes were used infrequently by northern long-eared bats (7 of 46 boxes), primarily during summer. Inadequate temperature regimes may have limited use of bat boxes to summer. Habitats selected by Indiana bats occurred in stands 1) dominated by pines with few 'other' trees present, and 2) with greater mean diameters at breast height, basal area, abundant dead hardwoods, and less abundant living hardwoods. Use of core areas over time was influenced by local availability of dead trees. Bats used pine trees as they became available following the infestation of southern pine beetles. Fidelity increased slightly during 2001-2003, but was statistically similar to data reported prior to the infestation. Roosts decayed over time; most pines were predicted to become unsuitable 2-7 years from the date they were used by bats, whereas hardwoods were predicted to remain suitable indefinitely. Used habitats likely provided warm temperatures that aided in thermoregulation. Abundant dead hardwood trees in habitats that were used by Indiana bats suggests that 1) bats use areas with many potential alternate roosts, and 2) hardwoods may have been used frequently before natural disturbances killed large numbers of pines. Although male Indiana bats used ephemeral roosts created by natural disturbance, bats showed fidelity to core areas as well as individual trees. Importance of natural disturbances to bats may depend on time intervals between disturbances.

ACKNOWLEDGMENTS

This project would have been extremely difficult if not for the support of many people. My wife, Deanne Moosman, deserves more credit than I will ever be able to show. More than just helping me track bats through rain, or carry bat boxes and concrete through a sea of thorns and fallen logs, she truly was my light at the end of this tunnel. I also thank Joe Metzmeier for his hospitality; all the hours spent sitting in front of those fires were well spent. Additionally, I am grateful for the help and friendship of Mark Gumbert and Brainard Palmer-Ball, Jr. who donated sweat and blood on many occasions to help capture and track bats. Also, I thank Joy O'Keefe for her companionship in the field and advice with Geographic Information Systems.

Numerous others deserve mention for help they provided in the form of assistance in the field, logistical support, or discussion of ideas, including John MacGregor, Jeremy White, Traci Hamberger, Price Sewell, Bill Moore, Tim Reed, Phillip Miller, Jim Bennet, Jerry Stevens, Tim Slone, Joel Beverly, Amy Covert, John Hunt, Gareth Turner, Charles Kilgore, Michelle Gilley, and Kerri White. Additional thanks are extended to Troy Best, Gary Hepp, and Robert Lishak, for their efforts to improve this research.

Funding was provided by the United States Forest Service, Southern Research Station, and Auburn University; additional support in the form of radiotransmitters or building materials was provided by East Kentucky Power Cooperative, Kentucky

Department of Fish and Wildlife Resources, and the Daniel Boone National Forest. This work was conducted as part of a graduate degree at Auburn University.

Style manual or journal used: Journal of Mammalogy

Computer software used: Arcview version 3.2, Microsoft Excel 2002, Microsoft Powerpoint 2002, Microsoft Word 2002, and SPSS version 10.0

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CHAPTER I

A REVIEW OF THE CONSERVATION AND LIFE HISTORY OF INDIANA BATS (*MYOTIS SODALIS*)

The Indiana bat (*Myotis sodalis*) was placed on the list of endangered species in 1967 following rapid and widespread declines in populations across most of its range (Clawson 2002). In 1960, the total population of Indiana bats was about 883,000; however, the population had declined to about 380,000 by 2001 (Clawson 2002). Original declines in populations were believed to have been caused by disturbances in hibernacula by humans (United States Fish and Wildlife Service 1999). However, populations have continued to decline despite construction of gates at most large hibernacula (Clawson 2002). Furthermore, populations of bats in northern and southern hibernacula have shown different rates of decline (Clawson 2002). These observations suggest that additional factors may be influencing current declines in populations, including loss of habitats used during the non-hibernation period, mortality due to pesticides, or consequences associated with small populations. Unfortunately, most of these issues have not been the subject of intensive investigation, with the possible exception of habitat used during the non-hibernation period.

Numerous studies have investigated summer habitat use by Indiana bats throughout their range (Callahan 1993, Callahan et al. 1997, Gardner et al. 1991, Gumbert 2001, Humphrey et al. 1977, Kurta et al. 1996), although most were descriptive in nature. Indiana bats occur throughout much of the eastern United States (Gardner and Cook 2002), but evidence of reproduction has occurred mainly in the Midwest (Clawson 2002), i.e., Illinois, Indiana, western Kentucky, southern Michigan, and Missouri (Gardner and Cook 2002). This region frequently has been referred to as the core range. Habitat in the region is often a mosaic of agricultural lands bordered by remnants of bottomland forest. Maternity colonies typically occur in patches of bottomland forests or fencerows, and individuals usually are captured while foraging or traveling along edges of agricultural fields (Gardner et al. 1991, Kurta et al. 2002). Although now dominated by extensive agricultural crops, much of the region would have been prairie before 1800 (Gardner and Cook 2002).

The importance of bottomland forests to female and young Indiana bats, combined with widespread destruction of wetlands, suggest that significant loss of habitat occurred before declines in populations were recognized during the 1960s. Also, large amounts of pesticides used throughout the core range of Indiana bats makes bioaccumulation of contaminants a potential threat. Geluso et al. (1976) and Clark and Rattner (1987) documented mortality in bats associated with specific contaminants. Additional sublethal effects have occurred in shrews (Braham and Neal 1974) and bats (Clark and Stafford 1981, Swanepoel et al. 1999), which are likely to decrease survival through winter (O'Shea and Clark 2002). Detectable levels of insecticides and other contaminants have been reported from bats in Missouri (Schmidt et al. 2002), including evidence of mortality of Indiana bats (during 1975-1978) due to insecticides (O'Shea and Clark 2002). Unfortunately, effects of contaminants on populations of Indiana bats have not been studied adequately. Clearly, greater investigation of various aspects of ecology, including habitat requirements and effects of contaminants, is needed throughout the range of Indiana bats.

Most studies of ecology of Indiana bats have focused on female and young bats during summer (Callahan et al. 1997, Carter 2003, Humphrey et al. 1977, Kurta et al. 2002). Relatively little is known about habits of male Indiana bats. Males congregate at hibernacula prior to arrival of females from summer maternity sites, a behavior known as swarming (Barbour and Davis 1969, Schowalter 1980). Several activities occur during the swarming period, including mating and accumulation of fat reserves for winter (Schowalter 1980, Thomson 1982). Hibernation occurs in >300 caves scattered throughout the eastern United States; however, colonies of >30,000 bats occur at 7 priority-1 hibernacula, in Indiana, Kentucky, and Missouri (Clawson 2002). Bats wintering in priority-1 hibernacula represent ca. 52% of the population (Clawson 2002). Hibernation occurs in caves and abandoned mines with a narrow range of temperature and humidity (Tuttle and Kennedy 2002).

Following hibernation, bats emerge in spring (Barbour and Davis 1969) and sexes begin roosting separately (Humphrey et al. 1977, Kurta et al. 1996). Female Indiana bats usually migrate to areas away from hibernacula to form maternity colonies (Barbour and Davis 1969, Kurta and Murray 2002, Mumford and Whitaker 1982). Maternity colonies of ≤384 bats have been documented (Gardner et al.1991, Humphrey et al.1977, Thomson 1982, M. Watson in litt.). Most males appear to roost in areas surrounding the hibernacula during spring, summer, and autumn; although a small proportion may leave and roost in unknown locations (Gumbert et al. 2002). Males typically roost alone or in small temporary groups of ≤3 bats (Gumbert 2001). Trees used by male Indiana bats tend to have smaller diameters at breast height than trees used by maternity colonies (6.4-86.6 cm---Gumbert 2001, J. R. MacGregor in litt., versus 18-108 cm---Callahan et al.1997, Kurta et al.1992, 1996, M. Watson in litt.). From one site in Kentucky, Gumbert (2001) and Gumbert et al. (2002) provided the most complete description of roosting behavior of male Indiana bats to date.

Roosts of both sexes usually occur under exfoliating bark or in cavities of dead or damaged trees (Brady et al. 1983, Gardner et al. 1991, Gumbert 2001, Humphrey et al. 1977, Kurta et al. 1992), as well as under bark of living trees (e.g., shagbark hickory, *Carya ovata*---Gardner et al. 1991, Gumbert 2001, Humphrey et al. 1977). Use of many species of trees has been documented (Callahan 1993, Gardner et al. 1991, Gumbert et al. 2002, Kurta and Whitaker 1998, Kurta et al. 1996) and selection of roosts seems to vary regionally. Although rare, Indiana bats have been reported to roost in manmade structures, including buildings (Butchkoski and Hassinger 2002), utility poles (V. Brack, pers. comm.), bridges (Barbour and Davis 1969), and bat boxes (Carter 2002). Important characteristics include temperature regime and protection from weather (R. Rommé et al. in litt.). Other characteristics such as proximity to alternate roosts also may be important (Humphrey et al. 1977). Like numerous species of bats that roost in dead or damaged trees, Indiana bats use an unknown number of trees and switch roosts every few days (Gumbert et al. 2002, Kurta et al. 2002).

Unfortunately, many aspects of the ecology of Indiana bats remain unknown. For example, how is gene flow among hibernacula achieved? In what portion of the population does most mortality occur? What is optimal habitat? How do Indiana bats respond to natural and anthropogenic disturbances? Do individuals maintain social bonds? Why do bats switch roosts? Until these kinds of issues are addressed, declines in populations of Indiana bats are likely to continue.

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CHAPTER II

USE OF HABITAT BY MALE INDIANA BATS (*MYOTIS SODALIS*)

ABSTRACT

The Indiana bat (*Myotis sodalis*) was placed on the list of endangered species in 1967 following rapid and widespread declines in population across most of its range. Most research has focused on maternity colonies and relatively little is known about males. Mortality of pine trees (*Pinus*) following a large infestation of southern pine beetles (*Dendroctonus frontalis*) provided an opportunity to gain insight into ecological requirements of male Indiana bats in Kentucky. My study described roosts used by male Indiana bats, attempted to determine if size of artificial roosts (bat boxes) influenced use by other species of snag roosting bats, and compared habitats used by Indiana bats with unused habitats at the site. Most roosts were under exfoliating bark of dead pines ca. 9 m from the ground and were positioned in sunny or partially shaded conditions. Bat boxes were used infrequently (7 of 46 boxes) by surrogate species (*Myotis septentrionalis* and *Eptesicus fuscus*), primarily during summer. Indiana bats used habitats 1) that were dominated by pines with few 'other' trees present, and 2) had greater mean diameters at breast height, greater basal area, more abundant dead hardwoods, and less abundant living hardwoods than random locations. Results indicated open, sunny conditions at roost trees are important, possibly for thermoregulation. This may explain selection of habitats with mature trees and open conditions. Abundant dead hardwood trees in used

habitats suggests 1) male Indiana bats use areas with many potential alternate roosts, and 2) hardwood trees may have been used frequently before natural disturbances killed large numbers of pine trees. Results add to a growing body of evidence suggesting Indiana bats may be adapted for savanna-like woodlands.

INTRODUCTION

The Indiana bat (*Myotis sodalis*) was placed on the list of endangered species in 1967 following rapid and widespread declines in populations across most of its range (Clawson 2002). Original declines in populations were believed to have been caused by disturbances of hibernacula by humans (United States Fish and Wildlife Service 1999). However, populations have continued to decline despite protection of most large hibernacula from intrusions by humans (Clawson 2002). Factors occurring during the non-hibernation period may be contributing to continued declines in populations of Indiana bats.

Numerous published and unpublished reports have investigated ecology of Indiana bats, but most were descriptions of roosts used by maternity colonies during summer (Callahan et al. 1997, Carter 2003, Humphrey et al. 1977, Kurta et al. 2002). Few studies have compared used versus unused habitats, and biology of male Indiana bats is less understood than that of females and young. Carter et al. (2002) and Gardner and Cook (2002) are the only published studies to have modeled use of habitat by Indiana bats. The study by Gardner and Cook (2002) used a geographic information system (GIS) to model habitat throughout the range of Indiana bats; Carter et al. (2002) modeled habitat of females in Illinois. Results of both studies indicated associations with relatively broad types of habitat (Carter et al. 2002, Gardner and Cook 2002). Gumbert

(2001) provided the only quantitative analysis of selection of habitat by male Indiana bats. Work by Gumbert (2001) and Gumbert et al. (2002) at South Goldson Cave, Pulaski Co., Kentucky, reported male Indiana bats roosted in core areas surrounding the hibernaculum. Unlike results from other parts of the range (Callahan et al. 1997, Carter 2003, Humphrey et al. 1977, Kurta et al. 2002), Indiana bats at South Goldson Cave roosted in dead pines (*Pinus*). Roosts primarily occurred on tops of ridges and slopes that were not steep, and were closer to the hibernaculum and ponds than random locations (Gumbert 2001). Variables such as availability of potential roosts, basal area, and tree diameter (dbh) were not assessed.

Characteristics of roosts of many species of bats appear related to maintaining sufficient, and stable, temperatures (Altringham 1999). This may explain why maternity colonies typically occur in roosts and climates that provide warm and stable temperatures, especially in temperate regions (Altringham 1999, Lourenço and Palmeirim 2004). For example, maternity colonies of Indiana bats often occur in trees with larger diameters than trees used by males (6.4-86.6 cm for males---Gumbert 2001, J. R. MacGregor in litt.;18-108 cm for maternity colonies---Callahan et al.1997, Kurta et al.1992, 1996, M. Watson in litt.), which are assumed to maintain more stable temperatures.

