

A Conservation Strategy
for
Rafinesque's Big-Eared Bat
(Corynorhinus rafinesquii)
and
Southeastern Myotis
(Myotis austroriparius)



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(*Corynorhinus rafinesquii*)
and
Southeastern Myotis
(*Myotis austroriparius*)

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STATEMENT OF INTENT

The policies of state and federal agencies and private organizations governing management and protection of populations and habitat associations of *Corynorhinus rafinesquii* and *Myotis austroriparius* are not affected by this strategy, nor are the activities proposed in this document intended to alter current regulatory requirements of agencies responsible for managing bats and other wildlife. This document has been developed to provide guidance in the conservation and management of these two bat species based on similarities and differences in behavior and habitat types used across the southeastern United States. The goal in developing this strategy is to provide a conservation approach that upon implementation will enhance populations and habitat associations of these bats, precluding the need to federally list one or both species. The strategy is based on an adaptive management framework that can be updated as new information becomes available. It is recognized that coordinated efforts and funding will need to be allocated toward these recommendations to ensure successful implementation.

PREFACE

The genesis of this document evolved from a long-standing perception among many scientists, land managers, environmental consultants, and state and federal agency personnel throughout the southeastern United States that Rafinesque's big-eared bat and southeastern myotis were in decline and in need of conservation attention. Disjunct distributions, limited data on population status and an incomplete understanding of the life history requirements of these bats serve as impediments to developing a long-term conservation strategy. Continued habitat loss, especially mature elements of bottomland hardwood forests, ensures that future protection and recovery efforts of these species will be difficult. Annual meetings of the Rafinesque's Big-eared Bat Working Group (RBBWG) began the dialogue necessary to move on development of a conservation strategy. These discussions, combined with input from biologists of Bat Conservation International, Inc. (BCI), led to the formation of a Technical Advisory Group which eventually met in Raleigh, NC, on 24 and 25 September 2008. This meeting was followed by another meeting of the RBBWG in Jonesboro, AR, on 11 February 2009, and a second meeting of the Technical Advisory Group in Nashville, TN, on 30 March and 1 April 2009. These were followed by a symposium on eastern big-eared bats, held in Athens, GA, on 9 and 10 March 2010. Results of these meetings provided substantial input to the content of this document.

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Toni Piaggio and Matina Kalcounis-Rüppell contributed information on systematics and echolocation biology, respectively, of these bats. Merlin Tuttle and Chester Martin provided extensive assistance coalescing natural history information and species descriptions. Shawna Ginger and staff at the Jackson, Mississippi, Field Office of the U.S. Fish and Wildlife Service provided considerable support in the developmental stage of this document. Darren Miller, Edward Arnett, Mike Armstrong, Jeanne Jones, Chester Martin, and Christine Willis provided input on threats to these bats. Additional information on distributions or natural history of these species was provided by Katie Gillies, Chris Rice, Tom Risch, Keith Johnson, Steve Shively, Stephanie Allison, Dave Richardson, Brian Carver, Susan Loeb, Gypsy Hanks, Mike Lacki, Laurie Lomas, Mylea Bayless, Matt Clement, and Tim Carter. This document benefited from a final review by Darren Miller, Susan Loeb, Paul Leberg, Janet Ertel, Ben Wigley, Blake Sasse, and Jeff Gore. Funding for the workshops, meetings, and other preparations in support of this document were provided by: Beneficia Foundation, Offield Family Foundation, and the National Fish and Wildlife Foundation (Agreement No. 2008-0094-000). The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the United States Government or the National Fish and Wildlife Foundation. Mention of trade names or commercial products does not constitute their endorsement by the United States Government or the National Fish and Wildlife Foundation.

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EXECUTIVE SUMMARY

Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and southeastern myotis (*Myotis austroriparius*) were formerly listed by the United States Fish and Wildlife Service (USFWS) as Category 2 species, because of limited distributions, low reproductive rates, and insufficient information on natural histories, survivorship rates and population status. These species are distributed throughout the coastal plain physiographic province of southeastern United States, and commonly inhabit bottomland hardwood forests where they share similar foraging habitats and structural resources for roosting; sometimes day and night-roosting communally within the same structures, especially bridges and large-diameter, hollow trees. Both species also inhabit upland pine and hardwood forests at the periphery of their distributions, roosting in limestone and sandstone caves, and human-made structures such as mines, cisterns and buildings. Thus, management and conservation efforts of these bats need to ensure approaches flexible enough to accommodate these regional differences in habitat associations across the distributions of the species. As with all bat species in eastern North America, these bats are insectivorous, with Rafinesque's big-eared bat feeding primarily on moths and the diet of southeastern myotis encompassing a wider range of insect and arthropod prey. Foraging behaviors of these species differ, with Rafinesque's big-eared bat primarily capturing prey from substrate surfaces, i.e., gleaning, by using echolocation calls of low frequency and intensity combined with enlarged pinnae for hearing prey generated sounds. Southeastern myotis captures prey in flight, i.e., aerial hawking, coupling highly maneuverable flight with echolocation calls of high frequency and intensity that permit these bats to feed in both vegetation-cluttered habitat types and in more open flight spaces over the surface of water. Primary threats to these bats in bottomland hardwood forests include degradation and loss of foraging habitats, and declines in the availability and suitability of tree and human-made structures for roosting. Primary threats to these bats in upland forests include degradation and loss of foraging habitats, human-disturbance at roosting sites, wind power development, and mortality from contact with *Pseudogymnoascus destructans*, the fungus responsible for White-nose Syndrome (WNS) in bats. Both species in uplands choose roosting structures where contact with other bat species is likely, but not always where temperature conditions inside caves are potentially suitable for the establishment of the WNS fungus. These bats do occupy roosting structures with other bat species in bottomland hardwood forests, but typically do so beneath bridges where temperature and humidity microclimates do not support conditions suitable to the development of the WNS fungus. This conservation strategy has been developed by BCI and the Southeastern Bat Diversity Network (SBDN) to address the needs of these bats, accounting for differences in habitat associations and threats to survival in varying parts of their distributions. The intent of the conservation strategy is to provide a course of action for state and federal agencies, conservation organizations, and private landowners to consider in management of these bats that will promote suitable habitat conditions and enhance population levels sufficient to prevent further declines and the need for federal protected status. The strategy is intended to be inherently flexible, permitting updates and changes as new information is accumulated and the perceived needs and threats of these bat species change.

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I. INTRODUCTION

Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and southeastern myotis (*Myotis austroriparius*) overlap considerably in distribution across the southeastern United States, including most of the coastal plain physiographic province (Jones, 1977; Jones and Manning, 1989). These species are endemic to bottomland hardwood forests of the coastal plain, where they roost primarily in live trees in low numbers (Gooding and Langford, 2004; Trousdale and Beckett, 2005; Carver and Ashley, 2008; Trousdale et al., 2008). Each species also has portions of their distribution where they are more cavernicolous, with Rafinesque's big-eared bat at the northern end of the distribution roosting primarily in sandstone caves and mines (Barbour and Davis, 1969; Harvey et al., 1991) and southeastern myotis at the southern and northern extremes of the distribution roosting in limestone caves (Rice, 1957; Barbour and Davis, 1969; Humphrey and Gore, 1992). These bats are known to use the same tree roosts during the summer maternity season, roosting communally (Mirowsky and Horner, 1997; Saugey, 2000; Lance et al., 2001) or occupying the same roost on different days (Carver and Ashley, 2008). These bats also co-habit bridge structures for roosting (McDonnell, 2001; Bennett et al., 2008). Currently, both species possess varying degrees of protective status at the state level across much of their distributions, reflecting that population sizes of both species are perceived to be low. Collectively, these commonalities would suggest that ecology and conservation needs of these bats are largely similar, at least for much of their distributions, and that a conservation strategy targeting them simultaneously is both plausible and logical, given the limited resources available for conservation and management of rare bats across the southeast. It is with this intent that BCI and the SBDN have prepared this conservation strategy for Rafinesque's big-eared bat and southeastern myotis.

2. RAFINESQUE'S BIG-EARED BAT: NATURAL HISTORY AND STATUS

2.1 Morphology and Systematics

Rafinesque's big-eared bat (*Corynorhinus rafinesquii*, Lesson, 1827) is identified by the presence of large ears or pinnae and two large lumps, or enlarged pararrhinal glands, on the face between the nose and eyes (Figs. 1 and 2). Typical coloration is gray to reddish brown with distinct ventral fur that is black at the base with sharply contrasting white or pale tips. Townsend's big-eared bat (*Corynorhinus townsendii*), a closely related species that is similar in appearance, has ventral hairs which are gray at the base and brown or buff at the tips (Kunz and Martin, 1982). Rafinesque's big-eared bat measures 92 to 106 mm in total length with a wingspan ranging from 268 to 301 mm. Body mass varies considerably, but typically ranges between 7 to 13 grams. Other morphometric measurements include ear (30–37 mm), forearm (40–46 mm), hind foot (9–13 mm) and tragus length (12–16 mm; Handley, 1959; Barbour and Davis, 1969; Jones, 1977). Average wing areas of Rafinesque's big-eared bat (112.8 cm²) appear to be less than their congener Townsend's big-eared bat (129.8 cm²), although wing loadings are similar between the two species at 0.069 g/cm² and 0.07 g/cm², respectively (Jones and Suttkus, 1971).



Figure 1. Rafinesque's big-eared bat possesses large ears and enlarged pararrhinal glands.

previously recognized; *C. r. rafinesquii* and *C. r. macrotus* (Handley, 1959). Handley's (1959) designations suggested *C. r. rafinesquii* occupied the Ohio River valley and karst regions of the Appalachians and central plateaus, and *C. r. macrotus* occupied habitats east and south of the Appalachians and throughout the gulf coastal plain region. Recent molecular phylogenetic studies no longer support sub-specific designation or distinct evolutionary lineages within the geographical boundaries identified by Handley (Piaggio and Perkins, 2005; Piaggio et al., 2011).

Rafinesque's big-eared bat belongs to the Class Mammalia, Order Chiroptera, Family Vespertilionidae, Subfamily Vespertilioninae, and Tribe Plecotini (Handley, 1959). In addition to the genus *Corynorhinus*, the Plecotini contains the New World genera *Euderma* and *Idionycteris* and the Old World genera *Barbastella*, *Otonycteris*, and *Plecotus*. Rafinesque's big-eared bat has been classified as both *Plecotus* and *Corynorhinus*; however, phylogenetic evidence based on morphological and chromosomal data (Frost and Timm, 1992; Tumlison and Douglas, 1992; Bogdanowicz et al., 1998) supports classification as *Corynorhinus* rather than *Plecotus* (Handley, 1959). Prior to Handley (1959), *C. rafinesquii* was the name also attributed to Townsend's big-eared bat (*C. townsendii*) and its subspecies (Dalquest, 1947). Two subspecies were



Figure 2. Rafinesque's big-eared bat is adept at gleaning prey off of objects and capturing prey in flight.

2.2 Breeding Biology

Mating in Rafinesque's big-eared bat occurs in the fall and winter, with ovulation and fertilization delayed until early spring (Hoffmeister and Goodpaster, 1963; Barbour and Davis, 1969). Observations demonstrate that captured individuals had bred in mid-February in North Carolina (Clark, 1990), and in mid-March in northwestern Tennessee (Goodpaster and Hoffmeister, 1952). Males of Rafinesque's big-eared bat with enlarged testes have been recorded from September to March (Handley, 1959; Hall, 1963; Jones and Suttkus, 1975; Clark, 1990). Males have descended testes for most of the year, with a maximum size of 19 x 12 mm reported on 8 September in North Carolina (Clark, 1990). Testes decrease in size between January and March, with the most noticeable change occurring in March (Lowery, 1974; Clark, 1990). Reports of large testes in this species are often based on measurements as small as 9 x 4 mm (Belwood, 1992) which may be large only when compared to sympatric bat species, leading to the probable misconception that males are reproductively active for most of the annual cycle (Finn, 2000). No enlarged testes were observed in first-year males in Louisiana and Mississippi, but marked young males older than one year had testes indistinguishable from older animals (Jones and Suttkus, 1975). No observation of courtship behavior in Rafinesque's big-eared bat has been reported, though Clark (1990) speculated that males may set up territories in late summer, forming resource-defense polygynous mating systems where females join them to form transient harems. Social network analyses of populations of Rafinesque's big-eared bat in western Kentucky suggest otherwise, however, as males were the least central nodes in all social networks examined (Johnson et al., 2012a).

Females give birth to a single pup, with young born in late May or early June in the northern part of the range and about mid-May in the deep-south (Harvey et al., 1999). A captive female that was mated on 13 February, gave birth 93 days later on 17 May (Clark, 1990). This is within the expected gestation period of 59–100 days for the related Townsend's big-eared bat (Pearson et al., 1952). No other reports with data on length of gestation are available for Rafinesque's big-eared bat. Mothers give birth to pups 2.3–2.6 grams in body mass, approximately 28% of adult body mass (Barbour and Davis, 1969; Lowery, 1974; Jones and Suttkus, 1975; Mirowsky, 1998). The young of Rafinesque's big-eared bat are closely associated with their mothers for about three weeks after parturition, at which time they acquire permanent dentition and become volant (Jones, 1977).

Young of Rafinesque's big-eared bat grow rapidly, beginning practice flights within 15–18 days, and becoming capable of flight in about 21 days (Jones, 1977). At one month of age, they achieve adult body mass, but still can be easily identified by their dark pelage (Jones and Suttkus, 1971; Jones, 1977; Clark, 1990). Thereafter, likely due to the stressors associated with becoming independent, body mass of young fluctuates and may be less than that of adults at three months of age (Jones and Suttkus, 1975). By mid-July, most young are able to feed independently (Clark, 1990), though males do not become reproductively mature until their second fall season (Jones and Suttkus, 1975; England et al., 1990). Molt to adult pelage occurs between late July and late August in southern areas, and later in the northern end of the range (Handley, 1959; Jones and Suttkus, 1975).