Similar trends have been observed using artificial roosts (bat boxes). Results of studies of other species of bats indicate that temperature and proximity to other roosts influence use by bats (Dillingham et al. 2003, Lourenço and Palmeirim 2004). Bat boxes have been constructed for several species of bats in North America, with mixed success (Carter 2002, Dillingham et al. 2003, Neilson and Fenton 1994). Indiana bats generally do not use bat boxes; however, at least one large colony was observed using a rocket-box style of artificial roost in Illinois (Carter 2002). Rocket boxes, a design with a continuous crevice around all 4 sides that mimics exfoliating bark, are used frequently by a sympatric species, the northern long-eared bat (*Myotis septentrionalis*; pers. observ.).

In 1999 and 2000, forests in Kentucky experienced an infestation of southern pine beetles (*Dendroctonus frontalis*) that killed many pine trees. Mortality of pines around South Goldson Cave was not quantified, although mortality was known to be high. Trees killed during the infestation were expected to create an abundant supply of roosts for male Indiana bats around South Goldson Cave. Combined with information from previous studies, the infestation of southern pine beetles provided an opportunity to gain insight into the ecology of male Indiana bats.

Objectives of this study were to identify factors associated with habitats of male Indiana bats. Two levels of habitat were assessed, including microhabitat (roosts) and macrohabitat (habitat surrounding roosts). Microhabitat was investigated using 1) natural roosts of Indiana bats and 2) an experiment involving rocket boxes and sympatric species as surrogates of Indiana bats. Macrohabitat was studied by comparing habitat surrounding roost trees to habitat surrounding locations not used by Indiana bats.

MATERIALS AND METHODS

The study area surrounds South Goldson Cave, a hibernaculum that supported ca. 317 Indiana bats in 1987, but contained ca. 185 Indiana bats during recent, semiannual, estimates of population size during midwinter (T. Wethington pers. comm.). A nearby cave (North Goldson Pit, Pulaski Co., Kentucky) is used sporadically as a night and day roost by Indiana bats, although not during hibernation. During the non-hibernation period, male Indiana bats roost in the forest surrounding the caves (Gumbert et al. 2002).

The study area is in the Mississippian Plateau and Pottsville Escarpment physiographic regions (Wharton and Barbour 1973). Topography is characterized by a relatively dense network of steep hills and valleys drained by tributaries of the Cumberland River. Cliff lines and rock overhangs are common along ridges, as are caves and sinkholes in valleys. Forests in the region are divided by the Pottsville Escarpment, with western mesophytic forest in the Mississippian Plateau and mixed mesophytic forest to the east (Wharton and Barbour 1973). Vegetation in valleys typically is mixed mesophytic forests; whereas, ridge tops and south-facing slopes support xeric forests dominated by oaks (*Quercus*) and pines (Wharton and Barbour 1973). Land surrounding South Goldson Cave and North Goldson Pit is part of the Daniel Boone National Forest, with scattered privately owned parcels that are mostly unforested (land belonging to the United States Forest Service = 64%; Gumbert 2001).

Efforts to capture Indiana bats were conducted in 5 periods during 2001-2004, including autumn 2001 (28-29 September), summer 2002 (30 June-27 July), and spring (12 April), summer (8-24 June), and autumn 2003 (1-5 October). Bats were captured using a harp trap (with plastic mesh) and mist nets outside of South Goldson Cave. A hand net also was used to capture bats at activity areas inside the hibernaculum and North Goldson Pit. The harp trap and plastic mesh were placed across the entrance of South Goldson Cave and mist nets (9 by 6 m) were erected ca.10 m in front of the cave. Additional attempts to capture Indiana bats were conducted during summer by erecting mist nets over ponds and road ruts on ridge-tops (n = 10) in the vicinity of the hibernaculum.

Mist nets were erected 15 min before sunset and operated until 5 h after sunset. Harp traps were erected before dark and operated until 10-12 Indiana bats were captured or until activity of bats decreased (typically 4-5 h after dark). Harp traps and mist nets were monitored every 5 min and all captured bats were weighed (to the nearest 0.25 g), sex and age were determined (adult or juvenile), and bands were attached (split-ring, rounded-lip, aluminum Kentucky Department of Fish and Wildlife Resources bands). Reproductive condition also was recorded (pregnant, lactating, post-lactating, or testes descended).

Male Indiana bats were fitted with a 0.54-g radiotransmitter (Model LB-2, Holohil Systems Ltd., Carp, Ontario, Canada) using surgical adhesive (Skin-bond Cement, Smith and Nephew, Inc., Memphis, Tennessee), then released at site of capture. When selecting bats for attachment of radiotransmitters, priority was given to Indiana bats that had been tracked previously by Gumbert et al. (2002) or during the present study. Bats were tracked to their roost trees each day using a 3-element Yagi antenna and radioreceiver (Model TRX-1000, Wildlife Materials, Carbondale, Illinois) until transmitters were shed (i.e., 10–17 days).

Roost trees were plotted using handheld GPS units (GlobalMap 100, Lowrance Electronics Inc., Tulsa, Oklahoma) and 7.5-minute topographic maps, then marked with numbered aluminum tags, and blue rings were painted around trunks. Trees were identified to species using bark characteristics (when possible), and classified as living, living-damaged, or dead. New roost trees were inspected to determine most likely cause of death (southern pine-beetle versus other). Trees with evidence of damage by southern pine beetles (pitch tubes or S-shaped tunnels and pupal chambers under the bark; United States Department of Agriculture 1981) were assumed to have been killed during the infestation; trees without evidence of damage by southern pine beetles were classified as "other." Additionally, diameter at breast height (dbh) was measured using a diameter tape (to the nearest 0.1 cm) and height of tree was visually estimated (to the nearest meter). Height of bats relative to the ground was estimated using a Yagi antenna while standing 7-10 m from the tree. Telemetric estimates of height were confirmed by visual identification of bats using a mirror and binoculars whenever possible. Solar exposure at height of each roost was estimated visually (shaded, intermediate, or sunny) because canopy coverage at ground level did not accurately reflect this characteristic (Gumbert 2001).

Bat boxes (n = 46) were constructed of rough-cut, tulip poplar (*Liriodendron tulipifera*), using a design modified from J. R. MacGregor and D. Dourson (in litt.; Fig. 1). Wooden portions of roosts were mounted to 3-m-long metal poles (3 cm

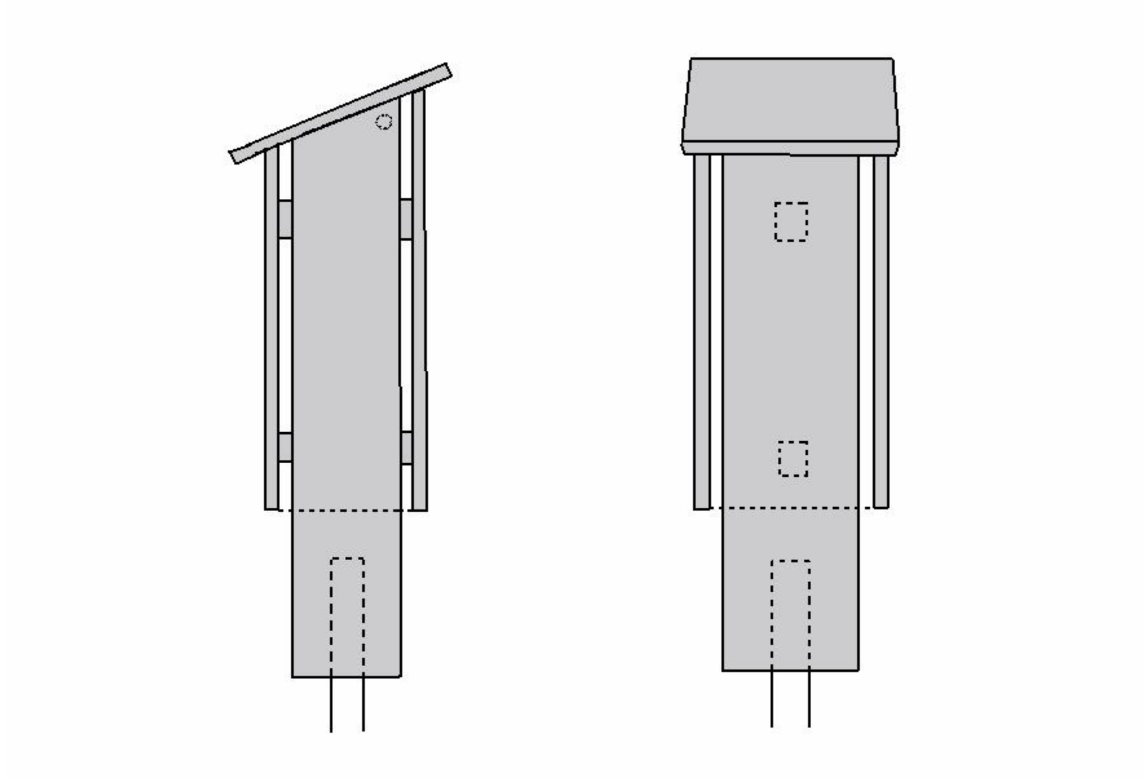

Fig 1. Diagram of bat boxes constructed of rough-cut tulip poplar (*Liriodendron tulipifera*) mounted to 3 cm or 6 cm diameter rigid conduit. Roosts were modified from a design by D. Dourson and J. R. MacGregor (in litt.).

or 6 cm diameter rigid conduit) and anchored in the ground with 27-kg of concrete. Centers of roosts were constructed using large (15 by 15 cm) or small (10 by 10 cm) 1-m-long wooden posts. Walls were constructed from 4-cm-thick by 83-cm-long wooden planks that were mounted to center-posts, leaving a 2-cm-wide cavity around center-posts for bats to roost. Pitched wooden roofs (22.5° angle; 4-cm thick) were attached to the tops of each box to exclude precipitation.

Large ($n = 23$) and small ($n = 23$) boxes were paired 2-m apart with entrances 3.3 m from the ground. Pairs of boxes were arranged into groups with each pair spaced 15-m apart. Boxes were placed at Double Tarkiln Ridge (<1 km from South Goldson Cave) and Goodwater (a reclaimed strip mine ca. 64 km northeast of South Goldson Cave, Pulaski Co., Kentucky) from August 2002 through October 2004. Surveys of boxes were conducted during April, June, and October 2003, and March and October 2004 to document use by bats. Use of artificial roosts by bats was determined by presence of guano at bases of roosts and by visually inspecting cavities for bats (using a small mirror to reflect sunlight into cavities). When possible, numbers and species of bats were recorded, or amounts of guano were estimated (low, moderate, or high).

Data describing macrohabitat characteristics were collected from the area surrounding 64 roost trees using a 10-factor prism (Avery 1967), while standing 1 m from the roost (Gumbert 2001). Nearby trees that were not fully displaced using the prism were counted, identified to species, classified as living or dead, measured using a diameter tape, and basal area of the habitat surrounding each roost was calculated (Avery 1967). Dead pines were classified according to cause of death (pine beetle or other). The same methods were used to describe the study area, using 10 randomly placed transects (ca. 200-250-m long), during July 2002. Transects were placed within a 5-km radius of the hibernaculum and each contained 6-8 evenly spaced non-overlapping points where data were collected (n = 63). Transects occurred outside of core areas identified by Gumbert et al. (2002).

Logistic-regression models were used to identify characteristics of macrohabitat that explained significant amounts of variation in use of habitat by Indiana bats. Related variables were separated into 2 suites of variables, including abundance of trees of different genera (numbers of pines, oaks, hickories, maples [*Acer*], or 'other'), and characteristics of nearby trees (basal area, numbers of dead pines, living pines, dead non-pines, and living non-pines). A separate logistic-regression model was used to analyze each suite of variables. Significant variables were identified using the backwards-elimination procedure, which selected variables that improved the predictive accuracy of logistic-regression models and excluded those that did not (∀ of removal = 0.05). Analyses were conducted using SPSS 10.0 at ∀ = 0.05 (Green et al. 2000).

RESULTS

Bats captured and banded at the entrance and inside of South Goldson Cave and North Goldson Pit included the Rafinesque's big-eared bat (*Corynorhinus rafinesquii*; *n* = 11), big brown bat (*n* = 7), eastern red bat (*Lasiurus borealis*; *n* = 1), little brown bat (*n* = 117), northern long-eared bat (*n* = 144), Indiana bat (*n* = 48), evening bat (*Nycticeus humeralis*; *n* = 1), and eastern pipistrelle (*Pipistrellus subflavus*; *n* = 155). In general, the same species of bats captured at caves also were captured over ponds, except no little brown bats or Indiana bats were caught, and relatively few eastern pipistrelles were caught. Bats captured over ponds included the Rafinesque's big-eared bat (*n* = 1), big brown bat (*n* = 13), eastern red bat (*n* = 7), northern long-eared bat (*n* = 91), evening bat (*n* = 1), and eastern pipistrelle (*n* = 4).

Male Indiana bats were captured (*n* = 34), equipped with radiotransmitters (*n* = 31), and located (*n* = 25) during 4 sampling periods (Table 1). Female Indiana bats (*n* =15) were captured using a hand net during spring and autumn 2003, but were not equipped with radiotransmitters because females typically enter hibernation earlier than males (Brady et al. 1983, J. R. MacGregor in litt.) or migrate from the study area following hibernation (Gumbert 2001). Success in capturing bats varied seasonally, with relatively low success during summer (Table 1).

Table 1. Number of male Indiana bats (*Myotis sodalis*) captured, equipped with radiotransmitters, and successfully located ≥1 bat day [a], Pulaski and McCreary counties, Kentucky, 2001-2003.

Tracking period	Captures	With radiotransmitters	Located
Autumn 2001	10	9	7
Summer 2002	5	5	5
Spring 2003 [b]	11	9	7
Summer 2003	0	0	0
Autumn 2003	9	9	7
Total	34	31 [c]	25 [c]

[a] A bat day represents 1 bat located during 1 day.

[b] Radiotransmitters were not affixed to 2 bats because of low body weights (radiotransmitters weighed >9% of body weight).

[c] Included a bat that was radiotracked twice (autumn 2001 and 2003).

Male bats were observed using 87 roost trees on 256 occasions. Pines were the predominant trees used by bats, but relative proportion of trees appeared to vary seasonally, with lowest use of pines occurring in spring 2003 (Table 2). Bats roosted alone or in small groups (2-3 bats), usually in dead trees (92% of roosts were dead; Appendix 1). Most (n = 74 of 87) roost sites were under exfoliating bark. Other roost sites were in boles of trees that were splintered at the top (n = 3), crevices (n = 1), or unknown locations (n = 5). Average height of roost sites was 9 ± 0.5 m (range = 3-21 m; Appendix 1). Individuals that roosted lower to the ground were easier to confirm visually than those higher up. Seventeen roosts were confirmed, but no bat was seen >12 m from the ground. Locations where bats roosted on trees usually had sunny (n = 49 of 81 roosts) or intermediate (n = 22) exposure to sunlight; relatively few (n = 10) were shaded.

Northern long-eared bats were the only species observed using artificial roosts; however, some large-sized guano underneath roosts suggested use by big-brown bats. Use of artificial roosts by bats was limited to 1 large roost (of 21 roosts available) in April 2003, and 5 small and 1 large roost (of 21 roosts available) during June 2003. Solitary bats were observed roosting in 3 roosts and moderate amounts of guano were observed under the remaining 4. No additional evidence of use was observed during subsequent surveys. Statistical analysis was not performed due to the large number of roosts (n = 39 of 46) that were not used by bats.

Data collected at points along random transects in summer 2002 indicated the forest surrounding South Goldson Cave was 33 ± 3% oaks, 18 ± 3% pines, 16 ± 2% maples, 11 ± 2% hickories, and 23 ± 3% other (Appendix 2). Twenty percent (106 of 539) trees surveyed were dead. Pines were the most abundant species of dead trees

Table 2. Species of trees used as roosts by male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, 2001–2003. Usage is expressed as number of trees used and percentage of the total number of trees used (in parentheses) within each radiotelemetric monitoring period.

Taxa	Autumn 2001	Summer 2002	Spring 2003	Autumn 2003	Total
Acer rubrum	1 (3%)		1 (5%)		2 (3%)
Carya ovata	1 (3%)		2 (10%)		3 (5%)
Pinus	20 (69%)	9 (100%)	14 (67%)	27 (96%)	70 (72%)
rigida	4			2	6
echinata	14	8	11	24	57
virginiana	2	1	3	1	7
Quercus	6 (21%)		2 (10%)	1 (4%)	9 (15%)
alba	1		1	1	3
borealis	3		1		4
velutina	2				2
Fraxinus	1 (3%)				1 (2%)
Unknown			2 (10%)		2 (3%)
Total	29	9	21	28	87

(92%, 97 of 106) compared to non-pines (8%, 9 of 106). Nearly all pines were dead (93%, 97 of 104); however, 59% (57 of 97) of those appeared to have been killed by southern pine beetles and 41% (40 of 97) showed no evidence of damage from pine beetles. Overall, 55% (57 of 104) of all pines appeared to have been killed by pine beetles.

Logistic-regression analysis indicated that roost trees occurred in macrohabitats (Appendix 3) that differed from random locations in the study area (Table 3). Specifically, analysis using abundance of 5 categories of tree species (model 1; Table 3) indicated bats roosted in habitats that were dominated by pines and had fewer ‘other’ trees present (Fig. 2). ‘Other’ trees included numerous species, many of which were common in the understory or were not associated with xeric ridges (e.g., *Liriodendron tulipifera*, *Liquidambar styraciflua*, *Prunus*). Used and available locations were classified correctly 68% of the time using this model. Other macrohabitat variables also were associated with used locations, including mean dbh, basal area, numbers of dead non-pines, and numbers of living non-pines (model 2; Table 3). Bats roosted in habitats with greater numbers of dead non-pines (Fig. 3), mean dbh, and basal area, than unused locations. Also, used habitats were negatively associated with living non-pines (Fig. 4). Locations were classified correctly 81% of the time using this model.

Table 3. Variables associated with locations that were used by Indiana bats (*Myotis sodalis*), compared to unused locations, using two logistic-regression models, Pulaski and McCreary counties, Kentucky, 2001-2003 [a].

Model	Variable [b]	β	W [c]	*Log odds*	P
1					
	Pine	0.33	14.06	1.39	≤ 0.001
	Other	-0.28	4.89	0.75	≤ 0.027
	Constant	-0.44	1.84	0.64	≤ 0.644
2					
	Mean dbh	0.01	7.24	1.10	≤ 0.007
	Basal area	0.04	13.73	1.04	≤ 0.001
	Dead non-pine	1.35	8.97	3.87	≤ 0.003
	Living non-pine	-0.57	23.84	0.56	≤ 0.001
	Constant	-3.90	7.08	0.02	≤ 0.008

[a] n = 127 locations (63 unused versus 64 used).

[b] Statistics are only given for variables that were included in the final models (using backwards elimination with α of removal = 0.05).

[c] Wald statistic---a measure of the relative importance of variables in the model.

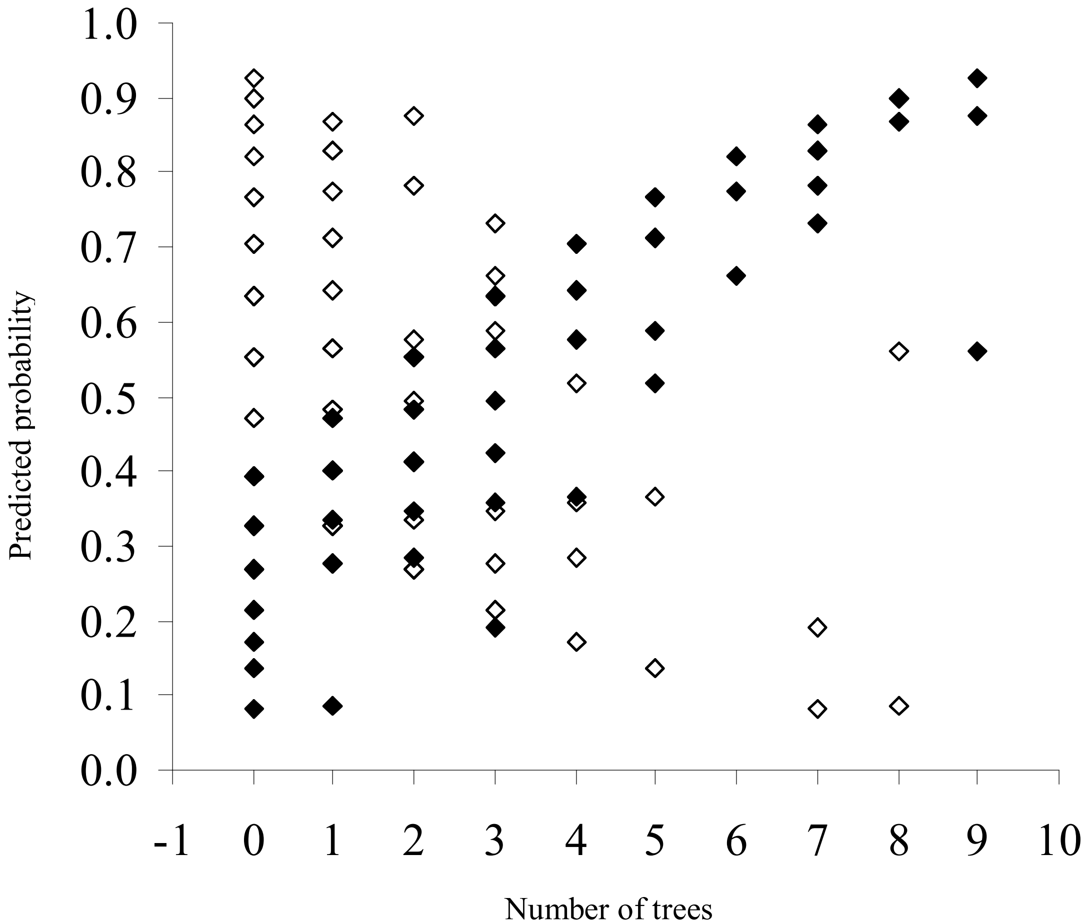

Fig. 2. Effects of abundance of pines and 'other' trees on predicted probability of locations being used by male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, 2001-2003. Number of pines and 'other' trees at locations are indicated by solid and open marks, respectively (n = 127 locations, 63 unused versus 64 used).

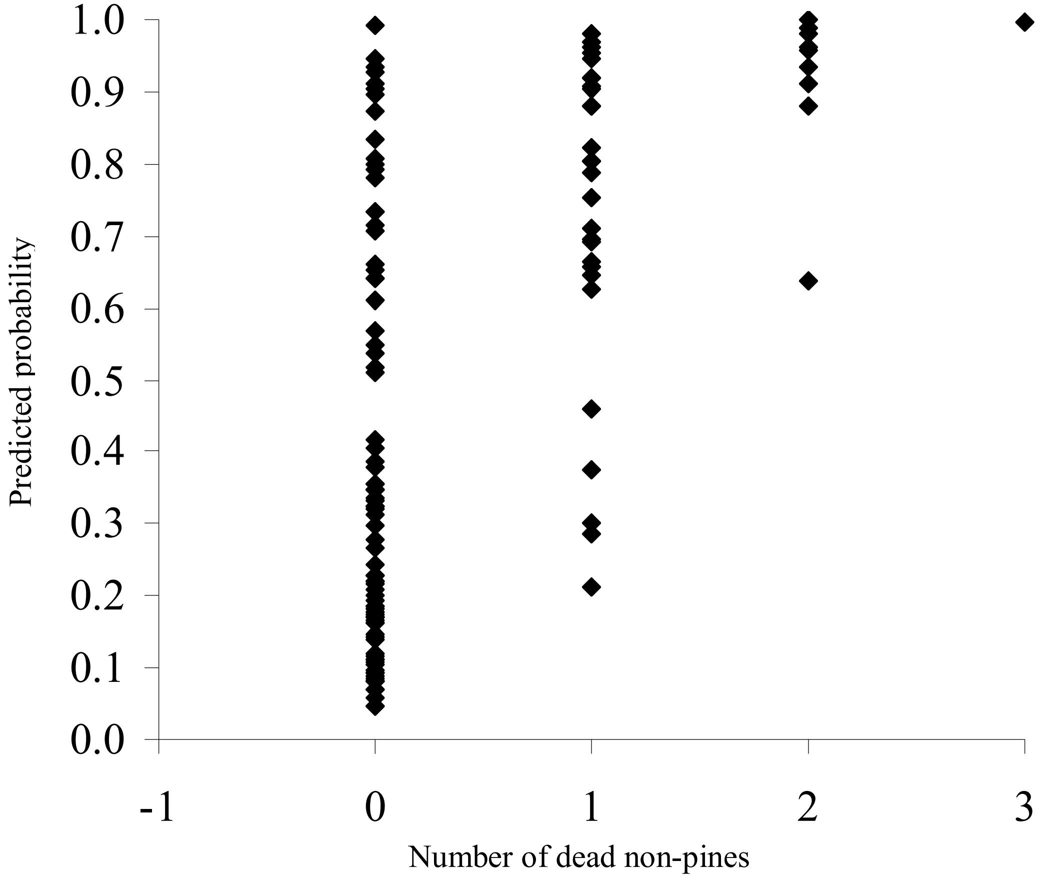

Fig. 3. Effect of availability of dead non-pine trees on predicted probability of locations (n = 127 locations, 63 unused versus 64 used) being used by male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, 2001-2003.