2.3 Echolocation

Rafinesque's big-eared bat has a relatively low amplitude echolocation call that is difficult to record with standard bat detectors. The structure of the echolocation call varies, but can be described as a frequency modulated sweep with a fundamental frequency around 40 kHz. Calls of this species are less than 10 ms in duration, frequently distributing energy in the call to the second harmonic at 60 kHz (Fig. 3). The bandwidth is also variable with some calls ending at relatively low frequencies in the ultrasonic range. In some cases, the frequency with the highest amplitude is in the second harmonic; this is characteristic of other *Corynorhinus* species (M. Kalcounis-Rüegg, pers. comm.). As is evident from the spectrograph, this low amplitude call is difficult to distinguish from background noise levels. The low amplitude call of Rafinesque's big-eared bat, when recorded, can be distinguished from other sympatric bat species (Fig. 4).

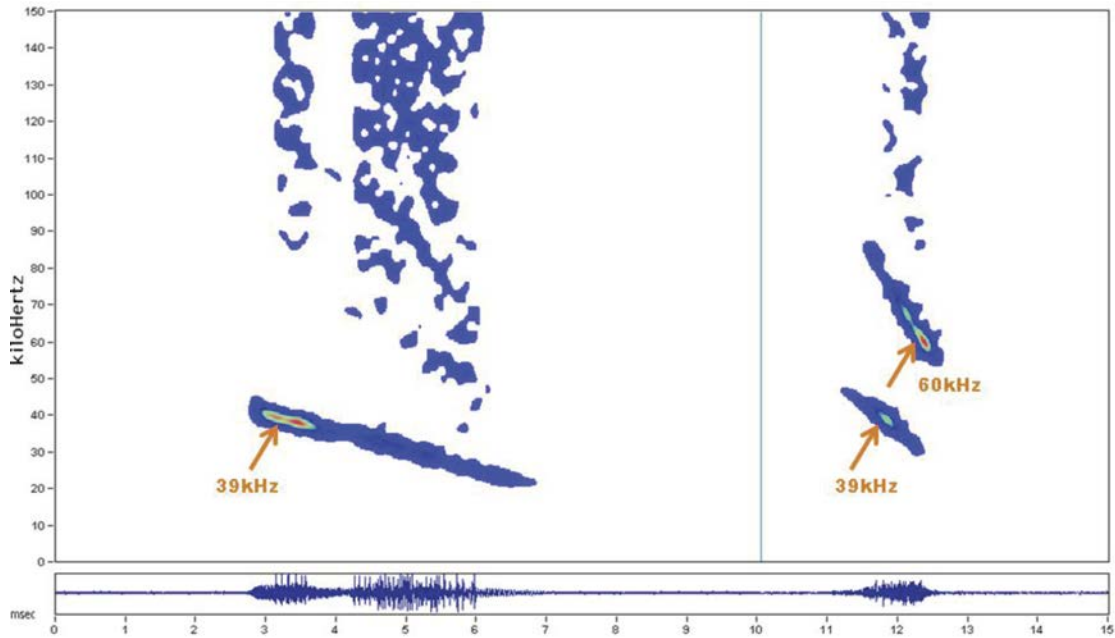


Figure 3. Spectrographs with waveforms of Rafinesque's big-eared bat echolocation calls. Calls recorded from hand held bats in Washington County, North Carolina. Each panel represents a single call from a different individual. Highest amplitude of calls is shown in red. The high background noise level (blue) indicates calls are not much louder than background noise. Spectrographs recorded with Pettersson D240x detectors (from M. Kalcounis-Rüeggell).

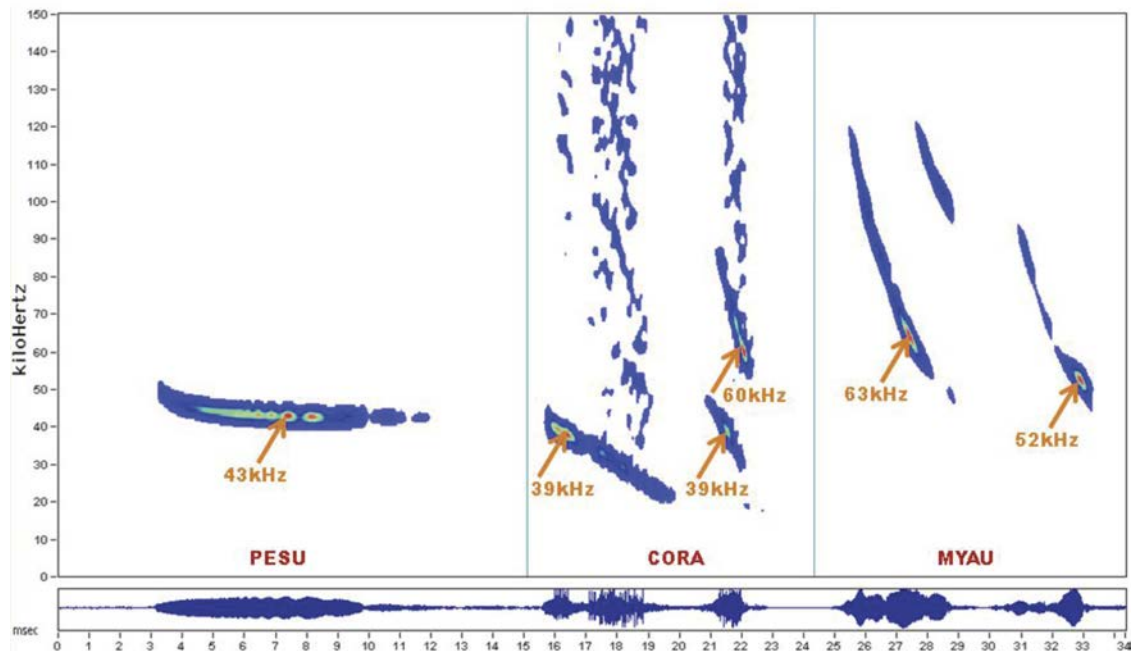


Figure 4. Spectrographs with waveforms of Rafinesque's big-eared bat (CORA) echolocation calls compared to southeastern myotis (MYAU) and tri-colored bats (PESU). Calls recorded from CORA were from hand held bats in Washington County, North Carolina. Calls recorded from MYAU (from Georgia, J Tigner) and PESU (from North Carolina, M. Kalcounis-Rüeggell) were of free-flying hand-released bats. Highest amplitude of calls is indicated in red. Note the comparable background noise for CORA calls and the short duration, large bandwidth of MYAU calls. All spectrographs were recorded with Pettersson D240x detectors.

2.4 Distribution and Abundance

Rafinesque's big-eared bat occurs throughout the southeastern United States, but populations are scattered and the species is considered uncommon over most of its range (Fig. 5). The species occurs from eastern Texas to southern Missouri in the western part of the range, north to southern Illinois, Indiana and Ohio, and eastward to Florida, North Carolina, and West Virginia (Jones, 1977; Harvey et al., 1999). Harvey and Saugey (2001) stated that the distribution included all southern states, except portions of northwestern Arkansas and northern Virginia.

However, studies in South and North Carolina suggest that this bat is largely absent from the piedmont physiographic province (Bunch et al., 1998; Menzel et al., 2003; Fields, 2007; Bennett et al., 2008; Appendix 3). Although widespread

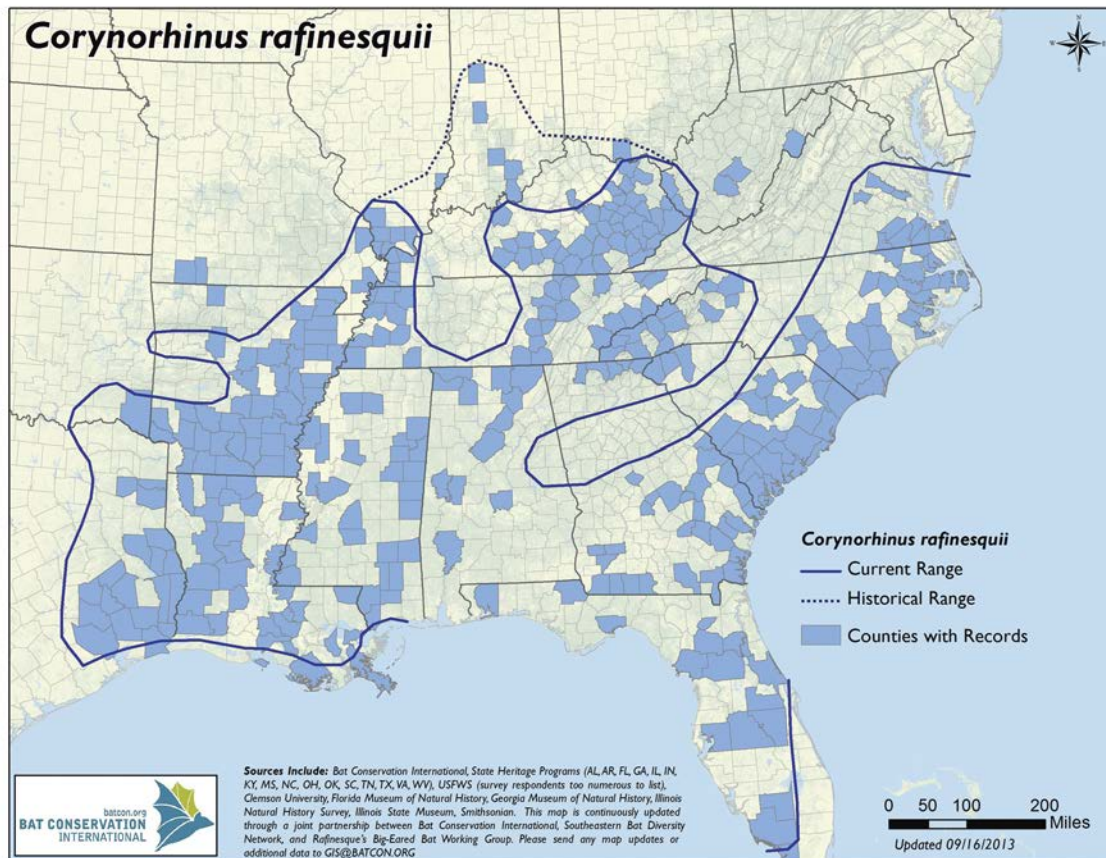


Figure 5. The range of Rafinesque's big-eared bat. Distribution based on natural heritage data from southeastern states and data from individuals. The dashed lines reflect historical records where the occurrence of this species is unclear.

in the southeastern United States, Rafinesque's big-eared bat is nowhere abundant, and populations appear to have declined in the past century (BCI, 2001).

Today, the largest colonies have been documented in Kentucky, North Carolina, and Tennessee where roughly 4,000 hibernate in six significant cave roosts in the Appalachian Mountains and central plateaus of North Carolina and Kentucky. Recent hibernation surveys for these six sites reported the following colony size estimates: Eagle Creek Mine (1575), Hickory Flat Cave Flat Cave (911), Saltpeter Pit Cave (550), Sugar Fork Mine (484), Dead Raccoon Sandstone Cave (303), and Shagbark Rock Shelter (296). Remaining colonies occur throughout the southeast in groups typically <50 individuals. The paucity of data and dispersed roosting habits of this species across much of its range make it difficult to accurately estimate the range-wide population size. Information gathered while updating distribution information on Rafinesque's big-eared bat for this conservation strategy indicates 1,138 known colonies as of 2009 (Bayless et

al., 2011), primarily located in caves, trees, bridges, and abandoned buildings. Insufficient information is available to determine if roosts that have been discovered still exist or are presently occupied by bats. It is likely that future field surveys will continue to add new colonies, both in previously surveyed and un-surveyed locations. For example, telemetry studies of Rafinesque's big-eared bat in Mammoth Cave National Park, Kentucky, from 2009 to 2011 discovered several previously undocumented colonies distributed over >30 new roosting sites, including five previously un-described cave roosts (J. Johnson, unpubl. data; Fig. 6).

2.5 Torpor, Movement Patterns, and Roost Fidelity

Rafinesque's big-eared bat is considered non-migratory, hibernating in the northern part of its range, but usually for only short periods of time, moving among roosting sites throughout the winter hibernation period (Hoffmeister and Goodpaster, 1963; Jones and Suttkus, 1975; Hurst and Lacki, 1999). Hibernation sites include caves, mines, wells, and cisterns (Barbour and Davis, 1969; England and Saugey, 1999; Harvey et al., 1999).

This bat is believed to remain active year-round in the deep-south (Ferrara and Leberg, 2005a), but has been observed using shallow torpor during cold spells and inclement weather (Jones and Suttkus, 1975). Winter roosts are usually near summer foraging grounds (BCI, 2001). Adult females in nursery colonies remain active throughout the summer season, but will enter shallow torpor in the spring before parturition when weather is not favorable (Clark, 1990). Summer colonies of Rafinesque's big-eared bat typically form clusters inside roosts, roosting on vertical surfaces (Mirowsky and Horner, 1997; Carver and Ashley, 2008; Stevenson, 2008). Clark (1990) observed solitary individuals in torpor more often than clustered individuals in colonies at similar temperatures. In one instance, a torpid individual was documented at 23° C (Clark, 1990). Through the use of temperature-sensitive radio-transmitters, Johnson and Lacki (2012) demonstrated that reproductive females entered fewer torpor bouts per day than non-reproductive females or males, with pregnant females spending less time torpid and lactating females entering deeper torpor bouts than other sex and reproductive classes.