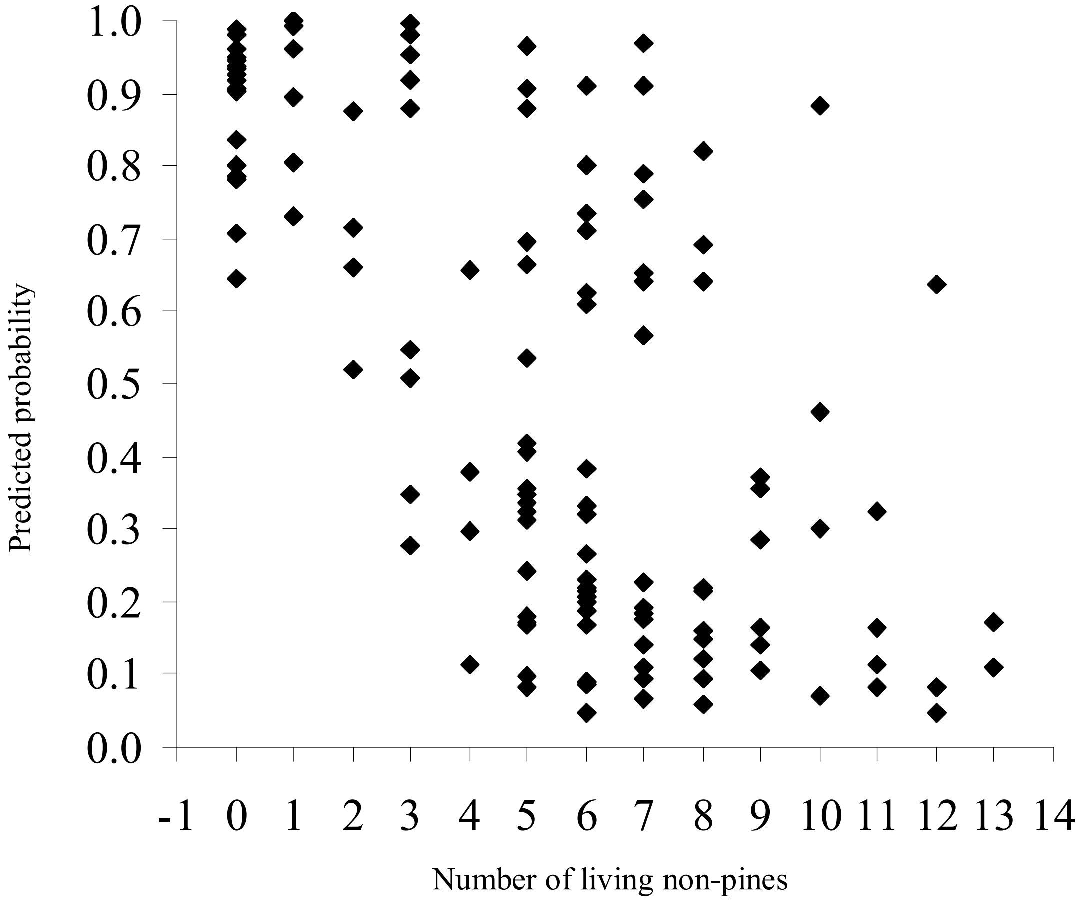

Fig. 4. Effect of abundance of living non-pine trees on predicted probability of locations (n = 127 locations, 63 unused versus 64 used) being used by male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, 2001-2003

DISCUSSION

Previous researchers (Gumbert 2001, J. R. MacGregor in litt.) did not report number of bats captured at caves versus over ponds, but overall proportions of species I captured appeared similar to results of (Gumbert 2001), with a single exception. Success in capturing Indiana bats has decreased steadily from initial sampling conducted in 1996 (J. R. MacGregor and M. W. Gumbert pers. comm., the present study). For example, Gumbert (2001) averaged 14 ± 6 Indiana bats/sampling period versus 7 ± 3.6 bats/sampling period during the present study. This difference occurred despite identical methods and equal trap efforts. Decreased success in capturing Indiana bats at South Goldson Cave likely was related, in part, to declining numbers bats that hibernate in the cave. Mid-winter estimates of population at South Goldson Cave suggest a 58% decline from 1987-2003 (Fig. 5; data provided by T. Hamberger and J. R. MacGregor, Kentucky Department of Fish and Wildlife Resources). This trend was similar to declines in populations of Indiana bats throughout the Daniel Boone National Forest (J. R. MacGregor pers. comm.).

Reasons for declines in populations of hibernating bats at caves throughout the Daniel Boone National Forest remain unknown. However, frequent use of caves by spelunkers and vandals remains a potential threat. At South Goldson Cave, evidence of visits by the public was abundant, including trash around the entrance, fresh footprints inside the cave, and construction of an illegal path to the cave (for all-terrain-vehicles).

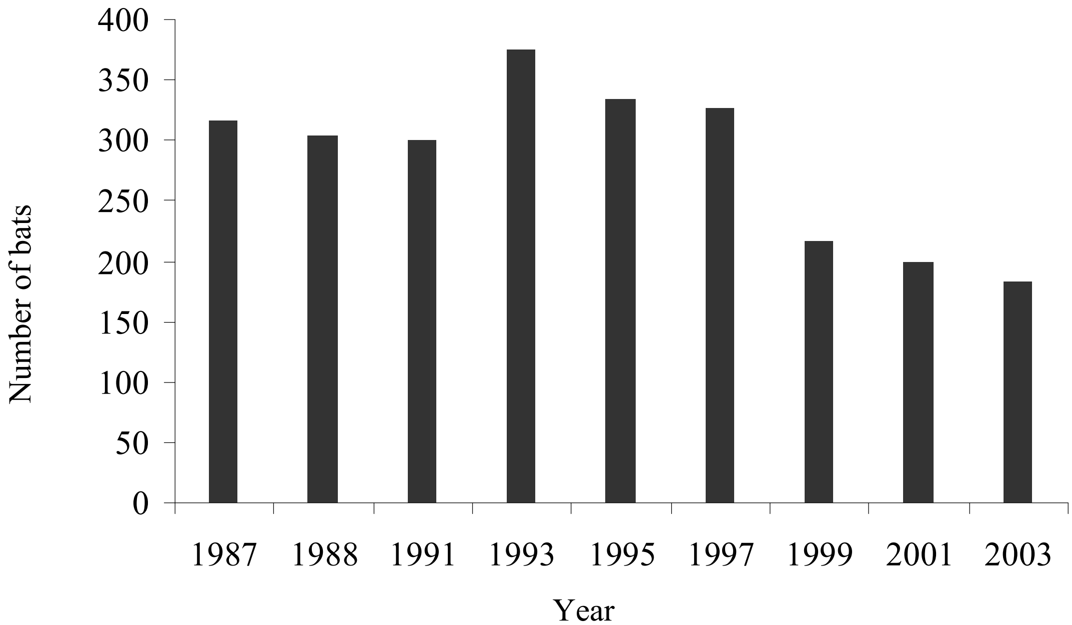

Fig. 5. Declining numbers of Indiana bats (*Myotis sodalis*) hibernating at South Goldson Cave, Pulaski Co., Kentucky, 1987-2003 ($r^2 = 0.50$, $\beta = -8.4$, $F = 6.96$, $d.f. = 1, 7$, $P \leq 0.034$. Data were provided by T. Hamberger and J. R. MacGregor, Kentucky Department of Fish and Wildlife Resources.

Disturbances in the cave likely occurred throughout the year, including during hibernation.

In addition to population declines, yearly and sometimes seasonal efforts by researchers to capture bats at South Goldson Cave during 1994-2003 probably contributed to lower capture success during the present study. Assuming the population of male Indiana bats at South Goldson Cave was 50% of the most recent mid-winter estimates (ca. 185 bats), $\leq$92 male bats may have been present during the non-hibernation period. Given the frequency that South Goldson Cave was sampled from 1994-2003, many of these bats may have encountered the harp trap and learned to avoid capture.

Evidence suggests that Indiana bats were not adversely affected by intensive banding and radiotelemetry. Of 38 Indiana bats captured during this study, 19 (50%) were recaptured on $\geq$1 occasion. Several bats (n = 5) received the added disturbance of being equipped with radiotransmitters during $\geq$1 radiotelemetry period prior to this study, including 1 bat that was tracked 5 times from October 1998 through September 2002 (Gumbert 2001, M. W. Gumbert pers. comm., Gumbert et al. 2002). During the present study, this particular bat was recaptured in a mist net and equipped with a radiotransmitter on 2 October 2003, and recaptured at South Goldson Cave 3 nights later. To my knowledge, this bat has been recaptured (n = 6 times) and located (n = 6 periods) more times than any other Indiana bat. These data support results by Kurta and Murray (2002), who reported relatively high rates of recapture.

Characteristics of roost trees were similar to those reported by Gumbert (2001), where bats roosted in pine trees that had full or intermediate exposure to sunlight. Although roosts were in uplands and most occurred in pines, versus hardwood trees in bottomlands, results supported trends in other regions where roosts typically occur in sunny microhabitats (Callahan 1993, Callahan et al. 1997, Gardner et al. 1991, Humphrey et al. 1977, Kurta et al. 1996). This supports the hypothesis that warm microclimates are important to many species of bats in temperate regions (Altringham 1999, Lourenço and Palmeirim 2004), including Indiana bats (Humphrey et al. 1977), and may explain why artificial roosts were occupied mostly during summer.

Selection of habitat by male Indiana bats provides more evidence to suggest the importance of temperature regime to roosting bats. Bats may have roosted in stands that were dominated by pines and had few species of trees common in the understory because of open, sunny conditions in those stands. In Kentucky, habitats dominated by pines typically occur on xeric ridges (Wharton and Barbour 1973), where Gumbert (2001) determined male Indiana bats were most likely to occur. Selection of habitats with greater average dbh, greater basal area, and few living hardwood trees, may have contributed to warm and stable temperatures at roosts.

Where male Indiana bats forage in relation to core areas is not available in published literature. Females and juveniles may forage <1-2.5 km of roosting sites, along edges of woodlots, and stream and road corridors (Brady et al. 1983, Humphrey et al. 1977, Mumford and Cope 1958). During the present study, 1 male bat was monitored and remained in the vicinity (ca. ≤ 1.5 km, i.e. within range of the radiotransmitter) of its core area throughout the night. Given foraging habitats used by female Indiana bats in other parts of the range, male bats likely foraged along roads and openings in the forest, or along the edges of canopy trees. Conceivably, conditions in core areas may have made them suitable places to forage.

Predominant use of pine trees by male Indiana bats at this site appears related to relative abundance of dead pines. Many dead pines showed evidence of having been killed by southern pine beetles, although, this estimate was lower than expected based on early estimates of 85% from the United States Forest Service. Differences between estimates may have been due to large numbers of pine trees that were killed by a storm in 1994 (Gumbert 2001). Number of pine trees killed during 1994 is not known, but some of the dead pines observed during my study were probably killed prior to the infestation of 1999-2001. The trend of increased use of pines observed during 1996-2003 suggests that Indiana bats used dead pine trees as they became available following both natural disturbances.

Habitats used by Indiana bats contained greater numbers of potential roosts than unused locations, specifically dead hardwood trees. This occurred despite the fact that hardwood trees were seldom used as roosts. Indiana bats in other parts of the range typically roost in hardwoods (Brady et al. 1983, Callahan et al. 1997). Perhaps, the population at South Goldson Cave roosted in hardwoods more frequently before natural disturbances provided an abundance of dead pines. More specifically, bats may have remained in core areas that previously were dominated by dead hardwoods, but used dead pine trees as they became more abundant. Data describing roosting behavior of bats at the site are not available prior to 1996; however, increased use of pine trees during 1996-2003 suggests, indirectly, that pines may have been used by bats less often prior to 1996.

In summary, my study supports descriptions of microhabitat from other parts of the range of Indiana bats. Additionally, habitats with open, sunny conditions, with greater average dbh, and abundant dead trees were more likely to be selected by male

Indiana bats. Natural disturbances created an abundant supply of dead pine trees that were used by bats. Although bats predominantly roosted in pine trees, dead pine trees were just as abundant in unused habitat as in habitats selected by male Indiana bats. Selection of habitats with abundant dead hardwood trees hints that hardwoods may have been important components of habitat prior to recent natural disturbances.

Declining numbers of Indiana bats at South Goldson Cave underscore the continued need to protect hibernacula and identify other factors contributing to range-wide trends. Indiana bats clearly are susceptible to disturbances during winter (Brady et al. 1983). Relatively high rates of capture at the hibernaculum during autumn and spring suggest these seasons may also be important, especially to males. Land around hibernacula should be managed to provide habitats with open sunny conditions, with relatively mature trees, and large numbers of dead trees, especially hardwoods. My results add to a growing body of evidence that suggests Indiana bats are adapted for savanna-like woodlands.

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CHAPTER III

FIDELITY OF MALE INDIANA BATS (*MYOTIS SODALIS*) FOLLOWING A LARGE-SCALE NATURAL DISTURBANCE

ABSTRACT

Indiana bats (*Myotis sodalis*) have been the subject of numerous ecological studies, partly because they are endangered. Fidelity of male Indiana bats has been studied at South Goldson Cave, Pulaski Co., Kentucky. The term fidelity often is used to describe how frequently bats switch roosts, but is not always defined in enough detail to permit comparisons among populations. Mortality of pine trees following a large infestation of southern pine beetles (*Dendroctonus frontalis*) provided an opportunity to gain insight into environmental factors that are believed to influence fidelity. I investigated behavior of Indiana bats at South Goldson Cave following the same methods used in previous studies that were conducted prior to the infestation. Goals of the present study were to 1) describe changes in behavior of male Indiana bats over time and 2) estimate how long dead trees may remain available to bats. Bats used pine trees as they became available following the infestation. Results suggest availability of standing dead trees influenced continued use of core areas, but had little to no effect on fidelity to individual trees. Roosts decayed over time; most pines were predicted to become unsuitable 2-7 years from the date they were used by bats, while hardwoods remained suitable indefinitely. Rapid decay of pine trees relative to hardwood trees supports the

hypothesis that hardwoods may have provided more permanent, although less abundant, roosts. Natural disturbances may provide an abundant local supply of roost trees, however long term effects on populations of male Indiana bats would depend on the duration of intervals between disturbances.

INTRODUCTION

Numerous species of vertebrates use more than one shelter and periodically switch shelters (Behrends et al. 1986, Morrison and Caccamise 1985), including many species of bats (Lewis 1995). Fidelity is a term often used to describe how frequently bats switch roosts (Lewis 1995). However, concepts of fidelity vary and the term is not always defined explicitly (Gumbert et al. 2002); this can prohibit comparisons among studies. The Indiana bat (*Myotis sodalis*) is a useful vessel to study factors that may influence fidelity of bats that roost in ephemeral structures.

The Indiana bat is an endangered species that typically roosts under the bark of dead trees (United States Fish and Wildlife Service 1999). As with other species of bats, Indiana bats use multiple roosts and switch roosts every few days (Gumbert et al. 2002, Humphrey et al. 1977, Kurta et al. 2002). Movements between roosts sometimes occur when trees are destroyed or become less suitable due to changing environmental conditions (Gumbert et al. 2002, Humphrey et al. 1977). However, bats also switch roosts for reasons apparently unrelated to weather (Lewis 1995).

Lewis (1995) quantified patterns of roost switching among 43 species of bats and observed that the lowest degree of fidelity occurred in species that roosted in ephemeral or abundant structures. These results were independent of phylogeny, and indicate that different modes of fidelity may be a result of natural selection. If fidelity is an adaptive response to environmental conditions, one might expect to observe variation in fidelity within a species. Changes in fidelity observed in conjunction with changing environmental conditions would support hypotheses discussed by Lewis (1995). Specifically, an increase in availability of roost trees should result in decreased fidelity.

Recent events in the Daniel Boone National Forest, Kentucky, provided a unique opportunity to understand how habitat characteristics during the non-hibernation period may influence fidelity of male Indiana bats. Kentucky has 2 priority-1 hibernacula (>30,000 hibernating bats; United States Fish and Wildlife Service 1999). However, Indiana bats hibernate in several smaller colonies throughout the state (B. Palmer-Ball, Jr. pers. comm.). Fidelity of male Indiana bats has been studied at a small hibernaculum, South Goldson Cave, Pulaski Co., Kentucky, since 1996 (Gumbert et al. 2002).

Land surrounding the cave is located in Pulaski and McCreary counties, Kentucky, in the Somerset Ranger District of the Daniel Boone National Forest. Research conducted by J. R. MacGregor (in litt.) and Gumbert (2001) revealed that Indiana bats at South Goldson Cave roosted in several species of trees, but pines (*Pinus*) were used most often (Gumbert 2001, J. R. MacGregor in litt.). Bats switched roosts often, but most days were spent roosting in core areas scattered around the hibernaculum (Gumbert et al. 2002). The study by Gumbert et al. (2002) was unique in that data were collected from many bats (n = 60), and some bats (n = 16) were tracked for multiple seasons or years.

Beginning in 1999 and peaking in 2000, the Daniel Boone National Forest experienced an infestation of southern pine beetles that killed large numbers of trees. Previously, pines were a dominant overstory species (Gumbert 2001). High mortality of pines was likely to influence the bat community in the Somerset Ranger District;

however, specific effects could not be predicted. Increased numbers of dead pines were expected to provide a temporary abundance of potential roosts around South Goldson Cave. I hypothesized that pine trees killed during the infestation would deteriorate at similar rates and might become unsuitable for use as roosts around the same time. Depending on how quickly roosts deteriorated and availability of alternative roosts, bats could experience a shortage of roosts. Unfortunately, little is known about dynamics of deterioration and replacement of standing dead trees (snags) and the effects on fidelity of bats.

Changes in abundance of dead pines at the site were expected to influence several species of bats that roost in dead trees, including; Indiana bats, little brown bats (*Myotis lucifugus*), northern long-eared bats (*Myotis septentrionalis*), and big brown bats (*Eptesicus fuscus*). In addition to influencing distribution of potential roosts, changes in structure and dominance of overstory trees was likely to influence distribution and abundance of insect prey. Distribution of food also may influence selection of roosts by bats, although the trend has not been demonstrated in insectivorous bats (Lewis 1995). Effects of changes in distribution and abundance of insect prey at the study site would be difficult to detect and predict. Identification of digested insects is limited to course taxonomic groups, and no baseline data existed at South Goldson Cave. Thus, the present study focused on aspects of fidelity directly related to abundance and distribution of roosts.

Major objectives of the current study were to determine if bats used trees killed during the infestation of southern pine beetles, and to determine if use of core areas and fidelity to individual roosts were influenced by increased abundance of potential roosts.

Specifically, I hypothesized that increased availability of potential roosts following the infestation would result in 1) increased use of pine trees, 2) changes in locations of core areas, and 3) decreased fidelity to individual roosts. Another goal was to measure rates of deterioration of roosts to estimate how long trees may remain available to bats.

MATERIALS AND METHODS

Bats were captured using harp traps and mist nets, and tracked via radiotelemetry (Chapter II) using the methods of studies conducted prior to the infestation (Gumbert 2001, Gumbert et al. 2002). Roosts were plotted and marked (Chapter II) and coordinates of roosts were incorporated into a geographic information system (GIS). Radio telemetry locations were analyzed using a fixed kernel (Powell 2000) to identify home range (95% contour) and core areas (50% contours) using the animal-movement extension (Hooge and Eichenlaub 2000) to Arcview 3.2 (Environmental Systems Research Institute, Redlands, California). Kernel estimates are based on the geographic distribution of radio telemetry locations and frequency that locations are used (Powell 2000). Estimates are expressed as contours, which represent the percentage of maximum probability a given location will occur in a homerange (Powell 2000).

Bats sometimes roosted in undetected locations before moving back to trees that allowed radiotelemetric detection. When this happened, bats were either too far from the study area to be detected, or were hidden by landscape features that made detection unlikely (e.g., ridges, steep valleys, caves). I argue that these movements are meaningful and should be considered when estimating fidelity. Thus, fidelity estimates for individual bats were calculated by dividing number of days a bat could be accounted for by number of movements observed during that period. In some cases, recorded movements included instances when bats moved from documented roosts to unknown locations. This approach was used to describe changes in fidelity during the present study (2001-2003). J. R. MacGregor (in litt.) used the same method to calculate fidelity during his work at South Goldson Cave during 1996-1997, but reported average values. Thus, comparisons between studies had to be conducted using a less accurate method of calculating fidelity (number of days bats were located divided by number of trees located). This method fails to take into account instances when bats move to unknown locations, but allowed combining of results for 1996-1997 and 2001-2003. Fidelity data from 1998-1999 (Gumbert et al. 2002) were not reported in a format that allowed comparisons.

Subsamples of roost trees (n = 59) identified during this study or by Gumbert et al. (2002) were revisited during spring and autumn 2003 and spring and autumn 2004 to determine how long trees remained suitable for use by bats. Trees that were still standing with bark or crevices were considered suitable for use as roosts; trees on the ground or standing with no obvious bark or crevices were considered unsuitable for use as roosts. Time was measured in months from the date a tree was first located until the tree was observed as unsuitable. If a tree remained suitable, time was measured as number of months from the date first located until the most recent survey.

Three linear-regression models were used to detect potential changes in roosting behavior over time. One model determined if Indiana bats used increasing proportions of pines during 1996-2003, using average values from J. R. MacGregor (in litt.), Gumbert (2001), and the present study. The remaining 2 models were used to determine if fidelity changed over time. Specifically, potential changes in fidelity (number of days a bat was observed divided by number of movements that were observed) during 2001-2003 were plotted using 1 model, and a separate regression model was used to plot fidelity (number of days bats were located divided by number of trees that were located) for 1996-1997 and 2001-2003. Additionally, logistic-regression analysis was used to determine probability of roosts remaining suitable over time. Variables included suitability of roosts (0 = unsuitable, 1 = suitable) as the dependent variable and age (months since located by a researcher) and type of roost (0 = non-pine, 1 = pine) as independent variables. Logistic-regression models were constructed using the backwards-elimination method, with variables selected based on α of removal = 0.05. Predicted probabilities of trees remaining suitable over time were generated from logistic-regression models (Green et al. 2000). Analyses were conducted using SPSS 10.0 (Green et al. 2000) at $\alpha = 0.05$.

RESULTS

Average distance between roost trees was 644 m and maximum distance was 8.5 km. Fixed-kernel analysis using 24 bats located in a total of 256 days indicated 3 core areas (2 discrete core areas; Bat Ridge and Double Tarkiln Ridge/Bauer) that were centered <2 km from South Goldson Cave (Fig. 6). The Bauer core area was used more frequently by bats during the present study than during Gumbert et al. (2002); likewise, Bethel Church and Yellowjacket were identified by Gumbert et al. (2002), but were not used as core areas during the present study. Roost trees in Yellowjacket (n = 20) were revisited in 2003 and only 2 living shagbark hickories (*Carya ovata*) were observed standing. Remaining roost trees in Yellowjacket had either fallen (n = 8) or were not found (n = 10).

In general, bats moved to new roosts every 2-5 days (Fig. 7). Some trees (n = 5) were used by >1 bat during the same radiotelemetry period (Appendix 3). Vocalizations from roosting bats, as well as observations made visually and using radiotelemetry, indicated bats sometimes used trees simultaneously (in groups of ≤3 bats). Several trees (n = 4) were used as roosts during previous studies, including a damaged white oak (*Quercus alba*), which was used during autumn 1998-2000 (Gumbert et al. 2002) and reused by the same bat during this study. Likewise, in spring 2003, I located bat 1929KY/A00010DB in the same living shagbark hickory it used during spring 1998 (M. W. Gumbert pers. comm.).

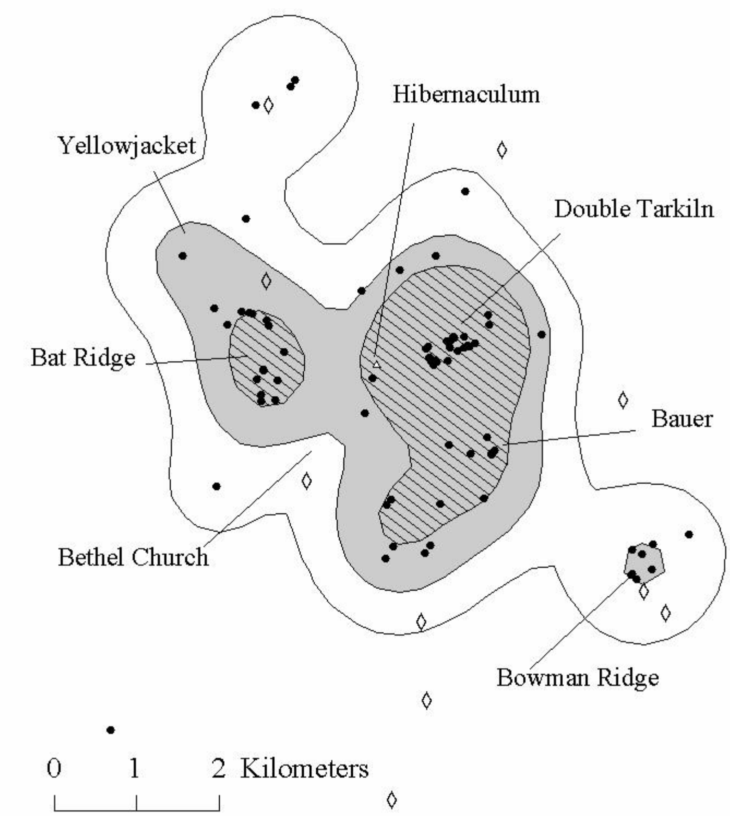

Fig. 6. Fixed-kernel estimates for a population of male Indiana bats (*Myotis sodalis*) at South Goldson Cave, Pulaski and McCreary counties, Kentucky, 2001-2003. Contours (95% and 75%) are represented by unshaded and shaded polygons, respectively; core areas (50% contours) are depicted by diagonal hatching. Locations of roost trees and transects are indicated by dots and diamonds, respectively.

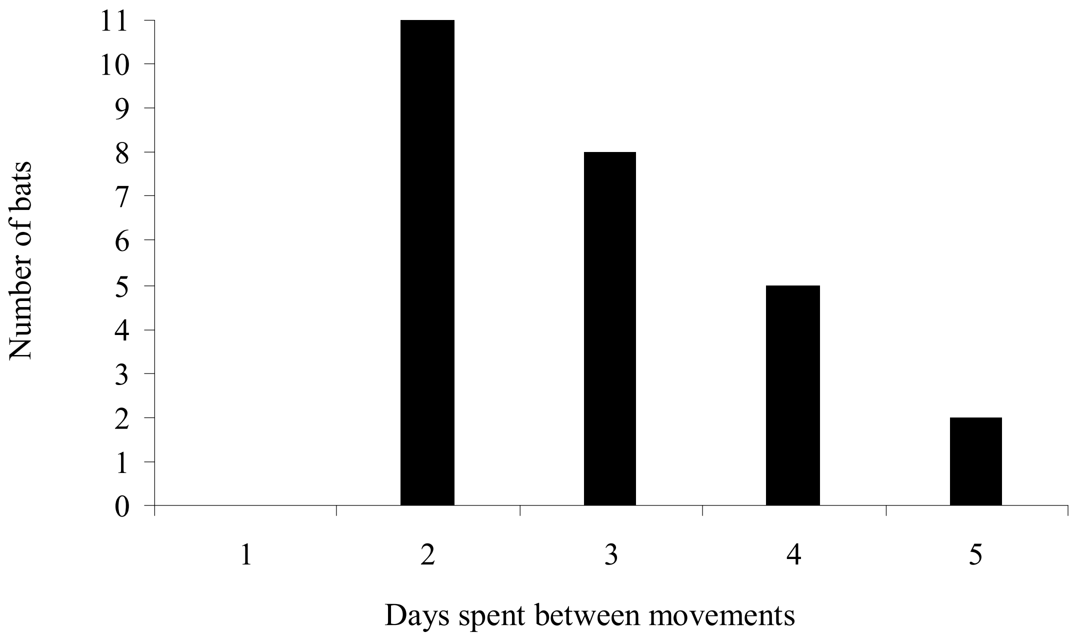

Fig 7. Frequency that male Indiana bats (*Myotis sodalis*) switched roosts, Pulaski and McCreary counties, Kentucky, 2001-2003.