Available evidence suggests that Rafinesque's big-eared bat is among the most sedentary of North American bat species. Radio-telemetry studies demonstrate colonies of this bat using hollow trees and frequently moving among trees in close proximity, showing high site fidelity to the same group of trees (Gooding and Langford, 2004; Trousdale and Beckett, 2005; Johnson and Lacki, 2011; Trousdale, 2011). The maximum distances that Rafinesque's big-eared bat has been detected away from primary roosting sites are 2.5–2.6 km in upland forests (England and Saugey, 1998; Hurst and Lacki, 1999; Lance et al., 2001) and 3.1–3.4 km in bottomland forests (Finn, 2000; Johnson and Lacki, 2011). Clark (1990) and Mirowsky (1998) reported that males changed roosts less frequently than females, consistent with observations of Jones and Suttkus (1975) where banded females were recaptured less frequently than males, despite colonies sustaining relatively even sex ratios over time. Clark (1990) found limited roost switching by colonies of Rafinesque's big-eared bat living in buildings, unless bats were disturbed. Strong fidelity to roosting sites has also been documented for this species roosting beneath bridges (Ferrara and Leberg, 2005a; Trousdale et al., 2008; Loeb and Zarnoch, 2011). Ferrara and Leberg (2005a) successfully recaptured most of the banded individuals at the same bridge where they were originally marked. Although band returns and surveys of bridges indicate Rafinesque's big-eared bat repeatedly roosts at the same bridges, the absence of individuals at intervening surveys (<50% occupancy, Ferrara and Leberg, 2005a; <66% occupancy, Bennett et al., 2008) suggests this bat frequently uses alternate roosts. In another study of bridge-dwelling



Figure 6. Recently discovered cave roost of Rafinesque's big-eared bat in Mammoth Cave National Park, Kentucky.

colonies, no banded individual was found in another bridge >100 m from the point of original capture (Trousdale and Beckett, 2001).

Most colonies of Rafinesque's big-eared bat change roosts seasonally (Loeb and Zarnoch, 2011; Roby et al., 2011), with caves or buildings possessing diverse microclimates used year-round (Jones and Suttkus, 1975; Hurst and Lacki, 1999; Finn, 2000). In most of the coastal plain physiographic province, colonies leave buildings or trees with basal openings in late summer for roosts with cooler and more stable temperature microclimates (Clark, 1990; Rice, 2009). In fall, Rafinesque's big-eared bat was observed switching from buildings to tree hollows in North Carolina (Clark, 1990), and in east Texas the species abandoned relatively warm tree hollows (Mirowsky, 1998) for cooler cisterns and abandoned water wells (Schmidly, 1983). Winter roosts are commonly occupied from November to March (England et al., 1990; Whitaker and Hamilton, 1998). Nevertheless, departure and arrival times can be variable. Nursery colonies typically disperse in early fall (Sept–Oct) and reform in spring between early April and late May (Jones and Suttkus, 1975; Clark, 1990).

2.6 Social Organization

Very little is known about the social organization or behavior of Rafinesque's big-eared bat. Adult males are suspected to be territorial, typically roosting separately but near nursery groups (Clark, 1990). Data on dispersal and recruitment of young bats into new colonies remain equivocal (Hurst and Lacki, 1999). Anecdotal evidence in North Carolina suggests that young females join their natal colonies, with young males dispersing to new locations (Clark, 1990). This pattern conflicts with band return data for colonies in Louisiana and Mississippi, where long-term residents of colonies were typically males (Jones and Suttkus, 1975). Clark (1990) hypothesized that reproductively active males set up territories in hollow trees where females join them to form transient harems, with individuals moving among harems; however, social network studies suggest that males are not focal elements of social networks in these bats (Johnson et al., 2012a). Most adult males roost alone while females are nursing, though some reproductively active males have been found with both pregnant and lactating females (Hurst, 1997). Others begin to join female clusters by mid-August, after nursing is complete (Hall, 1963; Barbour and Davis, 1969; England et al., 1990). Occasional males have been observed sharing roosts with nursing mothers, but rarely do they join clusters (Clark, 1990). Nursery colonies typically include 4–50 adults (Hall, 1963; Jones and Suttkus, 1975; England et al., 1990; Mirowsky, 1998; Clark, 1999; Lance, 1999), though groups of 60–300 have been reported (Mohr, 1933; Barbour and Davis, 1974; Clark, 1990; Saugey et al., 1993; Harvey et al., 1999; Hurst and Lacki, 1999). Social networks of Rafinesque's big-eared bat vary temporally (across reproductive seasons) and spatially (across habitats), with density of roost trees strongly influencing social structure in this species (Johnson et al., 2012a). A low density of roost trees leads to a more centralized and less dense social network, emphasizing a single maternity roost (Johnson et al., 2012a). These data suggest that a reduced density of roost trees can place a colony of Rafinesque's big-eared bats at risk should the focal roost become damaged or lost.

2.7 General Habitat Associations

Rafinesque's big-eared bat is closely associated with mature bottomland hardwood forests throughout the southeastern coastal plain and the Mississippi and Ohio River valleys, especially in cypress/tupelo-gum (*Taxodium* spp. and *Nyssa* spp.) stands near permanent water (Gardner et al., 1992; Brown and Brown, 1993; Mirowsky, 1998; Tuttle and Kennedy, 2005). The species is reported from a variety of forest types, but the most dense concentrations have been found in mature cypress/tupelo-gum stands (Lance et al., 2001; Trousdale and Beckett, 2005; Carver and Ashley, 2008). Day roosts of Rafinesque's big-eared bat in bottomland hardwood forests are found primarily in water tupelo (*N. aquatica*) and black gum (*N. sylvatica*), with occasional use of other species (Cochran, 1999; Hoffman, 1999; Gooding and Langford, 2004; Trousdale and Beckett, 2005). Rafinesque's big-eared bat roosts in hollow trees that are canopy dominants, characteristic of older cypress/tupelo-gum forests. Rafinesque's big-eared bat has also been documented using hammock-type vegetation in Florida (Jennings, 1958), mature (70–90 years old) oak-hickory forests in Kentucky (Hurst and Lacki, 1999), and upland oak-hickory forests in the central Cumberland Plateau and Highland Rim areas of Tennessee (M. Tuttle, pers. comm.). Males have been reported from mature, open, pine flatwoods in Florida and South Carolina (Brown, 1997; Menzel et al., 2001b), and a Rafinesque's big-eared bat was captured with a mist-net in a mixture of juniper (*Juniperus* sp.) and loblolly pine (*Pinus taeda*) in Texas (Schmidly et al., 1977). On a few occasions, Rafinesque's big-eared bat has been reported roosting in tree crevices (Lance, 1999), beneath loose bark (Handley, 1959), and among dead leaves (Harper, 1927), but these behaviors are presumed rare.

2.8 Winter Roosting

Bats select roosting sites based on proximity to foraging habitat, availability of nearby roosts, roost dimensions, energetic considerations, and the risks of predation and parasitism (Kunz, 1982; Lewis, 1995; Kunz and Lumsden, 2003).

Rafinesque's big-eared bat forms colonies in caves, mines, and other karst features during both summer maternity and winter hibernation seasons (Barbour and Davis, 1969; Harvey et al., 1999). Colonies in karst features tend to be larger (up to 1,500 individuals) in the northern part of the species range, with winter and summer colonies in southern forests usually much smaller and scattered across the landscape. In the coastal plain physiographic region, where cave and karst resources are not available, this bat is believed to remain in mature, closed canopy bottomland hardwood forests roosting in large hollow trees during winter. However, in landscapes where water wells and cisterns exist, these human-made structures are readily occupied in winter months (England and Saugey, 1999; Sasse et al., 2011).

Except where caves or human structures provide a sufficiently wide range of suitable temperatures (Hurst and Lacki, 1999; Finn, 2000), most colonies of Rafinesque's big-eared bat move seasonally among roosts. Fall and winter roosts are cooler and vary widely according to climate. Caves and mines, and rarely concrete culverts, are chosen in the northern extent of the distribution (Handley, 1959; Mumford and Whitaker, 1982; Whitaker and Hamilton, 1998). Abandoned cisterns and water wells are used in winter from northwestern Tennessee (Goodpaster and Hoffmeister, 1952) to southern Arkansas (Baker and Ward, 1967; England et al., 1990) and in central Louisiana (Patton, 2009) and eastern Texas (Schmidly, 1983). In North Carolina, tree cavities provide cooler, relatively stable temperatures that are believed to support winter use by colonies of Rafinesque's big-eared bat that rely on warmer, but less thermally stable buildings in summer (Clark, 1990; Clark and Williams, 1993). Similarly, in Louisiana, bridge roosts are abandoned during the coldest weather in exchange for hollow trees (Lance et al., 2001). However, in eastern Texas, tree cavities are abandoned in late fall presumably because they are too warm (Mirowsky, 1998).

Rafinesque's big-eared bat, though capable of entering hibernation, is typically more alert and active than other species in winter (Jones and Suttikus, 1975; Jones, 1977). Mumford and Whitaker (1982) summarized observations indicating a strong tendency for this species to hibernate at sites in or adjacent to mature forest, and in twilight zones near cave and mine entrances. Such locations are subject to substantial air flows and temperature fluctuations, which may alert individuals to outside conditions, enabling them to emerge and feed nearby on warm, winter evenings. By adapting to feed in winter, this bat has likely reduced the need for migration and probably exploits un-seasonal opportunities near quality foraging sites (Boyles et al., 2006). Further observations will likely demonstrate a range of winter behaviors in Rafinesque's big-eared bat, from lengthy hibernation where cooler roosts are available to nearly continuous nightly activity and winter feeding in the warmest climates. Florida populations are believed to feed on mild evenings year-round (Brown, 1997) and, in southern Louisiana, use of torpor increased by only 17% from summer to winter months (Jones and Suttikus, 1975); twenty percent of Rafinesque's big-eared bats were found torpid on average from December to May compared to 3% in remaining months (Jones and Suttikus, 1975). Some winter activity occurs as far north as northwestern Tennessee and central Kentucky (Hoffmeister and Goodpaster, 1963; Johnson, et al., 2012b).

2.9 Summer Roosting

In summer months, hollow trees provide stable, well-insulated internal environments and protection from predators essential for rearing young (Trousdale, 2011). Many authors describe summer roosts of Rafinesque's big-eared bat in hollow mature trees, primarily black gum and water tupelo, and occasionally baldcypress (*Taxodium distichum*), southern magnolia (*Magnolia grandiflora*), American sycamore (*Platanus occidentalis*), American beech (*Fagus grandifolia*), oaks (*Quercus* spp.) and hickories (*Carya* spp.) (reviewed in Trousdale, 2011). These trees typically possess basal openings that lead to chimney-shaped cavities (Fig. 7; Clark, 1990; Mirowsky and Horner, 1997; Gooding and Langford, 2004; Trousdale and Beckett, 2005; Carver and Ashley, 2008; Stevenson, 2008), although roost trees possessing broken tops and roost openings in the mid-section of the bole have also been reported (Rice, 2009; Johnson and Lacki, 2011).

Roost trees of Rafinesque's big-eared bat are typically tall (18 – 25 m), possess large cavities (height >120 cm; width >39 cm), and are often in close proximity to permanent water (Mirowsky, 1998; Gooding and Langford, 2004; Trousdale and Beckett, 2005; Carver and Ashley, 2008). Measured diameters of roost trees averaged 124.5 cm in Tennessee (Carver and Ashley, 2008), 120 cm in Louisiana (Lance et al., 2001; Gooding and Langford, 2004), 155 cm in Arkansas (Cochran, 1999), and 99 cm in Texas (Mirowsky and Horner, 1997). More recently, data indicate that colonies of Rafinesque's big-eared bat also select roost trees with both chimney hollows and additional openings either at the top or

upper sections of the tree to facilitate escape from predators and floods (Gooding and Langford, 2004; Rice, 2009; Johnson and Lacki, 2011; Clement and Castleberry, 2012). In bottomland hardwood forests in Mississippi, Rafinesque's big-eared bat selects larger trees, i.e., greater diameter, for roosting in winter than in spring and summer (Fleming et al., 2013a).

Interior cavities of roost trees were described as ranging from 3 to 4 m (Clark, 2000) and averaging 5.7 m (Stevenson, 2008) in height. A representative roost in a tupelo gum tree was described by Gardner et al. (1992) as having an opening at the base 60 cm tall by 25 cm wide, with an interior cavity 1.4 m wide at the base and ca. 7 m in height. Cavities with the largest basal openings appear to be preferred, with predator avoidance offered as an explanation for the selection of larger opening (Mirowsky, 1998; Clement and Castleberry, 2012). Roost tree species and configuration influenced torpor behavior in Rafinesque's big-eared bat in Kentucky, with bats entering torpor for longer periods of time when occupying water tupelos possessing only basal cavity entrances (Johnson and Lacki, 2012).

2.10 Artificial Structures for Roosting

Rafinesque's big-eared bat has been documented roosting in undisturbed buildings, barns, abandoned wells, bridges, cisterns, and culverts (Goodpaster and Hoffmeister, 1952; Handley, 1959; Barbour and Davis, 1969, Jones and Suttkus, 1975; Clark, 1990, 1999; Lance et al., 2001; Trousdale and Beckett, 2004; Ferrara and Leberg, 2005b; Bennett et al., 2008). Building roosts are typically wood frame or concrete construction, with dark zones and access through open doors and windows (Clark, 1990; Roby et al., 2011). Clark (1990) described most buildings used by Rafinesque's big-eared bat as dilapidated, and postulated that proximity to suitable foraging habitats was as important to this bat as internal roost characteristics in selection of sites for day-roosting. Based on data coalesced to develop this conservation strategy, some of the largest known maternity colonies of Rafinesque's big-eared bat (>100 individuals) exist in Mississippi, Tennessee, Kentucky, and Texas inside building roosts. Rafinesque's big-eared bat is sensitive to human disturbance, and has been documented abandoning roost sites when disturbed frequently, especially during the maternity season (Clark, 1990; Lacki, 2000).

Throughout its distribution, Rafinesque's big-eared bat has been observed using concrete T-beam cast-in-place girder or concrete multi-beam girder bridges (Lance et al., 2001; McDonnell, 2001; Trousdale and Beckett, 2004; Ferrara and Leberg, 2005b; Bennett et al., 2008). Preferred bridge roosts of this bat are of concrete construction, with girders running the length of the bridge creating compartments and a variety of dark zones (Ferrara and Leberg, 2005b). Multi-beam girder bridges are variable in structure but generally consist of parallel beams that span the entire length of the bridge and sometimes are referred to as I-beam or channel beam bridges. T-beam bridges also have parallel beams that span the entire length of the bridge, but the support beams are intersected at right angles by cross beams (Bennett et al., 2008). In Mississippi, this type of concrete T-beam bridge design is commonly referred to as "Choctaw" style (A. Trousdale, pers. comm.). In the western United States, colonies of Townsend's big-eared bat have been documented roosting in box beam girder bridges, which may indicate another potentially suitable design for Rafinesque's big-eared bat. The species has not been observed under slab bridges or found in narrow crevices or expansion joints (Ferrara and Leberg, 2005b; Bennett et al., 2008), and bridges of creosote-treated wood appear to be avoided (Lance et al., 2001).

Colonies of Rafinesque's big-eared bat roosting in bridges, range from solitary individuals to >100 individuals (P. Leberg, pers. comm.). Design and materials seem to be more important than bridge size. Although bridges used by this bat in a state-wide study by Bennett et al. (2008) were generally larger and longer than non-used bridges, other studies (Lance et al., 2001; McDonnell, 2001) and personal communication from state biologists indicate both large (spanning rivers and highways; >15 m [50 ft] high at center) and small (narrow U.S. Forest Service (USFS) gravel roads; <6 m [20 ft] high at center) bridges are used. In addition to bridge design and construction materials, surrounding landscape conditions also appear to be important in bridge selection by Rafinesque's big-eared bat. For example, in Louisiana, the proportion of mature deciduous forest and mean age of trees in surrounding habitats correlated with the selection of bridge roosts by this species (Lance et al., 2001).

Rafinesque's big-eared bat has been observed using open spaces between the beams of bridges in seven states during summer, spring, and fall seasons. Studies of bridge roosts consistently report seasonal use, with the majority of observations occurring in summer months (May-Sept) and only a few bats reported using bridges during winter (Trousdale and Beckett, 2004; Ferrara and Leberg, 2005b; Bennett et al., 2008; Loeb and Zarnoch, 2011). Maternity colonies of Rafinesque's big-eared bat have been observed using bridges to bear and raise young (Ferrara and Leberg, 2005b; Bennett et al., 2008; Trousdale et al., 2008; Wolters and Martin, 2011). Ferrara and Leberg (2005b) found bats roosting in the darkest portions of the bridge closer to abutments, but never <0.42 m aboveground. Although temperatures at

roosting sites were still about 5° C cooler than ambient, roosting sites were warmer than other areas of the bridge (Ferrara and Leberg, 2005b). Maternity colonies have been documented close to abutments on low bridges darkened by thick vegetation (Keeley and Tuttle, 1999), but also farther from abutments and higher off the ground (Ferrara and Leberg, 2005b). Because abandoned buildings likely deteriorate more rapidly over time, bridges with appropriate roosting characteristics probably offer more suitable long-term roosting opportunities.

2.11 Roosting Microclimates

Maternity colonies of Rafinesque's big-eared bat are believed to be able to tolerate a wide range in temperatures (6–42.8° C; J. MacGregor, unpubl. data). A maternity colony occupying a sandstone cave in eastern Kentucky roosted at temperatures in April and May with limited variation around 10° C (Hurst and Lacki, 1999); stable and predictably cooler temperatures during late pregnancy and parturition likely facilitated birthing and may have aided adult females in reducing energy expenditures through use of shallow torpor (Speakman and Thomas, 2003; J. Johnson, unpubl. data). Temperatures in this roosting site warmed in June and July reaching in excess of 15° C, and maximized at around 19° C in early September (Hurst and Lacki, 1999). These bats moved among different rooms throughout the year, likely taking advantage of varying temperatures among rooms to permit occupation of the cave year-round. A lone, cave-dwelling male was found roosting in the exact same location at 12° C for an entire summer (Hall, 1963).

Temperature ranges inside roosting sites used by maternity colonies of Rafinesque's big-eared bat in the southern end of the distribution appear to be warmer than those recorded in roosts at the northern edge of the range. Temperatures in tree cavities used by maternity colonies in Texas ranged from 24–27° C (Mirowsky, 1998), and in North Carolina temperatures ranged from 24.5–46° C in an attic of a building and 19–27° C in a cistern used by pregnant females in May (Roby et al., 2011). Hollow tree roosts in Texas were more thermally stable than unoccupied trees and ambient temperatures in summer months (Mirowsky, 1998), and in North Carolina roosts in hollow trees were more thermally stable than those in buildings, with temperatures in the latter more often higher and more variable (Clark, 1990; Clark and Williams, 1993). Diurnal temperatures in buildings occupied by nursery colonies ranged from 20–29° C and 22–30° C in North Carolina and Florida, respectively (Clark, 1990). Similar temperatures were observed in artificially-constructed roosts successfully occupied by maternity colonies of Rafinesque's big-eared bat throughout the southeastern US (M. Bayless, unpubl. data). Daily highs in temperature averaged 31° C (range 29°–33° C) and daily lows in temperature averaged 23° C (range 21–24° C).

In building roosts of Rafinesque's big eared bat, maternity colonies that used warmer attics often switched to lower, cooler rooms when attic temperatures reached 36° C (Clark, 1990), indicating this species may reach its upper critical threshold at or near this temperature (Speakman and Thomas, 2003). Bats probably moved to alternate roosting sites within structures to prevent energy expenditures required to keep the body cool while roosting in the attics at temperatures above the upper critical threshold (Geiser, 2003; Speakman and Thomas, 2003). Jones (1977) speculated that the need for nursery roost warmth likely accounts for the tendency of this species to form larger colonies in northern areas of its distribution. Even in milder climates, nursery colonies are more likely to cluster when faced with periods of relatively low temperatures; thus, varied roost types likely contribute to colony success (Clark, 1990). Where old cisterns or wells are used, reproductive females apparently abandon them for warmer roosts in summer (Goodpaster and Hoffmeister, 1952; England et al., 1990). Males often remain, perhaps because these roosts trap cool air facilitating shallow torpor in these bats to conserve energy. There are no data to suggest that humidity is a limiting factor in choice of summer roosts; hollow trees measured in Texas had relative humidity values reaching 100% (Mirowsky, 1998).

Rafinesque's big-eared bat has adapted to winter survival in an extraordinarily wide range of climatic conditions, complicating interpretation of temperature conditions recorded inside roosts. Hibernation temperatures of this species reported for Indiana and Illinois range from 0.6 to 14.4° C, with most at or below 8.9° C (Layne, 1958; Pearson, 1962; Mumford and Whitaker, 1982). Selection of temperatures in roosts in Kentucky, Tennessee, and Arkansas seem to be similar. In a small eastern Kentucky cave, a group of 49 bats hibernated where winter roost temperatures ranged from 0–8° C (Hurst and Lacki, 1999). A single male was observed hibernating at 9° C in a cave in central Kentucky (Hall 1963). In northwestern Tennessee, a group of more than 60 Rafinesque's big-eared bats overwintered in a 6-m deep cistern, roosting in the upper half in warm weather and the lower half when ambient conditions became colder (Hoffmeister and Goodpaster, 1962). Two males in Arkansas caves were hibernating at 5.0 and 8.3° C in late January (Saughey et al., 1993).

Temperatures inside roosting structures of Rafinesque's big-eared bat in winter months further south in the distribution appear warmer, although existing data sets are even more limited. A nursery colony in central Florida occupied an

abandoned trailer house year-round, roosting where daily temperatures ranged from 8.4–28.3° C, and averaged 18.9° C from mid-November through February (Finn, 2000). Numbers of bats sharing the roost were more than halved in February and March compared to the maternity season. Temperatures beneath bridge roosts of Rafinesque's big-eared bat in Louisiana from November to March averaged ca. 13° C and were significantly warmer than ambient (Ferrara and Leberg, 2005b). Few data on relative humidity have been recorded at winter roosts. Rafinesque's big-eared bat occupied a cave in Arkansas with relative humidity values ranging from 45–95% (Saughey et al., 1993). A population using an abandoned house trailer in central Florida roosted at relative humidity values ranging from 65–85% (Finn, 2000).

2.12 Communal Roosting

Several authors indicate that Rafinesque's big-eared bat rarely uses roosts occupied by other species of bats (Jones and Suttikus, 1975; Clark, 1990; Mirowsky, 1998; Lance, 1999; Stevenson, 2008), although southeastern myotis does use the same roosts, sometimes simultaneously (Mirowsky and Horner, 1997; Saughey, 2000; Lance et al., 2001; Sasse et al., 2011) or on different days (Carver and Ashley, 2008). These two bat species also co-habit bridge structures (McDonnell, 2001; Bennett et al., 2008) and water wells (Sasse et al., 2011) for roosting. Southeastern myotis has been observed during winter months roosting within clusters of Rafinesque's big-eared bat (Mirowsky, 1998; Stevenson, 2008). Carver and Ashley (2008) investigated sympatric use of roosts by southeastern myotis and Rafinesque's big-eared bat in Tennessee and found only two of the 30 roost trees identified to be used by both species (97 and 101 cm dbh). These two trees were among the smallest roosts of Rafinesque's big-eared bat (range 77–195 cm dbh), and among the largest roosts of southeastern myotis (range 23–101 cm dbh; Carver and Ashley, 2008). This apparent preference by southeastern myotis and Rafinesque's big-eared bat for different sizes of roost trees during the maternity season was also noted by Stevenson (2008). In her study, both non-reproductive and wintering bat colonies shared trees, but maternity colonies of Rafinesque's big-eared bat roosted in larger trees (minimum 115 cm dbh) than did maternity colonies of southeastern myotis (maximum 95 cm dbh). Larger roosts were selected more frequently by both species during winter months (Stevenson, 2008).

In shared roosts, Rafinesque's big-eared bat typically roosts along the sides of the tree cavity below the apex, whereas southeastern myotis roosts in densely packed clusters at the top of cavities (Horner and Mirowsky, 1996; Carver and Ashley, 2008; Stevenson, 2008). An explanation for this apparent difference in roosting behavior is unclear, but Carver and Ashley (2008) speculate that it represents either: 1) different thermal requirements for roosting between the two species, or 2) behavioral differences in selection of micro-sites for roosting. During winter months in Mississippi, southeastern myotis and Rafinesque's big-eared bat were regularly documented using the same tree roosts simultaneously, even clustering together in a torpid state (Stevenson, 2008). Rafinesque's big-eared bat has also been recorded cohabiting water wells with tri-colored bats, *Perimyotis subflavus* (Sasse et al., 2011).

2.13 Foraging Habitats

Much less is known about use of foraging habitats than use of roosting habitats by Rafinesque's big-eared bat (Lacki et al., 2007). In the eastern Cumberland Plateau of Kentucky, a large nursery colony of this species foraged in 70–90 year-old oak-hickory forests along mid-slopes of ridges, avoiding lowland areas and yellow poplar and beech-maple forests (Hurst and Lacki, 1999). In bottomland hardwood forests of the coastal plain, Clark (1991) observed Rafinesque's big-eared bat foraging low, perhaps gleaning, in dense vegetation. Swamp forests represented 32.2–87.2% of the area used by radio-tagged bats of this species in South Carolina (Clark et al., 1998). Males foraged primarily in young pine stands in the Upper Coastal Plain of South Carolina, even though large contiguous tracts of mature bottomland hardwoods were common in the area (Menzel et al., 2001b). Home ranges of this species were located closer to forested and herbaceous wetlands and upland deciduous forests than to agricultural areas and open fields in western Kentucky (Johnson and Lacki, 2011). Pregnant females of this bat were found to forage extensively in deciduous forests on drier soils where moths were abundant, even though roost sites were situated further away in forested wetlands (Johnson and Lacki, 2013). Mist net captures in bottomland forests of northeast Arkansas demonstrated an association with dry land corridors and less use of flight corridors over water (Medlin and Risch, 2008).

Size of foraging areas of Rafinesque's big-eared bat ranged from 61.6–225.3 ha in eastern Kentucky (Hurst and Lacki, 1999). Foraging areas were located within 0.1–1.2 km of the roost and overlapped each other by 33.5–85.5%. In North Carolina, foraging occurred 0.7–3 m above ground, mostly beneath the sub-canopy. Open water, fields, and

roadways were avoided (Clark, 1991). In the Upper Coastal Plain of South Carolina, males commonly fed in uplands, such as natural pine communities and pine plantations, where they preferred sapling stage stands over sawtimber stands (Menzel et al., 2001b). Feeding areas were relatively small, 93.1 ha on average, and were located <1 km from roosting sites. Size of foraging areas did not significantly differ between lactating (178.5 ha) and post-lactating (231.7 ha) females feeding in bottomland hardwood forests in Kentucky, due in part to the wide variation in foraging area size among individual bats (Johnson and Lacki, 2011). In central Florida, no size difference was found among bats of various sex and reproductive classes (Finn, 2000), but foraging areas were larger in February (late winter) than in other seasons. Bats foraged most often in forested wetlands in November to February, switching to upland oak forests in August through April. Forested wetlands and pastures were used more than other habitat types, while palmetto and non-forested wetlands were used the least by Rafinesque's big-eared bat; wet prairie and unimproved pastures were not used at all for foraging (Finn, 2000).

2.14 Foraging Behavior and Diet

Rafinesque's big-eared bat is an agile flier that can glean insects from foliage and other substrates, often foraging within 1 m of the ground surface (Barbour and Davis, 1969; Clark, 1991; Ellis, 1993). The species is extraordinarily versatile, capable of flight ranging from direct and swift to slow and highly maneuverable (Barbour and Davis, 1969; Griffin, 1986; Whitaker and Hamilton, 1998). Rafinesque's big-eared bat can navigate in small spaces and can hover in place for several seconds at a time (Belwood, 1992). Mothers are capable of carrying babies weighing as much as 5.0–6.2 grams from one roost to another, even though this added mass equates to as much as 66.4% of adult body mass (Jones and Suttkus, 1971; England et al., 1990). This bat emerges late in the evening to feed and is not known to forage at twilight (Harvey et al., 1999), although extensive consumption of Tabanid flies by a colony of this bat in North Carolina suggests otherwise, as swarms of these flies have diurnal to crepuscular activity periods (Gaugler and Schutz, 1989; Schutz and Gaugler, 1992), with cessation of hovering activity associated with threshold lows in light intensity (Corbet and Haddow, 1962). The activity patterns of four male Rafinesque's big-eared bats tracked in South Carolina were biphasic, with bats beginning to forage shortly after sunset and continuing until ca. midnight, and then re-emerging to forage around 0530 hr and continuing until shortly before sunrise (Menzel et al., 2001b). Rafinesque's big-eared bats are believed to respond to calls from conspecifics while in flight, and to use this information in establishing spatially separated flight paths in foraging areas occupied by multiple individuals (Loeb and Britzke, 2010).