Increasing use of pines occurred during 1996-2003 ($r^2 = 0.51$, $F = 10.4$, $d.f. = 1, 10$, $P \leq 0.009$) and peaked at 100% in summer 2002 (Fig. 8). Data from the present study, using days accounted for/known movements, suggested a weak trend of increasing fidelity during 2001-2003 ($r^2 = 0.16$, $F = 4.39$, $d.f. = 1, 24$, $P \leq 0.047$; Fig. 9). This trend was not observed with combined data for 1996-1997 and the current study, using fidelity calculated as number of days bats were located divided by number of located roosts ($F = 1.85$, $d.f. = 1, 46$, $P \leq 0.18$; Fig. 10).

Surveys of roosts indicated suitability of roosts declined over time (Appendix 4). In one case, a roost was used by a bat despite having fallen against a neighboring tree (Fig. 11). In another instance, a short-leaf pine (*Pinus echinata*) fell to the ground 4 days after a bat was first observed using the tree (Appendix 3); the flap of bark the bat had been roosting under was crushed against a neighboring tree during the fall. Logistic-regression analysis using the backwards-elimination method to select variables (α of removal = 0.05) identified a relationship between suitability of roosts and age (months since located) and type (pine versus hardwood) of roost. A preliminary model indicated months since roosts were located and type of roost influenced suitability over time ($\chi^2 = 20.2$, $d.f. = 2$, $P < 0.001$. This model correctly identified 87% of roosts that were suitable and 54% that were unsuitable (overall correct = 72%). However, the backwards elimination process excluded type of roost from the final model, ($\chi^2 = 10.5$, $d.f. = 1$, $P \leq 0.001$). The final model correctly identified 90% of roosts that were suitable and 50% that were unsuitable (overall correct = 73%).

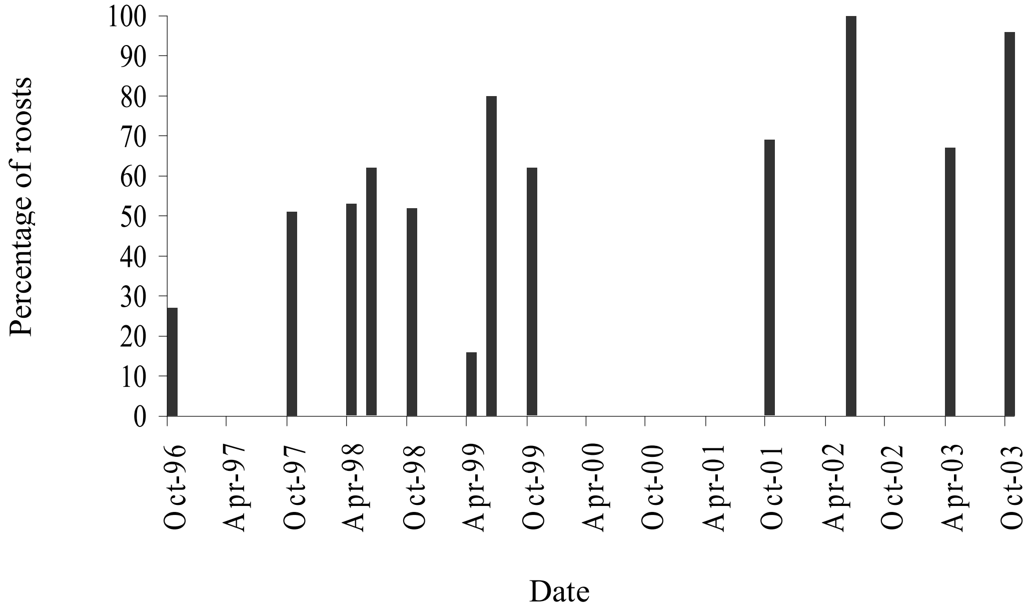

Fig. 8. Increasing use of pines (*Pinus*) by male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, 1996-2003. Data for 1996-1997 are from J. R. MacGregor (in litt.) and data for 1998-1999 are from Gumbert (2001); data were not collected during 2000.

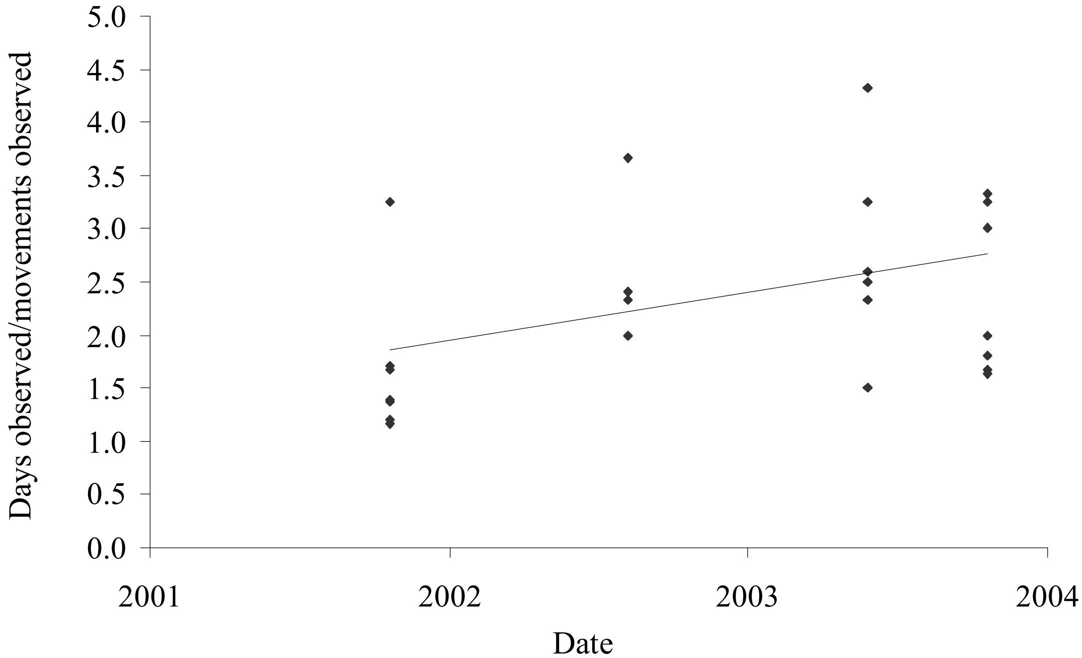

Fig. 9. Fidelity (number of days a bat was accounted for/number of movements that were observed) of male Indiana bats (*Myotis sodalis*) following an infestation of southern pine beetles (*Dendroctonus frontalis*), Pulaski and McCreary counties, Kentucky, 2001-2003.

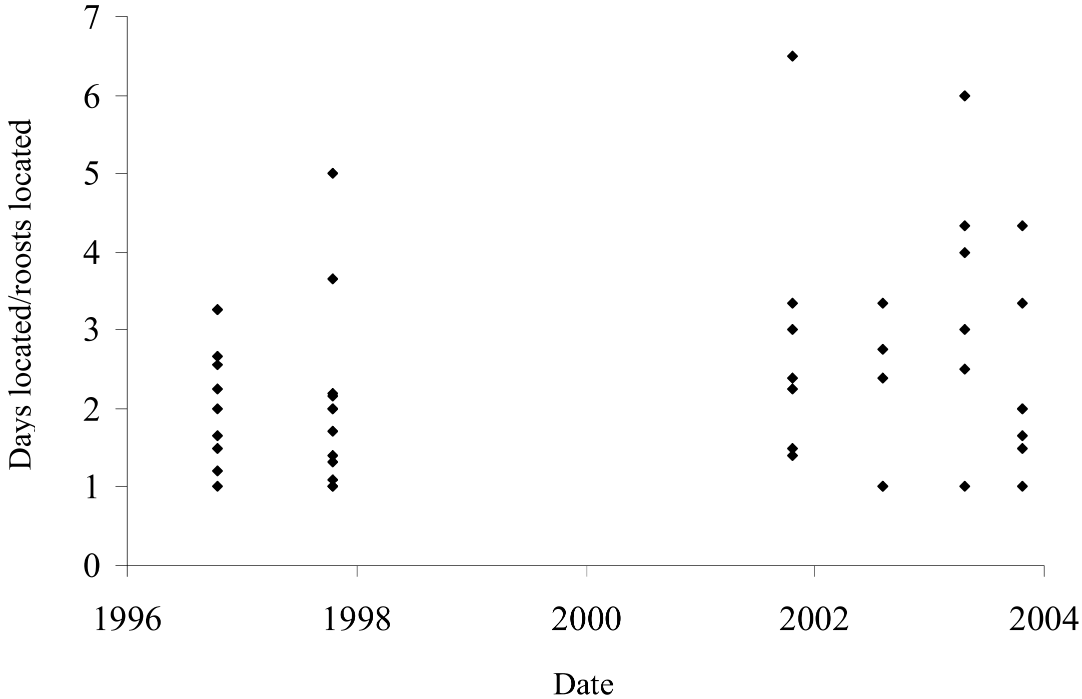

Fig. 10. Fidelity (number of days a bat was located/number of roosts located) of male Indiana bats (*Myotis sodalis*) to roosts, Pulaski and McCreary counties, Kentucky, 1996-1997 and 2001-2003. Data were from J. R. MacGregor (in litt.) and the present study.

Fig. 11. A conceptual illustration of how suitability of roost trees varies over time; beginning with low suitability after death of the tree (tight bark), followed by near maximum suitability (abundant exfoliating bark), and eventual decay (center). The leaning pine (*Pinus*) was used as a roost by a male Indiana bat (*Myotis sodalis*), despite having fallen against a neighboring tree, McCreary Co., Kentucky, 5 October 2001.

DISCUSSION

Bats displayed behaviors that were similar to those observed by Gumbert et al. (2002). Individuals switched trees often and continued to use core areas identified by Gumbert et al. (2002). However, not all core areas identified by Gumbert et al. (2002) were used by bats during this study. This study identified only 3, centrally located, core areas, whereas Gumbert et al. (2002) identified 4 core areas scattered around the cave. Did fluctuating availability of roosts in the area surrounding South Goldson Cave account for differences in location and number of core areas between studies, or were differences a result of a smaller sample?

Data from my study suggest availability of potential roosts was a likely factor in determining use of core areas by bats. Specifically, Yellowjacket and Bethel Church (Gumbert et al. 2002) received little use by bats during the present study (only 2 roosts were observed in Yellowjacket). During 2003, only 2 of the roosts at Yellowjacket that were used prior to the infestation (during spring 1998) were observed standing; both were living shagbark hickories. Other roosts at Yellowjacket had fallen and were in advanced stages of decay (little or no paint remaining and trunks covered with mosses and fungi). Decay made it difficult to distinguish roosts from other fallen trees; thus, roosts that I could not locate also may have fallen but were overlooked. Furthermore, bats began using Bauer following the infestation, when availability of potential roosts probably increased at the site. Together, this evidence suggests that formation and use of core areas was dictated by abundance of potential roosts. I suggest that male Indiana bats may continue to use core areas, if potential roosts remain abundant. Although, I recognize that changes in other characteristics of habitat (Chapter II) also are likely to influence use of core areas.

Despite large numbers of potential roosts that became available following the infestation (54% increase; Chapter II), results did not support the hypothesis that increased availability of roosts would result in increased movements between roosts. In fact, fidelity (number of days bats were observed/movements that were observed) increased during my study, although this trend was slight and was not evident when data for 1996-1997 were combined with data from the present study (fidelity = number of days bats were located/number of trees that were located). Overall, fidelity of bats seemed unaffected by the increase in abundance of roosts that occurred following the infestation. Dead trees were relatively abundant prior to the infestation due to a storm in 1994 (Gumbert 2001); perhaps, changes in fidelity would have been detected following a more dramatic change in abundance of potential roosts. For example, will changes in fidelity occur when roosts became scarce?

Data from the present study suggest most trees become unsuitable for use by Indiana bats within 2-7 years from the date they were used by bats (Fig. 12). Pine trees may even fall while bats are roosting in them, possibly killing bats, as nearly happened during the present study. Sample size of hardwood trees was too small to significantly affect estimated suitability over time, however hardwood trees probably remain standing for longer periods (Fig. 12). Relatively rapid decay of pine trees, combined with current

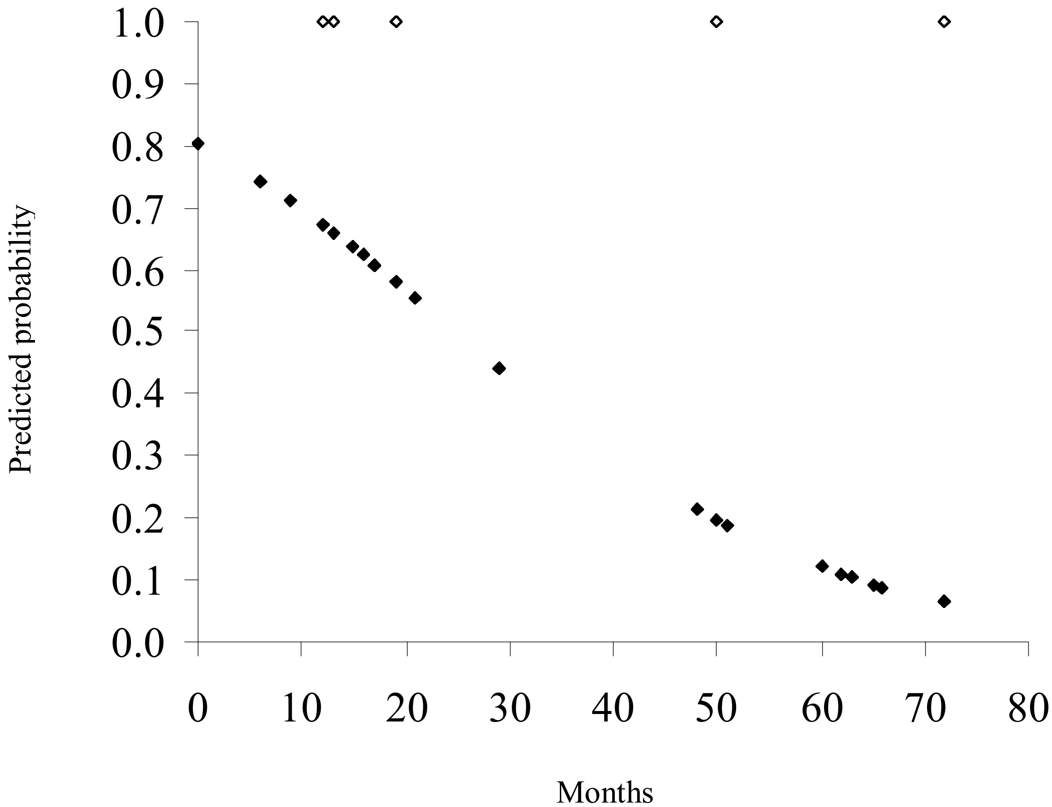

Fig. 12. Predicted probability of roosts remaining suitable for use by Indiana bats (*Myotis sodalis*) over time, Pulaski and McCreary counties, Kentucky. *Pinus* (n = 54) and non-pines (n = 5) are indicated by solid and hollow markers, respectively. Months represent time since roosts were first located using radiotelemetry.

low numbers of dead hardwoods in the forest surrounding South Goldson Cave (Chapter II), suggest that roosts might become scarce in the near future. Continued study of the population at South Goldson Cave could provide valuable insight into the ecology of Indiana bats and answer questions about fidelity of bats. Comparative studies of fidelity of Indiana bats from various parts of the range might provide additional insight, particularly if fidelity is influenced by environment. However, this will require use of a single definition of fidelity.

Combined data point to the potential importance of hardwood trees, as well as the possible role of natural disturbances in the ecology of Indiana bats. Some researchers (T. C. Carter and E. R. Britzke, in litt.) suggest that populations of Indiana bats are dependent on natural disturbances and may become nomadic as they follow patches of disturbance over time. This seems unlikely to provide adequate supplies of roosts around hibernacula, particularly for male bats that stay near caves all year, or when large numbers of bats aggregate around hibernacula during autumn (especially at large hibernacula). Male Indiana bats clearly use trees killed during natural disturbances; the present study documented male Indiana bats using trees killed during the infestation (Chapter II), and J. R. MacGregor (in litt.) and Gumbert (2001) documented bats using trees killed during an earlier natural disturbance. However, bats showed long-term use of core areas that maintained adequate numbers of roosts and showed fidelity to trees that remained suitable. Similarly, Kurta and Murray (2002) demonstrated repeated use of sites by female Indiana bats in Michigan. Moreover, my study indicates the importance of a continuous supply of potential roosts, especially around hibernacula. Given an adequate supply of dead hardwood trees close to the hibernaculum, pine trees killed by large-scale natural disturbances may have been relatively unimportant to bats. Natural disturbances could create peaks in abundance of potential roosts, but long-term effects would depend on intervals between disturbances.

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APPENDICES

Appendix 1. Characteristics of trees used as roosts by male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, 2001-2003.

Roost tree	Sampling period	Days tree was used	R[a]	Dbh of roost (cm)	Type of tree	Height of tree (m)	Height of roost above ground (m)	Living or dead tree	Bark on tree (%)	Solar exposure
591	Autumn 2001	2		37.3	Pine	.	.	Dead	.	Sunny
592	Autumn 2001	5		75.2	Non-pine	19	4	Dead	25-100	Sunny
593	Autumn 2001	1		29.4	Pine	19	4	Dead	<10	Sunny
594	Autumn 2001	1		25.0	Pine	22	4	Dead	10-24	Sunny
595	Autumn 2001	2		19.5	Non-pine	12	.	Dead	<10	Sunny
596	Autumn 2001	1		34.6	Non-pine	13	.	Dead	<10	Sunny
597	Autumn 2001	1		46.6	Non-pine	24	13	Living	25-100	Shaded
598	Autumn 2001	2		42.8	Pine	21	12	Dead	25-100	Sunny
600	Autumn 2001	1		29.4	Non-pine	24	13	Living	25-100	.
798	Autumn 2001	1		36.5	Pine	.	4	Dead	10-24	.
800	Autumn 2001	2		33.2	Non-pine	13	6	Dead	<10	Sunny
887	Autumn 2001	2		48.7	Non-pine	26	18	Living	<10	Shaded
888	Autumn 2001	1		43.2	Pine	15	.	Dead	10-24	Partially shaded
889	Autumn 2001	3		28.3	Pine	19	9	Dead	<10	Partially shaded
891	Autumn 2001	5		33.0	Pine	12	7	Dead	<10	Sunny

Appendix 1 continued.

Roost tree	Sampling period	Days tree was used	R[a]	Dbh of roost (cm)	Type of tree	Height of tree (m)	Height of roost above ground (m)	Living or dead tree	Bark on tree (%)	Solar exposure
892	Autumn 2001	7		37.0	Pine	21	7	Dead	<10	Sunny
894	Autumn 2001	3		57.5	Pine	.	.	Dead	<10	Sunny
895	Autumn 2001	6		45.0	Pine	18	.	Dead	<10	Sunny
896	Autumn 2001	8		34.5	Pine	15	4	Dead	<10	Partially shaded
897	Autumn 2001	3		45.3	Pine	16	7	Dead	<10	Shaded
898	Autumn 2001	1		39.0	Pine	15	.	Dead	10-24	Sunny
899	Autumn 2001	1		40.0	Non-pine	19	9	Dead	25-100	Sunny
900	Autumn 2001	1		29.0	Non-pine	22	7	Dead	25-100	Sunny
992	Autumn 2001	1		42.3	Pine	16	7	Dead	10-24	Sunny
993	Autumn 2001	1		27.8	Pine	18	6	Dead	<10	Sunny
994	Autumn 2001	1		34.5	Pine	22	18	Dead	10-24	Sunny
995	Autumn 2001	3		54.6	Non-pine	19	4	Dead	<10	Shaded
996	Autumn 2001	5		33.2	Pine	9	6	Dead	<10	Partially shaded
997	Autumn 2001	5		48.9	Pine	19	7	Dead	<10	Sunny
999	Autumn 2001	1		36.9	Pine	12	10	Dead	10-24	Sunny
567	Summer 2002	4	X	48.1	Pine	15	4	Dead	25-100	Sunny

Appendix 1 continued.

Roost tree	Sampling period	Days tree was used	R[a]	Dbh of roost (cm)	Type of tree	Height of tree (m)	Height of roost above ground (m)	Living or dead tree	Bark on tree (%)	Solar exposure
568	Summer 2002	4		37.6	Pine	13	9	Dead	25-100	Sunny
569	Summer 2002	1		38.1	Pine	12	7	Dead	25-100	Sunny
570	Summer 2002	3		32.1	Pine	12	6	Dead	25-100	Partially shaded
571	Summer 2002	3		52.1	Pine	15	9	Dead	25-100	Sunny
573	Summer 2002	3	X	43.7	Pine	15	9	Dead	10-24	Sunny
574	Summer 2002	2	X	33.5	Pine	15	7	Dead	10-24	Sunny
576	Summer 2002	1		45.6	Pine	18	6	Dead	25-100	Shaded
674	Summer 2002	6	X	37.6	Pine	15	6	Dead	<10	Shaded
1	Spring 2003	1		.	Non-pine	.	.	Dead	.	.
2	Spring 2003	1		.	Pine	.	.	Dead	.	.
3	Spring 2003	1		.	Pine	.	.	Dead	.	.
446	Spring 2003	1		26.7	Pine	24	21	Dead	<10	Sunny
447	Spring 2003	1		41.0	Pine	15	14	Dead	<10	Sunny
448	Spring 2003	5		29.4	Pine	7	6	Dead	25-100	Sunny
566	Spring 2003	2		61.9	Non-pine	6	3	Dead	.	Shaded
572	Spring 2003	4		55.2	Non-pine	18	.	Living	.	Sunny

Appendix 1 continued.

Roost tree	Sampling period	Days tree was used	R[a]	Dbh of roost (cm)	Type of tree	Height of tree (m)	Height of roost above ground (m)	Living or dead tree	Bark on tree (%)	Solar exposure
577	Spring 2003	5		41.0	Pine	18	15	Dead	25-100	Partially shaded
578	Spring 2003	1		23.5	Non-pine	13	2	Dead	25-100	Partially shaded
579	Spring 2003	4		41.5	Pine	12	4	Dead	25-100	Partially shaded
580	Spring 2003	5		36.4	Pine	15	4	Dead	25-100	Shaded
581	Spring 2003	2		43.9	Pine	10	7	Dead	25-100	Partially shaded
582	Spring 2003	8		34.7	Pine	16	4	Dead	25-100	Partially shaded
583	Spring 2003	8		51.5	Pine	15	9	Dead	25-100	Sunny
584	Spring 2003	1		27.7	Non-pine	6	6	Living	.	Sunny
769	Spring 2003	11	X	37.0	Non-pine	18	7	Living	.	Sunny
882	Spring 2003	1		.	Pine	.	.	Dead	.	.
883	Spring 2003	4		36.0	Pine	18	9	Dead	25-100	Partially shaded
885	Spring 2003	4		19.6	Non-pine	6	5	Dead	10-24	Sunny
991	Spring 2003	1		26.2	Pine	15	12	Living	.	Sunny
4	Autumn 2003	1		25.5	Pine	15	9	Dead	10-24	Sunny
5	Autumn 2003	1		.	Pine	15	10	Dead	10-24	Partially shaded
6	Autumn 2003	1		.	Pine	22	10	Dead	10-24	Sunny

Appendix 1 continued.

Roost tree	Sampling period	Days tree was used	R[a]	Dbh of roost (cm)	Type of tree	Height of tree (m)	Height of roost above ground (m)	Living or dead tree	Bark on tree (%)	Solar exposure
7	Autumn 2003	1		.	Pine	22	10	Dead	<10	Sunny
8	Autumn 2003	1		.	Pine	18	4	Dead	<10	Partially shaded
9	Autumn 2003	1		.	Pine	22	15	Dead	10-24	Sunny
451	Autumn 2003	4		17.7	Pine	12	7	Dead	25-100	Partially shaded
458	Autumn 2003	6	X	32.8	Pine	13	6	Dead	<10	Sunny
561	Autumn 2003	4		39.2	Pine	18	10	Dead	25-100	Partially shaded
562	Autumn 2003	2		34.9	Pine	18	10	Dead	25-100	Sunny
563	Autumn 2003	22	X	37.2	Pine	18	4	Dead	10-24	Sunny
564	Autumn 2003	1		35.9	Pine	15	9	Dead	<10	Sunny
565	Autumn 2003	1		47.6	Pine	12	10	Dead	25-100	Sunny
684	Autumn 2003	6	X	27.5	Pine	9	7	Dead	10-24	Sunny
732	Autumn 2003	1	X	44.6	Non-pine	10	10	Dead	25-100	Partially shaded
979	Autumn 2003	1		50.9	Pine	19	7	Dead	<10	Partially shaded
980	Autumn 2003	1		35.5	Pine	18	4	Dead	<10	Sunny
981	Autumn 2003	1		28.5	Pine	7	6	Dead	<10	Sunny
982	Autumn 2003	2		24.6	Pine	18	10	Dead	<10	Sunny

Appendix 1 continued.

Roost tree	Sampling period	Days tree was used	R[a]	Dbh of roost (cm)	Type of tree	Height of tree (m)	Height of roost above ground (m)	Living or dead tree	Bark on tree (%)	Solar exposure
983	Autumn 2003	3		34.5	Pine	22	5	Dead	25-100	Partially shaded
984	Autumn 2003	1		49.8	Pine	19	6	Dead	10-24	Sunny
985	Autumn 2003	1		45.8	Pine	16	12	Dead	<10	Partially shaded
986	Autumn 2003	1		23.2	Pine	13	6	Dead	<10	Partially shaded
987	Autumn 2003	1		36.4	Pine	21	7	Dead	10-24	Partially shaded
988	Autumn 2003	1		26.3	Pine	12	7	Dead	<10	Sunny
989	Autumn 2003	1		37.1	Pine	21	9	Dead	10-24	Shaded
990	Autumn 2003	1		26.6	Pine	12	6	Dead	25-100	Partially shaded

[a] Indicates tree was used by >1 bat, including trees 458, 732, 674, and 769, which were reused from previous studies.

Appendix 2. Characteristics of habitats not used by male Indiana bats (*Myotis sodalis*) in the vicinity of South Goldson Cave, Pulaski and McCreary counties, Kentucky, July 2002.