Rafinesque's big-eared bat feeds primarily on Lepidoptera (Lacki et al., 2007), including moths in the families Arctiidae, Geometridae, Megalopygidae, Noctuidae, Notodontidae, and Sphingidae (Hurst and Lacki, 1997; Lacki and LaDeur, 2001). Moths comprised 90.9–96.7% (by volume) of the prey consumed at four roosts and five feeding shelters of this species in Kentucky, and all of the 94 fecal pellets examined contained moths (Hurst and Lacki, 1997). Other insect remains from fecal pellets (by volume) included beetles (Coleoptera), cicadas and leafhoppers (Homoptera), flies (Diptera), true bugs (Hemiptera), bees and ants (Hymenoptera), and traces of caddis flies (Trichoptera). Rafinesque's big-eared bat also on occasion consumes large numbers of horseflies and crane flies when available (Ellis, 1993; Tuttle and Kennedy, 2005).

Discarded moth wings, collected from March to September at a nursery cave in Kentucky, represented all six families of moths known to be prey of Rafinesque's big-eared bat, as well as 22 moth species (Lacki and LaDeur, 2001). Average wingspan size of the moths eaten by month ranged from 42.5 mm in August to 53.5 mm in March. Species of moths, eaten by this bat, ranged in wingspan size from 28 mm (*Allagrapha aerea*) to 70 mm (*Deidamia inscripta*; Hurst and Lacki, 1997). Recent studies using DNA-based techniques (Dodd et al., 2012a) on fecal samples of Rafinesque's big-eared bats in Mammoth Cave National Park, Kentucky, are demonstrating that the range of moth species eaten based on wingspan size exceeds the lower limit of values reported in the literature (e.g., 23 mm, *Palthis angulalis*; L. Dodd, unpubl. data), suggesting that these bats consume other families and species of moths, particularly larger microlepidoptera, and likely due so by aerial hawking in flight. A large proportion of moth species in the diet of these bats feeds on oaks and hickories in the larval stage (Covell, 1984; Hurst and Lacki, 1999), consistent with the abundance of these tree species in surrounding forests in Kentucky. Rafinesque's big-eared bat was commonly seen gleaning moths directly from the walls and ceiling of the entrance to a maternity cave, in addition to catching moths in flight (Lacki and LaDeur, 2001).

Rafinesque's big-eared bat is too rare to likely have an impact in controlling larval moth pests (Whitaker and Hamilton, 1998); however, this species does consume pest species, from disease-transmitting flies to moth larvae that attack forests and agriculture (Ellis, 1993; Lacki and LaDeur, 2001). Ellis (1993) emphasized the consumption of horse and

deer flies that inflict painful bites and can transmit diseases. She found these flies comprised nearly a third of the diet of Rafinesque's big-eared bat at her study site in North Carolina, and noted the possible importance of this bat in locally disrupting the life cycle of these flies by preying on reproductive swarms that have few other predators.

2.15 Survivorship and Mortality

Few observations of mortality or longevity exist for Rafinesque's big-eared bat. Early juvenile mortality has been reported to be low in Arkansas (England et al., 1990), but as high as 40–60% in one South Carolina colony (Thomas and Best, 2001). The maximum longevity reported is of a female banded on 14 July 1951 in West Virginia which was recovered 10 years and one month later (Paradiso and Greenhall, 1967). In southern Louisiana, banding of Rafinesque's big-eared bats of unknown age documented survival of some bats for at least eight years (Jones and Suttkus, 1975); relatively few banded individuals were seen again after three years. Loeb and Zarnoch (2011) observed two bats that were at least five and six years in age, respectively. Such reports are likely conservative, as banded bats may learn to avoid recapture or never return to the site where they were banded. Sources of mortality are poorly documented, though loss of roosts, human vandalism, flooding, and predation are most frequently noted (Clark, 1990; Finn, 2000; Bennett et al., 2004). Finn (2000) concluded that rat snakes (*Scotophis* sp.) were primary predators at a nursery roost in a central Florida house trailer, and Clark (1990) observed gray rat snakes (*S. spiloides*) stalking bats in North Carolina buildings. Jones (1977) lists a variety of suspected predators, including additional species of snakes, raccoons (*Procyon lotor*), house cats (*Felis catus*), and opossums (*Didelphis virginiana*).

2.16 Parasites and Diseases

Limited information exists on parasites and diseases of Rafinesque's big-eared bat (Whitaker and Hamilton, 1998). Surveys for the prevalence of rabies (*Rhabdovirus*) in bats in Arkansas and Florida show that Rafinesque's big-eared bat rarely tests positive for the disease (Bigler et al., 1975; McChesney et al., 1983; Heidt et al., 1987), with only a single rabid individual recorded from Howard County, Arkansas (Sasse and Saugey, 2008). Regardless, Heidt et al. (1987) suggested caution in assuming this species is largely rabies-free. Parasites of this species are virtually unknown, with only data on helminth parasites of the stomach and small intestines recorded, including one genus of Cestoidea (*Vampirolepis* sp.) and two genera of Nematoda (*Physaloptera* sp. and *Capillaria palmata*; McAllister et al., 2005). Wolters and Martin (2000) reported on a maternity colony of partially hairless Rafinesque's big-eared bats located beneath a concrete bridge in west-central Mississippi. The cause was unknown, but the summer of 2000 was extremely dry and the bats may have been subjected to a high degree of environmental stress. Hairless bats were again observed beneath the bridge in 2004. Skin scrapings and hair samples taken from several specimens and dermatophyte cultures were positive but non-pathogenic (M. Wolters, unpubl. data).

Impacts to populations of Rafinesque's big-eared bat from possible occupation of roosting sites harboring the *Pseudogymnoascus* fungus remain unclear (Blehert et al., 2009; Gargas et al., 2009; Meteyer et al., 2009; Frick et al., 2010). No evidence of infection in this species has been recorded; however, if vulnerable, Rafinesque's big-eared bat is more likely to be so at the northern end of its distribution than the central and southern regions, because of its tendency to roost in caves and form larger hibernating populations further north (Barbour and Davis, 1969; Harvey et al., 1991). Several other bat species have been observed hibernating or roosting in the same caves as Rafinesque's big-eared bat at the northern end of the distribution, including species known to be affected by WNS including tri-colored bat, big brown bat (*Eptesicus fuscus*), and northern myotis (*Myotis septentrionalis*; Hurst, 1997; Hurst and Lacki, 1999; Lacki, 2000; Lacki and LaDeur, 2001). Rafinesque's big-eared bat is typically more alert and active than other bat species in winter (Jones and Suttkus, 1975; Jones, 1977), and its preference for hibernating in the twilight zone of cave and mine entrances where substantial air flow and temperature fluctuations occur (Mumford and Whitaker, 1982) may render the species less affected by WNS. A recent study of hibernating behavior in several populations of this bat in Kentucky also suggests that Rafinesque's big-eared bat may be less affected by the fungus than other cave-hibernating species of bats, because these bats used shallow torpor in hibernation, aroused frequently and remained active in winter, and commonly switched among roosts during winter hibernation (Johnson et al., 2012b).

2.17 Species Status

Rafinesque's big-eared bat occurs throughout the southeastern United States but has never been considered common and was formerly listed by the USFWS as a Category 2 species. Handley (1959) expressed concern about the status of the species because so few large roosts and so few museum specimens existed at that time. Jones and Suttkus (1975) studied Rafinesque's big-eared bat in Louisiana and concluded that populations were declining. Some experts believe the species should be considered as a candidate for federal protection, with the species currently undergoing a status review by the USFWS. Throughout its range, Rafinesque's big-eared bat has drawn special attention by both federal and state agencies. Currently, this bat is ranked as vulnerable (G3/G4 status) by NatureServe (Appendix 1), a non-profit conservation organization whose mission is to provide the scientific basis for effective conservation action. The USFS, Southern Region (R8), designates this bat as sensitive with a vulnerable (N3/N4) rank. State Wildlife Action Plans (SWAP) designate special status to Rafinesque's big-eared bat throughout the range. The species is listed as threatened, endangered, or special concern in 16 of 18 states where it is known to occur, the exceptions being Louisiana and Missouri (Appendix 1). Rafinesque's big-eared bat is listed as vulnerable to extinction (VU) in the 2004 IUCN Red List, considered a federal species at risk (USFWS, 1985), and is listed as critically imperiled in Alabama, Virginia, and West Virginia.

Many old-timers in Alabama, Kentucky, Tennessee, and Virginia recall populations of "mule-eared bats" (Barbour and Davis, 1969; 1974). Roosts of Rafinesque's big-eared bat in rock shelters and caves can be easily discovered, and the movement of its large ears likely has long attracted the attention of both predators and human visitors. All too often investigators have checked caves reported to have sheltered colonies of this species by locals, only to find clear evidence of an old roost, sometimes with a lone individual present, where up to 100 or more had lived prior to human disturbance. Rafinesque's big-eared bat appears to be intolerant of disturbance at roosts in buildings, cave entrances and rock shelters (Clark, 1990; Lacki, 2000). Impacts of human disturbance at roosting sites, coupled with degradation of bottomland hardwood forests, particularly the loss of extra large, tree hollows from both land clearing and drainage of bottomland hardwood forests (Tiner, 1984; Mitsch and Gosselink, 2001), have likely rendered the species vulnerable and rare throughout much of its range prior to modern research and conservation efforts (Clark, 2000).

Many existing colonies of Rafinesque's big-eared bat are now using human-made structures that are themselves rapidly disappearing (Clark, 1990; Belwood, 1992; Lance, 1999). Additionally, populations are becoming increasingly more isolated and susceptible to natural threats, such as hurricanes (Clark, 2000). Conservation of remaining old-growth forests and reestablishment of corridors connecting suitable habitat are important to the long-term conservation of this bat (Clark, 2000), as is provision of artificial roosts in areas of depleted roosting resources (Clark and Williams, 1993). Given its reliance on moths (Hurst and Lacki, 1999; Lacki and LaDeur, 2001), the species may also be vulnerable to pesticides and larvacides used against pest moth species in forests, and to overall loss of woody plant diversity in forests essential for larval development of moth prey (Dodd et al., 2008, 2012b; Lacki and Dodd, 2011).



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3. SOUTHEASTERN MYOTIS: NATURAL HISTORY AND STATUS

3.1 Morphology and Systematics

Southeastern myotis (*Myotis austroriparius* (Rhoads, 1897)) is a relatively small myotis that is highly variable in color (Figs. 7 and 8). The dorsal fur varies from gray to gray brown to bright orange-brown, and the ventral fur varies from tan to white (LaVal, 1970; Gardner et al., 1992; Humphrey and Gore, 1992). Three distinct color phases, red,

gray/brown, and a mottled mixture of colors, were reported from 145 captures of southeastern myotis in July and August (Mirowsky, 1998). Rice (1957) observed that juvenile bats could be distinguished from adults based on pelage through early August, but during September they molt and become indistinguishable from adults. Mirowsky (1998) found only adults were red, and a young-of-the-year male recorded as gray/brown was recaptured later in the year with reddish fur.

The wing membrane attaches at the base of the toe, no keel is present on the calcar, and toe hairs extend to or beyond the tip of the claws. Southeastern myotis measures 78–92 mm in total length with a wingspan ranging from 24–29 cm. Body mass ranges from 4–9 g (Schmidly, 1991; Choate et al., 1994). Adult females are generally larger in size than adult males, and body mass varies geographically. Forearm length was reported as 36–41 mm by Schmidly (1991) and 31–41 mm by Mirowsky and Horner (1997). Other standard measurements include ear (12–15 mm), hind foot (8–11 mm), and tail length (34–42 mm; Choate et al., 1994). No subspecies are recognized (LaVal, 1970).

Southeastern myotis belongs to the class Mam-



Figure 7. Southeastern myotis is quite variable in color, with bi-colored ventral fur that is dark gray at the base and light-colored at the tip.

malia, order Chiroptera, family Vespertilionidae, subfamily Vespertilioninae, and Tribe Myotini (Miller and Allen, 1928). Myotini includes the New World genera *Lasionycteris* in addition to *Myotis*, which occurs globally. The species is believed to be monotypic because of variation in appearance among demes (LaVal, 1970); thus, *M. a. gatesi* Lowery and *M. a. mumfordi* Rice are considered synonyms of *M. austroriparius* (Jones and Manning, 1989). Variation in appearance of southeastern myotis contributed to errors in identification from little brown bats (*Myotis lucifugus*), rendering inaccuracies in the historical distribution of the species from collected specimens (Davis and Rippey, 1968). *Myotis austroriparius* is the currently accepted binomial as described by Rhoads (1897), although Nowak (1999) suggested the feminine form, *M. austroriparia*, is more appropriate in accordance with Woodman (1993).



Figure 8. Southeastern myotis is agile in flight.

3.2 Breeding Biology

The timing of mating in southeastern myotis is unclear, although copulation is believed to occur in autumn (Rice, 1957). Most males in western Florida populations had enlarged testes during the fall and early winter, but almost all males examined in peninsular Florida had enlarged testes from mid-February to mid-April (Rice, 1957). Males with enlarged testes have been collected in March, April and August in Indiana (Mumford and Whitaker, 1982). Approximately 90% of pregnant females give birth in late April or mid-May (Harvey et al., 1999). The species is unique within North American *Myotis* with adult females usually giving birth to twins, and sex ratios at birth equaling 1:1 (Rice, 1957). A female carrying three fetuses to full-term has been documented (Foster et al., 1978). In Florida, females begin to congregate at maternity sites by mid-March, and the young are born in mid-May (Rice, 1957). The young are more altricial than other cave bats (Sherman, 1930) and experience higher mortality during the first few weeks of life (Foster et al., 1978; Hermanson and Wilkins, 1986). The young remain in the maternity roost while females forage during the evening and older young form clusters while adult females are away from the roost (Rice, 1957). The young are capable of flight at five to six weeks in age, usually between early June and early July (Rice, 1957). In Texas, Horner and Mirowsky (1996) found that parturition occurs from the end of April to early May and the young become volant by the end of May, a few weeks earlier than in Florida.

3.3 Echolocation

Echolocation calls of southeastern myotis are typical of call structures of bats in the genus *Myotis* and are relatively easy to distinguish from other species because of a steep, frequency modulated sweep with a large bandwidth and short duration, i.e., <5 ms (Fig. 9). Commuting calls, i.e., emitted in flight without active feeding, are frequency modulated with a large bandwidth that often spans >60 kHz. There is large variability in echolocation calls of this species depending on the context of individuals producing calls and the habitat within which individuals are flying. Most of the energy in the call occurs between 50–60 kHz; however, it is common for there to be substantial energy at higher frequencies so that calls appear fragmented. The first harmonic is typically evident in commuting individuals. Calls of southeastern myotis are easily recorded with standard bat detection equipment, although care must be taken to distinguish its call from those of the northern myotis and the little brown bat in habitats where the species co-exist.

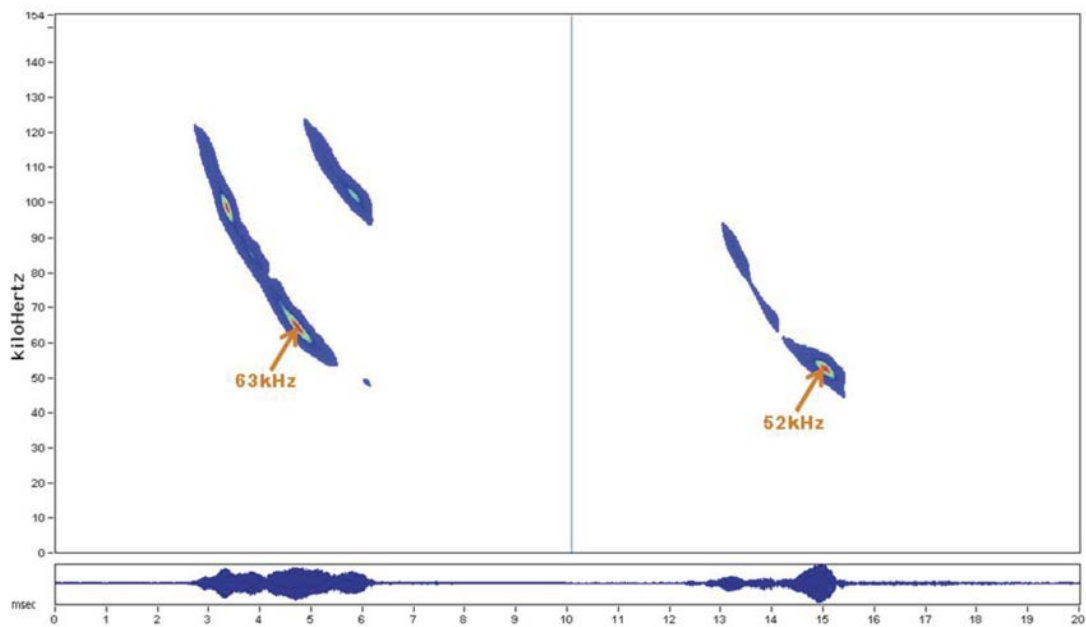


Figure 9. Spectrographs with waveforms of southeastern myotis echolocation calls. Calls recorded from free flying bats exiting a cave in Florida Caverns State Park (from J.Tigner). Each panel represents a single call from different individuals. Highest amplitude of calls is indicated in red. The large bandwidth and frequency modulated sweep begins at frequencies at or >100 kHz.

3.4 Distribution and Abundance

Southeastern myotis occurs throughout much of southeastern United States (Fig. 10), but data on the species is lacking or scarce in many portions of the distribution (Whitaker and Hamilton, 1998). The range of this species extends from southeastern North Carolina to central Florida, across southern states to eastern Texas and Oklahoma, and northward up the Mississippi River Valley to western Kentucky, southern Illinois, and southern Indiana (Jones and Manning, 1989; Humphrey and Gore, 1992). As with Rafinesque’s big-eared bat, this species is largely absent from the piedmont physiographic regions in North and South Carolina (Bunch et al., 1998; Menzel et al., 2003; Fields, 2007) and from uplands in northwestern Arkansas (Fokidis et al., 2005; Medlin et al., 2006; Appendix 4). The species is believed to have two distinct populations in Florida, the panhandle and peninsular regions, with varying life histories because of differences in climate (Rice, 1955; Humphrey and Gore, 1992). Until the 1990s, the western limit of the distribution was assumed to be the eastern edge of Texas, as only a few specimens were known from counties along the eastern border (Packard, 1966; LaVal, 1970; Michael et al., 1970; Schmidly et al., 1977). Recent surveys, however, demonstrate that the range of the species extends beyond the border counties and includes woodland areas throughout eastern Texas (Schmidly, 1991; Horner, 1995; Walker et al., 1996; Mirowsky and Horner, 1997; Mirowsky et al., 2004).

Summer and winter ranges of southeastern myotis may be similar, as both lactating females and wintering colonies are known from Alabama (Best et al., 1992), Mississippi (Sherman, 2004), western Tennessee (Graves and Harvey, 1974), Illinois (Gardner et al., 1992), and Florida (Rice, 1955). The largest colonies have been documented roosting in Florida caves (Rice, 1957; Gore and Hovis, 1998). Tucker et al. (2007) estimated 190,000 southeastern myotis in seven maternity sites, with 94% of these bats roosting in just three caves. This number is 50% lower than a previous estimate of 380,000 bats in the 1950s and 40% lower than the 320,000 bats estimated during surveys in the winter of 1991–1992. The scattered roosting habits and paucity of data for this species make range-wide population estimates impossible to calculate. Information gathered to update distribution information for this conservation strategy indicates roosting sites primarily in caves, trees, bridges, and abandoned buildings, with 457 known roosting sites of this species recorded in the data base of BCI (M. Bayless, pers. comm.). There is insufficient information to determine if all documented roosts still exist or remain occupied, and it is unknown to what extent some historic locations represent misidentified bats.

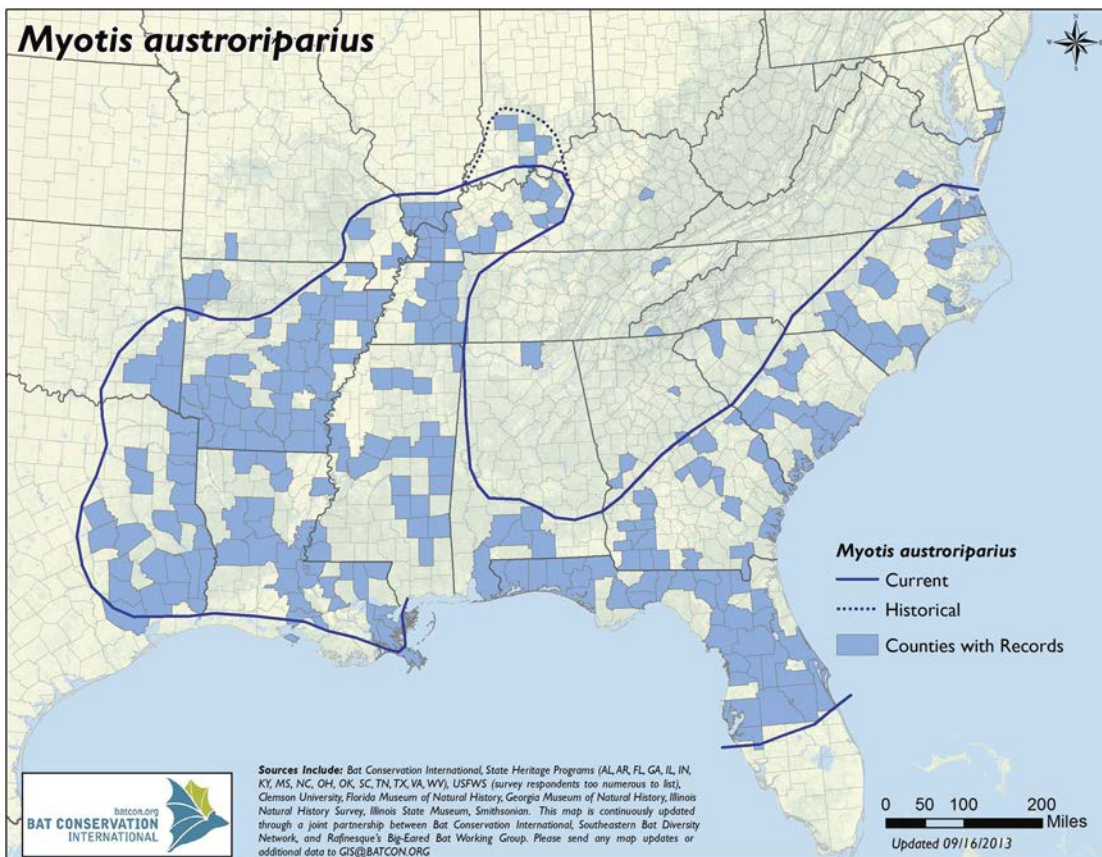


Figure 10. The range of southeastern myotis. Distribution based on natural heritage data from southeastern states and data from individuals.

3.5 Torpor, Movement Patterns, and Roost Fidelity

During hibernation, southeastern myotis forms tight clusters (≤ 50 bats) hanging from ceilings and walls of caves or beneath buildings (Jones and Pagels, 1968; Lowery, 1974; Mumford and Whitaker, 1982; Jones and Manning, 1989). Southeastern myotis arouses more easily than other species, even in northern areas of the distribution where this bat hibernates throughout most of the winter (Barbour and Davis, 1969; Mumford and Whitaker, 1982; Hoffmeister, 1989). Harvey et al. (1999) stated that cave-roosting populations often leave caves in winter and form small groups in outdoor-roosting sites. In the northern part of its range, this bat hibernates for as long as seven months (September to March), but in southern portions of the distribution stores less fat reserves than other hibernating bat species and remains active throughout much of the winter (McNab, 1974; Bain, 1981; Jones and Manning, 1989). Regardless, southeastern myotis does enter torpor in the deep-south when temperatures fall below 7°C (Brown, 1997). In Florida, Bain (1981) described a colony exhibiting dormant behavior during cold weather, and in Mississippi, Martin et al. (2008) observed small numbers of torpid bats tucked away in crevices or hanging singly on the walls of culverts during winter.

Few data are available on seasonal movements of southeastern myotis, and no record of long-distance migration exists. Although winter hibernacula and summer maternity sites are often in different locations (Rice, 1957; Mumford and Whitaker, 1982; Gardner et al., 1992), summer and winter ranges are presumed to be identical (Barbour and Davis, 1969). In Florida, southeastern myotis typically occupies different roosts during summer and winter, but some roosts are occupied year-round (Ludlow and Gore, 2000). Regardless, patterns of movement among sites are largely unknown (Jones and Manning, 1989). Rice (1957) recorded movement distances as long as 28.9 and 72.4 km for banded individuals in Florida. In Florida, southeastern myotis abandons maternity caves as early as July, when young become volant, and as late as November or early December (Rice, 1957). Bats begin to return to maternity caves by the second week of March (Rice, 1957). Where colonies use hollow trees for roosting structures, multiple roosts appear to be essential with more frequent roost switching after young are reared (Clark et al., 1997; Mirowsky, 1998). Roost switching was also documented in radio-tagged males in Arkansas, where bats used solitary roosts in mines, bridges, and small cavities of hollow trees (Reed, 2004). In the same study, bats banded and tracked from a maternity roost in a concrete bridge did not switch to alternate roosts, possibly due to surrounding upland pine forests which possessed few large, hollow trees suitable for roosting.

3.6 Social Organization

Little is known about roosting behavior of colonies of southeastern myotis. Maternity colonies of this species have been recorded roosting in caves in clusters at densities of 1,440 bats/ m^2 (Hermanson and Wilkins, 1986) and 2,000 bats/ m^2 (Gore and Hovis, 1992). Rice (1957) found males represented 18% of the bats in a nursery colony in one Florida cave. Adult males were documented roosting among reproductive females from April to September in two Arkansas bridge roosts, with males representing 68% of the total captures in 2001 and 9% of the total captures in 2002 (Reed, 2004). Only males were found in cave roosts in Illinois during summer surveys (Whitaker, 1975; Hoffmeister, 1989).

3.7 General Habitat Associations

Southeastern myotis are usually in or near habitats associated with permanent sources of water (Jones and Manning, 1989), with bottomland hardwood forests the preferred foraging and roosting areas, especially during the summer maternity season (Cochran, 1999; Hoffman, 1999). In Illinois, Kentucky and Tennessee, the species typically occurs in mature, wetland forests where it has been netted mostly over streams and flooded hardwood forests (Graves and Harvey, 1974; Hofmann et al., 1999; M. Tuttle, pers. comm.). In the southern coastal plain and lowlands, the species is rarely found far from bottomland hardwood forests. Preferred foraging areas are slow moving streams, reservoirs, and lakes surrounded by mature bottomland hardwoods (Jones and Manning, 1989; Clark et al., 1997). Horner and Mirowsky (1996) monitored maternity colonies of this bat in hollow trees of bottomland hardwood forests in east Texas where the dominant trees were black gum, water tupelo, bald cypress, water oak (*Quercus nigra*), willow oak (*Q. phellos*), and swamp chestnut oak (*Q. michauxii*). In peninsular Florida, Zinn (1977) described southeastern myotis as commonly occurring in river swamps. A single bat of this species was mist netted over water in a managed forest comprised largely of loblolly pine (*Pinus taeda*) interspersed with hardwood forests (25% of the area) in eastern Mississippi (Miller, 2003).