Random location	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
1	34.9	14.8	0	10	0	0	2	0	0	0	0	12
2	24.7	11.1	3	3	2	0	1	2	3	0	0	6
3	31.3	18.5	2	5	6	2	0	2	2	0	0	13
4	35.9	14.8	3	6	3	0	0	0	3	0	0	9
5	32.8	14.8	1	6	5	0	0	0	1	0	0	11
6	27.9	14.8	4	3	4	0	1	1	1	3	1	7
7	22.6	13.6	3	4	3	0	1	0	0	3	0	8
8	42.0	14.8	4	3	3	0	2	0	1	3	0	8
9	37.9	17.3	3	7	4	0	0	0	0	3	0	11
10	39.6	16.0	0	6	4	1	2	0	5	0	0	7
11	27.2	12.3	0	0	3	0	7	0	0	0	1	9
12	27.5	7.4	0	0	1	1	4	0	0	0	0	5
13	26.4	6.2	0	2	0	1	2	0	0	0	0	3
14	25.1	4.9	0	0	1	1	2	0	0	0	0	4
15	15.4	14.8	7	2	0	0	3	4	7	0	0	5

Appendix 2 continued.

Random location	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
16	15.9	11.1	5	1	2	0	1	3	5	0	0	5
17	16.5	13.6	7	2	0	1	1	4	7	0	0	5
18	22.3	9.9	7	0	0	0	1	7	7	0	0	1
19	14.5	8.6	1	3	.	1	2	0	1	0	0	6
20	16.3	12.3	2	3	0	3	2	0	2	0	0	8
21	23.3	6.2	0	3	0	0	2	0	0	0	0	5
22	23.2	12.3	5	0	0	1	4	3	5	0	0	5
23	30.0	9.9	2	6	0	0	0	0	2	0	1	5
24	43.9	4.9	0	1	1	0	2	0	0	0	0	5
25	35.4	8.6	0	2	1	1	3	0	0	0	0	7
26	29.8	9.9	0	1	1	4	2	0	0	0	0	8
27	31.8	9.9	1	4	0	1	2	1	1	0	0	7
28	24.5	8.6	0	4	3	0	0	0	0	0	0	7
29	33.4	8.6	2	2	2	0	1	2	2	0	0	5
30	54.0	12.3	9	1	0	0	0	8	9	0	0	1
31	26.0	7.4	0	0	0	1	5	0	0	0	0	6

Appendix 2 continued.

Random location	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
32	28.7	8.6	3	0	0	0	4	0	3	0	0	4
33	29.2	14.8	1	3	0	0	8	0	1	0	0	11
34	42.3	7.4	0	4	0	1	1	0	0	0	0	6
35	39.1	7.4	0	3	1	0	2	0	0	0	0	6
36	37.4	11.1	2	1	1	1	4	2	2	0	1	6
37	32.7	11.1	0	6	2	0	1	0	0	0	0	9
38	34.5	7.4	0	3	2	1	0	0	0	0	0	6
39	28.1	8.6	0	2	4	0	1	0	0	0	0	7
40	32.6	8.6	1	3	0	0	3	0	1	0	1	5
41	25.4	7.4	0	2	3	0	1	0	0	0	0	6
42	18.4	8.6	0	3	2	0	2	0	0	0	1	6
43	23.0	14.8	2	1	4	2	3	0	2	0	1	9
44	29.0	9.9	3	3	1	0	1	3	3	0	0	5
45	16.8	8.6	2	2	0	1	2	2	2	0	0	5
46	29.7	6.2	2	2	0	0	1	1	2	0	0	3
47	20.2	14.8	7	1	1	0	3	3	7	0	0	5

Appendix 2 continued.

Random location	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
48	22.8	8.6	5	1	0	0	1	5	5	0	0	2
49	23.5	8.6	2	3	0	0	2	2	2	0	0	5
50	28.8	14.8	0	4	4	4	0	0	0	0	0	12
51	35.8	7.4	0	1	0	4	1	0	0	0	0	6
52	33.3	7.4	0	1	0	5	0	0	0	0	0	6
53	37.8	11.1	0	1	1	4	3	0	0	0	0	9
54	32.7	8.6	0	1	2	1	3	0	0	0	0	7
55	36.5	8.6	0	5	2	0	0	0	0	0	0	7
56	32.6	9.9	0	3	1	3	1	0	0	0	0	8
57	35.3	7.4	0	3	3	0	0	0	0	0	0	6
58	26.2	12.3	3	5	2	0	0	2	3	0	0	7
59	30.0	8.6	0	4	1	1	1	0	0	0	0	7
60	36.1	11.1	0	4	2	0	3	0	0	0	0	9
61	29.8	12.3	0	3	0	2	5	0	0	0	0	10
62	29.7	13.6	0	7	0	3	1	0	0	0	1	10
63	40.7	8.6	0	3	0	3	1	0	0	0	1	6

Appendix 3. Characteristics of habitat surrounding roosts of male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, 2001-2003.

Roost tree	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
592	72.5	4.9	1	2	0	0	0	0	0	1	2	1
595	19.5	4.9	2	2	0	0	0	2	2	0	2	0
596	29.1	6.2	2	2	1	0	0	1	2	0	2	1
800	26.5	3.7	1	1	0	0	1	0	2	0	1	0
887	26.8	12.3	0	7	1	0	2	0	0	0	0	0
888	38.4	7.4	2	4	0	0	0	0	1	1	1	3
889	39.8	9.9	2	6	0	0	0	0	2	1	0	8
891	20.7	18.5	8	3	4	0	0	8	8	0	0	7
892	39.1	4.9	2	2	0	0	0	0	1	1	2	0
894	29.3	12.3	8	2	0	0	0	2	5	2	0	2
895	36.9	13.6	7	2	0	0	2	6	7	0	1	3
896	32.2	11.1	3	5	0	1	0	3	3	0	0	6
897	32.4	14.8	3	0	1	1	7	2	3	0	1	10
898	37.9	8.6	6	1	0	0	0	2	5	0	0	1
899	40.9	9.9	1	7	0	0	0	0	1	0	2	5

Appendix 3 continued.

Roost tree	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
992	35.5	18.5	9	2	2	0	2	8	9	0	0	6
993	42.4	9.9	2	6	0	0	0	0	2	0	3	3
994	31.7	6.2	3	2	0	0	0	0	3	0	2	0
995	36.8	18.5	2	5	6	1	1	2	2	0	0	13
996	28.0	8.6	3	1	1	1	1	1	2	0	0	5
997	32.0	8.6	1	3	1	1	1	2	2	0	0	5
999	36.0	8.6	7	0	0	0	0	4	7	0	0	0
567	48.1	1.2	1	0	0	0	0	1	1	0	0	0
569	41.4	6.2	5	0	0	0	0	4	4	1	0	0
570	20.9	16.0	6	4	2	0	1	6	6	0	1	6
571	43.1	4.9	3	0	0	1	0	0	1	2	0	1
576	28.4	17.3	7	2	2	2	1	7	7	0	0	7
674	35.4	11.1	3	3	3	0	0	0	1	2	0	8
572	36.5	7.4	0	3	0	2	1	0	0	0	0	6
447	28.8	17.3	3	7	2	0	2	0	3	0	0	11
448	30.7	21.0	9	0	0	0	8	5	4	0	1	7

Appendix 3 continued.

Roost tree	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
446	29.4	11.1	4	0	0	0	5	1	3	1	0	6
885	26.3	3.7	1	1	0	0	1	0	0	1	2	0
577	28.2	8.6	4	1	2	0	0	4	4	0	0	3
883	29.4	13.6	5	3	2	0	1	5	5	0	1	5
769	38.8	11.1	0	5	0	2	2	0	0	0	2	7
583	41.1	3.7	3	0	0	0	0	3	3	0	0	0
581	36.5	11.1	5	4	0	0	0	4	5	0	1	3
582	37.4	12.3	4	4	1	0	1	4	4	0	0	6
584	27.7	1.2	0	1	0	0	0	0	0	0	1	0
580	29.6	17.3	5	4	5	0	0	2	5	0	1	8
578	29.4	17.3	0	11	1	0	2	0	0	0	2	12
566	40.7	14.8	0	2	2	4	4	0	0	0	2	10
579	28.4	9.9	3	0	1	1	3	0	3	0	0	5
991	31.9	11.1	1	0	1	4	3	0	0	1	0	8
563	35.5	7.4	4	4	0	0	0	1	4	0	0	2
562	29.6	6.2	4	1	0	0	0	0	4	0	1	0

Appendix 3 continued.

Roost tree	Average dbh (cm)	Basal area (m^2/ha)	*Pinus*	*Quercus*	*Acer*	*Carya*	Other	Number of trees killed by southern pine beetles	Dead pines	Living pines	Dead non-pines	Living non-pines
684	36.0	3.7	3	0	0	0	0	0	3	0	0	0
561	32.4	13.6	5	2	1	0	3	5	5	0	1	5
451	24.3	12.3	3	2	3	1	1	3	3	0	1	6
990	24.9	8.6	3	2	2	0	0	3	3	0	0	4
989	28.0	17.3	7	0	5	0	2	7	7	0	0	7
988	31.0	7.4	1	4	1	0	0	1	1	0	0	0
986	18.2	14.8	8	3	0	0	1	8	8	0	1	3
985	41.2	4.9	2	2	0	0	0	2	2	0	0	2
984	26.5	8.6	2	0	3	0	2	2	2	0	1	4
983	30.7	16.0	7	2	3	0	1	6	7	0	0	6
458	38.5	4.9	3	1	0	0	0	0	1	2	1	0
982	21.5	11.1	6	0	0	0	3	6	6	0	0	3
979	34.7	13.6	2	4	4	0	1	2	2	0	1	8
980	32.0	4.9	3	1	0	0	0	3	3	0	1	0
981	33.1	7.4	5	1	0	0	0	2	5	0	1	0

Appendix 4. Suitability over time of a subsample of trees used as roosts by male Indiana bats (*Myotis sodalis*), Pulaski and McCreary counties, Kentucky, as determined by revisiting trees first located during this study and by Gumbert et al. (2002).

Date located	Roost tree	October 2001	July 2002	September 2002	April 2003	October 2003	April 2004	Months[a]
01-Oct-97	605					Unsuitable		72
01-Oct-97	606					Unsuitable		72
01-Apr-98	123					Unsuitable		66
01-Apr-98	125					Unsuitable		66
01-Jul-98	130					Unsuitable		65
01-Jul-98	136					Unsuitable		63
01-Jul-98	146					Unsuitable		63
01-Oct-98	186					Unsuitable		60
01-Oct-98	191					Unsuitable		62
01-Oct-98	722					Unsuitable		72
01-Oct-98	732			Suitable		Suitable	Suitable	72
01-Oct-98	750					Suitable		60
01-Oct-98	789						Suitable	72
01-Apr-99	690					Unsuitable		54
01-Jul-99	653				Unsuitable			45
01-Jul-99	654	Suitable				Unsuitable		51
01-Oct-99	634			Suitable		Suitable		50
01-Oct-99	650					Unsuitable		50
01-Oct-99	659					Unsuitable		60
01-Oct-99	662					Unsuitable		48

Appendix 4 continued.

Date located	Roost tree	October 2001	July 2002	September 2002	April 2003	October 2003	April 2004	Months[a]
29-Sep-01	895	Suitable					Unsuitable	29
30-Sep-01	891	Suitable			Suitable			17
02-Oct-01	992	Suitable			Unsuitable			17
04-Oct-01	898	Suitable			Unsuitable			17
04-Oct-01	999	Suitable					Suitable	29
05-Oct-01	993	Suitable			Unsuitable			17
07-Oct-01	996	Suitable			Unsuitable			17
11-Oct-01	598	Suitable					Suitable	29
13-Oct-01	888	Suitable			Suitable		Suitable	29
14-Oct-01	594	Suitable			Unsuitable			17
02-Jul-02	575		Suitable				Suitable	21
03-Jul-02	567		Suitable			Unsuitable		15
04-Jul-02	674		Suitable		Suitable			9
06-Jul-02	570		Suitable			Unsuitable		16
12-Sep-02	458			Suitable		Suitable	Suitable	19
13-Sep-02	459			Suitable		Suitable		13
14-Sep-02	455			Suitable		Suitable		13
15-Sep-02	456			Suitable		Suitable		13
16-Sep-02	457			Suitable		Suitable	Unsuitable	19
17-Sep-02	441			Suitable	Suitable	Suitable	Suitable	19
17-Sep-02	483			Suitable		Suitable	Suitable	19
13-Apr-03	446				Suitable	Suitable		6

Appendix 4 continued.

Date located	Roost tree	October 2001	July 2002	September 2002	April 2003	October 2003	April 2004	Months[a]
13-Apr-03	883				Suitable	Suitable	Suitable	12
15-Apr-03	583				Suitable		Suitable	12
18-Apr-03	582				Suitable		Suitable	12
23-Apr-03	566				Suitable	Suitable		12
04-Oct-03	563					Suitable	Suitable	6
04-Oct-03	564					Suitable	Suitable	6
05-Oct-03	562					Suitable	Suitable	6
06-Oct-03	451					Suitable	Unsuitable	6
06-Oct-03	561					Suitable	Suitable	6
10-Oct-03	988					Suitable	Suitable	6
10-Oct-03	989					Suitable	Unsuitable	6
11-Oct-03	984					Suitable		<1[b]
11-Oct-03	986					Suitable	Suitable	6
12-Oct-03	982					Suitable	Suitable	6
12-Oct-03	983					Suitable	Suitable	6
15-Oct-03	979					Suitable	Suitable	6

[a] Time from date a bat was first observed using a roost tree until the tree was observed unsuitable, or until the most recent date it was observed suitable

[b] Tree 984 became unsuitable 4 days after it was used by a bat