The species has been found using oak-pine and longleaf pine (*P. palustris*) vegetation zones in Texas (Schmidly et al., 1977), and upland pine forests in Arkansas (Reed, 2004). In parts of Florida, southeastern myotis can also be found in urban parks and neighborhoods with many trees, but these populations are likely small relative to the rest of the species distribution (J. Gore, pers. comm.).

3.8 Cave and Mine Roosts

Southeastern myotis has been documented roosting in caves, hollow trees, bridges, buildings, wells, and cisterns (Rice, 1957; Barbour and Davis, 1969; LaVal, 1970; Harvey et al., 1991; Best et al., 1992; Saugey et al., 1993; Clark et al., 1998; Gore and Hovis, 1998; Mirowsky, 1998; Hoffman, 1999; Gooding and Langford, 2004; Wilf, 2004; Carver and Ashley, 2008). The species roosts primarily in caves in the northern part of its distribution (Harvey et al., 1991) and in cavernous regions of the southeast, especially in Florida, where the presence of suitable caves appears essential to roost-site selection (Gore and Hovis, 1994). The largest summer colonies roost in limestone caves in Florida, with maternity colonies estimated to reach 100,000 adults (Rice, 1957; LaVal, 1970; Gore and Hovis, 1992). Suitable caves have been described as those with entrance diameters greater than 2 m and ceilings higher than 3 m (M. Tuttle, pers. comm.). Wet caves are preferred with these bats often roosting directly over water (Rice, 1957; Humphrey and Gore, 1992); this preference does not appear essential for nursery use in this species, however (Gore and Hovis, 1992).

From Arkansas and Tennessee, northward through Kentucky, Indiana and Illinois, southeastern myotis appears to undergo extended periods of winter hibernation in caves and mines (Rice, 1957; Barbour and Davis, 1969). Relatively large groups of this species, up to 3,000, hibernate in caves in far western Kentucky (Harvey et al., 1991). In Indiana, this bat forms clusters of 8–120 individuals on cave ceilings and also roosts alone or in groups of up to six in ceiling crevices (Barbour and Davis, 1969; Hoffmeister, 1989). In peninsular Florida, where caves are apparently too warm to permit deep torpor, some southeastern myotis abandon these roosts in fall for cooler, more exposed roosts in tree hollows, buildings, culverts, and bridges (Rice, 1957; Humphrey and Gore, 1992). Best et al. (1992) reported southeastern myotis from three caves in Alabama. One of these caves (Sanders Cave, Conecuh Co.) harbored a maternity colony of ca. 8,000 individuals, yet only 47 bats were observed during winter months suggesting this cave was not used as a primary hibernaculum (Best et al., 1992). Mumford and Whitaker (1975) reported winter cave use by male and female bats in Indiana, but found the cave not occupied by a maternity colony of southeastern myotis in summer.

Southeastern myotis also roosts in abandoned mines across much of its distribution during the winter (Harvey et al., 1991). In many cases mines occupied by this bat are located in areas devoid of caves (Heath et al., 1983; Saugey et al., 1993), but may also be used in the vicinity of caves (Smith and Parmalee, 1954; Whitaker and Winter, 1977). Reed (2004) found southeastern myotis in a mine in an upland pine forest in Arkansas, where up to 150 bats hibernated in winter in abandoned cinnabar mine adits, preferring to roost in drill holes and crevices. Mines that were more thermally stable and maintained higher temperatures were more frequently used for roosting by southeastern myotis in southern Arkansas, where this species is believed to not hibernate (Reed, 2004). Despite attempts to locate summer colonies in mines in Illinois (Hofmann et al., 1999), use of mines for roosting during summer months was not observed.

3.9 Hollow Tree Roosts

Maternity colonies of southeastern myotis prefer roosting in mature, live hollow trees that possess large basal openings, primarily black gum, water tupelo, American sycamore, sweetgum (*Liquidambar styraciflua*), Nuttall oak (*Quercus texana*), water hickory (*Carya aquatica*), American beech, bald cypress, Pignut hickory (*C. glabra*), swamp chestnut oak (*Q. michauxii*), and overcup oak (*Q. lyrata*) (Horner and Mirowsky, 1996; Clark et al., 1997; Mirowsky and Horner, 1997; Cochran, 1999; Hoffman, 1999; Gooding and Langford, 2004; Wilf, 2004; Stevenson, 2008; Fig. 11). In Texas, roost trees of this bat were closer to water, larger in diameter, and possessed larger cavities than unoccupied random hollow trees (Mirowsky, 1998). All roost trees were located in a flood plain within 20 m of standing water at some time during the study period. Primary roosting sites of southeastern myotis in bottomland hardwood forests of eastern Arkansas were in live water tupelo with large triangular basal openings (Cochran, 1999; Hoffman, 1999). In west-central Mississippi, roost trees included sweetgum, Nuttall oak and water hickory (Wilf, 2004), whereas in east-central Mississippi this bat selected American sycamore, black tupelo, water oak, and sweetgum for roosting (Stevenson, 2008). Southeastern myotis used large, hollow water tupelos and cavities in red maple (*Acer rubrum*) for roosting in Tennessee (Carver and Ashley, 2008). Reed (2004) also documented use of cavities in red maple by single males. In South Carolina, 36 roosting

sites of southeastern myotis were in tupelo gum trees, one was in a black gum, and all were in stands with closed canopies (Clark et al., 1998). Small colonies of this bat were observed using narrow crevices in hollow black mangrove (*Avicennia germinans*) trees on a small island near Tampa Bay, Florida (Fargo, 1929). Southeastern myotis used large, bald cypress trees for roosting in Mississippi, but did not in South Carolina or Texas, even where they were available (Clark et al., 1998; Mirowsky, 1998; Stevenson, 2008).



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Figure 11. Summer tree roosts of southeastern myotis in Tennessee.

Roost trees of southeastern myotis are large in size. Water tupelos used by this bat for roosting averaged 76 cm in diameter at breast height (dbh) in Tennessee (Carver and Ashley, 2008) and 135 cm in Arkansas (Hoffman, 1999). In Mississippi, roost trees averaged 78.5 cm in dbh, with a range in roost tree size of 50–155 cm (Stevenson, 2008). Single tree roosts of this bat in Louisiana and Illinois measured 108 cm and 105 cm in dbh, respectively (Hofmann et al., 1999; Gooding and Langford, 2004). In Mississippi, southeastern myotis roosts in trees in winter that are larger in diameter and possess larger internal cavities than in spring and summer months (Fleming et al., 2013a). Roost trees typically provide chimney-like cavities, where colonies cluster at cavity apices and overflow down the sides of the cavity. Cavity heights averaged 8.9 m in Texas (Mirowsky, 1998) and 6 m in Illinois (Hofmann et al., 1999). Roost tree entrances averaged 90 cm in height by 50 cm in width in east Texas (Mirowsky, 1998), 106 cm in height and 26 cm in width in Tennessee (Carver and Ashley, 2008), and 60 cm in height by 25 cm in width in Illinois (Hofmann et al., 1999). In Texas, roost tree entrances of southeastern myotis generally faced southeast (Mirowsky, 1998), but this pattern was not observed in Tennessee (Carver and Ashley, 2008).



PHOTO CREDIT: G. HANKS

Figure 12. Summer colony of southeastern myotis in a hollow tree in Bayou Cocodrie National Wildlife Refuge, Louisiana.

Nursery colonies of southeastern myotis in hollow trees typically include 100–300 individuals (Hoffman et al., 1998; Mirowsky, 1998; Hoffman, 1999), but the species has been documented roosting in colonies of over 5,000 individuals in a large water tupelo in Louisiana (G. Hanks, pers. comm.; Fig. 12). In southern regions, hollow trees are used year-round for roosting in this species, but there is little information describing characteristics of roost trees used in winter (Horner and Mirowsky, 1996; Mirowsky and Horner, 1997; Cochran, 1999; Hoffman, 1999; Stevenson, 2008). Stevenson (2008) noted that although some trees were used year-round, trees with diameters from 60–95 cm were used by maternity colonies of southeastern myotis in summer while larger (up to 155 cm) and smaller (down to 50 cm) tree roosts were used either during winter or by non-reproductive adults in summer (Stevenson, 2008).

3.10 Artificial Structures for Roosting

In addition to using caves, mines, and hollow trees during summer months, southeastern myotis has been documented roosting in a variety of artificial structures including cisterns (Sherman, 2004), concrete culverts (Bain, 1981; Martin et al., 2005), bridges (Lance et al., 2001; Wolters and Martin, 2001; Trousdale and Beckett, 2002), buildings (Kern et al., 1996; Trousdale and Beckett, 2000), and chimneys (Foster et al., 1978). Southeastern myotis is known to use both bridges and culverts as nursery roosts, and as many as 2,000 to 3,000 mothers and pups have been found at these sites (Keeley and Tuttle, 1999). A large maternity colony occurs in elongated airstrip culverts at Meridian Naval Air Station in eastern Mississippi (Martin et al., 2008). Several abandoned cisterns were found to support large populations of southeastern myotis near St. Catherine Creek National Wildlife Refuge in southwest Mississippi (Sherman, 2004). In Florida, 7,680 southeastern myotis shared an attic with 3,312 Brazilian free-tailed bats (*Tadarida brasiliensis*; Hermanson and Wilkins, 1986), and an abandoned warehouse colony in North Carolina also contained thousands of southeastern myotis (Lee et al., 1982). The University of Florida, in Gainesville, constructed a large bat house to accommodate free-tailed bats, but a small colony of southeastern myotis also occupies the structure (M. Bayless, pers. comm.).

Southeastern myotis has been documented using both open spaces and crevices underneath concrete bridges in at least four states within its range. Concrete arch, concrete flat slab, and concrete I or T-beam bridges have been documented with seasonal use by this species. In concrete slab bridges, southeastern myotis use the joints between parallel slabs and between sections of the bridge. In concrete arch and beam bridges the species is found roosting only in the rough concrete expansion joints above the pillars and between the bridge sections. Both maternity and bachelor colonies (numbering up to 500 individuals) were documented using rough expansion joints over water in a concrete arch bridge in Arkansas from April to September (Reed, 2004). Steel and wood typically do not provide acceptable roosting conditions except where concrete joints are involved, although at one site Reed (2004) documented these bats roosting in steel joints embedded within a concrete bridge. Southeastern myotis chose crevices under bridges with widths ranging from 1.3–12.7 cm (Reed, 2004). In the coastal plain of North Carolina, southeastern myotis roosted under channel beam bridges more frequently than other bridge designs (McDonnell, 2001).

Most artificial structures are not regularly used during winter months, but wintering populations of southeastern myotis have been documented using cisterns, culverts, and occasionally buildings. More than 2,000 southeastern myotis were counted emerging from a cistern in December 2003 in southwestern Mississippi, indicating that these structures can serve as winter roosts for large populations (Sherman, 2004). In Texas, southeastern myotis uses culverts as day roosts throughout the year (Walker et al., 1996), and colonies have been reported roosting in abandoned water wells during winter months (D. Saugey and B. Sasse, pers. comm.). A colony of several thousand lived year-round in a North Carolina warehouse (Lee et al., 1982). Three hundred bats of this species overwintered in a long narrow crevice of an open shed in Georgia (Barbour and Davis, 1969), and in East Texas, colonies broke up into smaller groups during winter with some individuals roosting in hollow gum trees, while others continued to rely on human structures (Mirowsky, 1998).

3.11 Roosting Microclimates

Although southeastern myotis seem to prefer lower summer temperatures than sympatric species of bats, thermal stability and high humidity remain important to energy conservation and fetal and pup development (Kunz, 1982). Hollow trees used by nursery colonies of southeastern myotis in east Texas provided less variable and cooler temperatures than either ambient conditions or nearby unoccupied hollow trees (Mirowsky, 1998). Temperatures recorded a meter inside four roost trees of southeastern myotis ranged from 23.0–26.8 °C from May through August (Mirowsky, 1998). Live trees appear to provide an insulating effect that creates stable temperature conditions suitable for roosting by this

species. One explanation for this is the base of roost trees are usually enclosed by the plant understory, thus, much of the bole and the hollow basal opening receives little direct sun in summer (Clark et al., 1997). Slightly warmer temperatures have been reported for colonies using artificial structures. Reed (2004) recorded maximum mean daily temperatures (33.6 °C) and minimum mean daily temperatures (12.7° C) in a concrete bridge used as a maternity roost by southeastern myotis. Temperatures inside a nursery cave of southeastern myotis in Florida were maintained at 28° C while bats were inside the cave, with temperatures dropping 3° C at night when bats emerged to feed (Zinn, 1977). In winter, temperatures in caves occupied by this species varied from 14.4–17.8° C from November to March (Rice, 1957). There are no published data for temperatures inside roosting structures of southeastern myotis at the northern edge of the range.

Humidity appears to have an important role in roost selection of southeastern myotis (Rice, 1957; Humphrey and Gore, 1992). Water loss in bats is high compared to other mammals, and evaporative water loss increases significantly at temperatures above 32° C (Herreid and Schmidt-Nielsen, 1966). At high temperatures (>25° C), evaporative water loss is 65% less in high humidity (>85%) compared with water loss at low humidity (<20%; Webb et al., 1995). For lactating females, this may be especially important, because their water consumption and metabolic requirements are higher than other reproductive classes of females. The importance of humidity to roost-site selection in southeastern myotis is noted by several authors, with maternity colonies often observed roosting on domed ceilings directly over water (Rice, 1957; Zinn, 1977; Humphrey and Gore, 1992). Humphrey and Gore (1992) postulated that access to drinking water likely aids adult females during lactation as it permits them to drink without having to leave the roost cave.

3.12 Communal Roosting

Carver and Ashley (2008) investigated syntopic roost use by southeastern myotis and Rafinesque's big-eared bat in Tennessee. Results from their study suggest these species are found roosting together but have different preferences for roost sites within the same roosting structure. Only two of 30 roost trees identified were used by both species (97 and 101 cm diameter). These two trees represented some of the smallest roosts used by Rafinesque's big-eared bat (range: 77–195 cm) and some of the largest roosts of southeastern myotis (range: 23–101 cm). This apparent preference by southeastern myotis and Rafinesque's big-eared bat maternity colonies for different size of trees is also described in Stevenson (2008). Although non-reproductive and wintering bat colonies shared trees, Rafinesque's big-eared bat maternity colonies used larger trees (minimum 115 cm diameter) while southeastern myotis used somewhat smaller roosts (maximum 95 cm diameter). Larger roosts were selected more often by both species during winter months (Stevenson, 2008).

In shared roosts, Rafinesque's big-eared bat roosts along the sides of the tree cavity below the apex, whereas southeastern myotis roosts in densely packed clusters at the cavity apices (Horner and Mirowsky, 1996; Carver and Ashley, 2008; Stevenson, 2008). The reason for this apparent difference in roost site selection is unknown, but Carver and Ashley (2008) hypothesized that it represents either different thermal requirements or differences in behavior. During winter months in Mississippi, southeastern myotis and Rafinesque's big-eared bat were often documented using the same roost trees simultaneously, even roosting together in clusters of torpid bats (Stevenson, 2008). Southeastern myotis has also been documented occasionally sharing roosts with gray bats (*Myotis grisescens*), Brazilian free-tailed bats, tri-colored bats, evening bats (*Nycticeius humeralis*), and big brown bats (Rice, 1957; Bain, 1981; Wenner, 1984; Hermanson and Wilkins, 1986; Gore and Hovis, 1994); however, these roosts are usually in caves or artificial structures and most often in Florida.

3.13 Foraging Habitats

Southeastern myotis likely uses a variety of foraging sites but prefers foraging over water (Harvey et al., 1999; Menzel et al., 2005). Harvey et al. (1999) stated this species is usually associated with bodies of water and forages low, close to the water surface. Foraging behavior has been observed in bottomland hardwood and bald cypress-tupelo gum swamp in Illinois, Arkansas, and South Carolina (Clark et al., 1998; Hoffman et al. 1998; Hoffman, 1999). Mist net captures of this species were found to be directly associated with percent oaks and stem density of adjacent stands, and inversely related to canopy height (Medlin and Risch, 2008). Southeastern myotis was reported to feed over narrow, slow-moving creeks adjacent to upland areas of loblolly pine and shortleaf pine (*P. echinata*), stands of hardwoods, and narrow beech-magnolia bottoms (Schmidly et al., 1977). This bat forages in Carolina bays in the coastal plain of South Carolina (Menzel et al., 2005), and has been recorded over water in managed pine forests in Mississippi (Miller, 2003). Other foraging sites include mature, forested wetlands in Illinois (Gardner et al., 1992) and Texas (Horner, 1995), water-courses through forests in Tennessee (Graves and Harvey, 1974), open water and wetlands in Alabama (Gardner, 2008), and livestock ponds in Florida (Bain, 1981). In dry areas of Florida, southeastern myotis feeds around live oaks (*Quercus*

virginiana) and over upland areas such as small woodlots and shrubby old fields (Zinn and Humphrey, 1981; Humphrey and Gore, 1992). No data have been published on size of home ranges or foraging areas in this species or on spatial use of available foraging habitats.

3.14 Foraging Behavior and Diet

The propensity to feed over bodies of water in open air space suggests southeastern myotis uses an aerial hawking foraging strategy. A variety of insects are consumed by southeastern myotis (Whitaker and Hamilton, 1998), but the diet of this species is not well known (Harvey et al., 1999). Zinn and Humphrey (1981) examined seasonal food habits of southeastern myotis in Florida. On cooler spring nights, Diptera species were most abundant, and these bats consumed mosquitoes and crane flies. Feeding took place during the first three hours after sunset, when insect prey were most active. A wider variety of prey items were available on warmer spring and summer nights, and this species selectively consumed mosquitoes (Diptera), beetles (Coleoptera), and moths (Lepidoptera), in decreasing preference (Zinn and Humphrey, 1981). Two peaks of foraging activity were observed on warmer nights, one at dusk when insect species richness and activity were greatest, and another between 0100 and 0300 hr when Diptera were most available (Zinn and Humphrey, 1981). It is probable that prey selection in this bat is quite variable across other portions of its range, because the insects available to them are likely to be different. For example, these bats consumed a high percentage (59%) of trichopterans (Trichoptera) in Illinois (Feldhamer et al., 2009).

3.15 Survivorship and Mortality

Little is known about either longevity or age-related survival in southeastern myotis. Greatest pre-flight mortality appears to occur soon after birth (Hermanson and Wilkins, 1986), with approximately 75% taking place in the first week of life. Eighty-eight percent of young reared in a building survived till at least they learned to fly (Foster et al., 1978). Southeastern myotis has not been observed retrieving fallen young, perhaps due to high predation risks and the frequency with which the species roosts over water (M. Tuttle, pers. comm). In peninsular Florida, Rice (1957) calculated an annual birth rate of 116% (1.16 births/adult bat) and concluded that maintenance of a stable or increasing population would require a mortality rate $\leq 54\%$. Life spans of up to 15 years have been suggested for this species (Whitaker and Hamilton, 1998), and are likely to be longer in northern areas of the distribution where predation is presumed to be lower than in the deep-south. Band recoveries in Florida indicate southeastern myotis lives up to 8 years in age (M. Tuttle, unpubl. data).

Known predators of southeastern myotis include snakes, owls, opossums, and cockroaches (Rice, 1957; Foster et al., 1978; Hermanson and Wilkins, 1986; Humphrey and Gore, 1992). According to Rice (1957), predation was the most important proximate mortality factor among populations of southeastern myotis in Florida. However, Harvey et al. (1999) stated that the destruction of roost sites and killing of bats by humans are the major threats to the species. Black rat snakes (*Scotophis alleghaniensis*) and gray rat snakes are primary predators, with corn snakes (*Pantherophis guttatus*) believed to also consume these bats (Rice, 1957; Foster et al., 1978). Cockroaches and beetle larvae have been reported to kill young that have fallen from the roost (Hermanson and Wilkins, 1986), including *Periplaneta americana* (Jones and Manning, 1989) and the introduced Australian cockroach (*P. australasiae*; Rice, 1957). Other reported predators of southeastern myotis in flight include screech owls (*Megascops asio*; Mumford and Whitaker, 1982) and bullfrogs (*Rana catesbeiana*; Lee, 1969). Raccoons and house cats are likely additional predators.

3.16 Parasites and Diseases

Whitaker and Hamilton (1998) report on several parasites of southeastern myotis, including streblid flies (*Trichobius major*), nycteribiid flies (*Basilia boardmani*), mites (*Olabidocarpus whitakeri*), and chiggers (*Euschoengastia pipistrelli*). Additional parasites found on this bat in Florida populations include fleas (*Sternopsylla texana*), bat flies (*Cimex adjunctus*), ticks (*Ornithodoros yumatensis*), and other species of mites (*Spinturnix* sp. and *Ichoronyssus quadridentatus*) (Rice, 1957; Bain and Zinn, 1982; Reeves et al., 2005). The malarial parasite (*Polychromophilus*) was detected in cave-roosting populations of southeastern myotis (Foster, 1979), and the bacteria *Bartonella* is associated with blood-feeding arthropods of this species (Reeves et al., 2005), presenting a potential disease threat to humans which come into contact with feces of southeastern myotis.

Disease was perceived to not be a serious threat to southeastern myotis (Rice, 1957); however, this may change should the *Pseudogymnoascus* fungus expand its distribution across the southeastern U.S., resulting in subsequent mor-

talities of cavernicolous bats across the deep-south due to WNS infection. Southeastern myotis roosts extensively in caves in Florida and at the northern end of the range (Rice, 1957; Harvey et al., 1991; Humphrey and Gore, 1992) and the species has been recorded with the fungus (Foley et al., 2011), so the extent to which this bat will be affected by WNS remains to be seen. Rabies was recorded in southeastern myotis in Florida (Bigler et al., 1975), but bats tested in Arkansas were negative (Sasse and Saugey, 2008). This bat is also documented to be associated with the histoplasmosis fungus (*Histoplasma capsulatum*) in at least one Florida cave (Humphrey and Gore, 1992).

3.17 Species Status

Southeastern myotis was a Category 2 candidate for federal listing as either a threatened or endangered species (USFWS, 1989), until this category was eliminated in 1995. This bat is now considered imperiled or vulnerable throughout its distribution except in Louisiana (Appendix 1). Southeastern myotis is disappearing from former hibernation caves in the northern extent of its range (Mumford and Cope, 1964) and is also absent from a majority of its former nursery caves in the southern range, especially Florida (Gore and Hovis, 1992). This species is dependent on bottomland hardwood forests for foraging areas and summer maternity sites (Jones and Manning, 1989; Cochran, 1999; Hoffman, 1999), and, although overall acreage of oak-gum-cypress forests in the southeast has stabilized, the amount of these forests in ≥ 100 year-old age classes continues to decline (USDA Forest Service, 2009a). Thus, availability and suitability of large-diameter older trees for roosting by this bat in bottomland hardwood forests remains a concern (Miller et al., 2011).

In the Florida Panhandle, approximately half of the nursery caves of southeastern myotis discovered between 1957 and 1970 were permanently closed to bats by 1971, including at least four caves that were bulldozed shut (M. Tuttle, pers. comm.). One cave was buried by an expanding city dump and three by landowners who considered them a liability risk. Other caves have become too heavily disturbed and vandalized for continued use by bats. By 1971, only four caves of this species in the Florida Panhandle continued to support large nursery colonies where adult females reared young on an annual basis (Wenner, 1984). These remaining maternity cave roosts likely support a greater proportion of the local population of southeastern myotis than they did historically. Southeastern myotis currently uses five caves in northwest Florida as maternity roosts (J. Gore, pers. comm.).

The wettest caves have been least disturbed by humans, and now support the remaining nursery colonies of southeastern myotis, with bats concentrated in roosting sites that are highly vulnerable to flooding (M. Tuttle, pers. comm.). In 1989 and 1990, all of the most important remaining nursery caves were flooded by severe storms, killing a minimum of 6,500 in Judges Cave and 57,000 in Snead's Cave (Gore and Hovis, 1992). Others nursery caves were not surveyed, but the number of dead in Snead's Cave alone is suspected to have totaled upwards of 250,000 mothers and pups (J. Gore, pers. comm.). Flooding of the relatively few protected roosting caves in the Florida Panhandle remains a serious threat to southeastern myotis.

In a state-wide status survey in Florida, Gore and Hovis (1992) found nine occupied caves that contained a minimum of 319,000 southeastern myotis. Unfortunately, the total population size of cave-roosting southeastern myotis in Florida is difficult to estimate, because surveys cannot be carried out simultaneously at all roosting sites. This bat is easily disturbed during roost counts, leading to movement of individuals among caves resulting in duplicate counts and inflated estimates of population size (Gore and Hovis, 1992). The findings of Gore and Hovis (1992) remain a cause for concern, however. They discovered 10 caves documented as formerly occupied by nursery colonies of southeastern myotis to no longer be used. A majority was at risk of flooding, three had intentionally closed entrances, and four showed evidence of frequent vandalism. Of sites found occupied in 1991, only five were caves of historical use by the species, and in other caves bats were at increased risk of mortality. For example, in one cave used as a nursery site, bats sometimes crawled, rather than flew out of a very small entrance corridor, placing them at increased risk of predation (Hermanson and Wilkins, 1986; Humphrey and Gore, 1992).

Protection of important cave roosts is essential for maintaining ecologically significant populations of southeastern myotis in Florida, Illinois, Indiana, and Kentucky (Harvey et al. 1991; Whitaker and Hamilton, 1998; Humphrey and Gore, 1992); however, it has been noted that conservation of southeastern myotis will require conservation of connected stands of mature, lowland hardwood forests (Clark, 2000). Conservation of this increasingly rare habitat type for southeastern myotis should also have broader implications for other flora and fauna endemic to the region. Additionally, protection of cave-dwelling populations of this bat may be important in the conservation of troglobitic organisms and associated ecosystems that rely on bat droppings as a primary energy resource (Franz and Lee, 1982).

4. THREATS

The following section overviews areas of greatest concern for the global survival of Rafinesque's big-eared bat and southeastern myotis. Many different threats were identified by the Technical Advisory Group in preparation of this document, and the majority is synthesized here; each threat is addressed in the most relevant topic areas as needed to ensure full coverage. The most significant threats to these two bats are emphasized, and in some cases concerns over synergistic effects of multiple threats are raised. Remaining threats that are serious in nature but local in effect (e.g., scabies; Wolters and Martin, 2000) are given limited attention. The listing of topic areas is not necessarily in order of importance as impacts from various threats are likely to change in magnitude, either higher or lower, in the years ahead as management policies shift in emphasis, approach and degree of success, and as variation in natural disturbance continues to take place.

4.1 Loss and Degradation of Bottomland Hardwood Forest

Loss, fragmentation, and degradation of bottomland hardwood forests are among the most significant threats to populations of Rafinesque's big-eared bat and southeastern myotis. Mature bottomland hardwood forests were once common throughout the southeastern United States, but during the last century significant declines in wetland habitats have occurred, with the most dramatic losses in forested wetlands of the Lower Mississippi River Alluvial Plain ecoregion (Twedt and Loesch, 1999). Early estimates suggested bottomland hardwood forests in the Mississippi Alluvial Valley had decreased by as much as 78% (MacDonald et al., 1979). Fifty-six percent of southern bottomland hardwood and bald cypress forests were lost between 1900 and 1978 (Mississippi Museum of Natural Science, 2005). As of the mid-1980s, bottomland hardwood forests in the Mississippi Alluvial Valley were highly fragmented and occupied 20% of their historic land base (Haynes, 2004; Wilson et al., 2007). Across the entire southeastern United States, bottomland hardwood forest declined by >25% since 1977, but, fortunately, this trend has stabilized and begun to reverse over the past decade (USDA Forest Service, 2009a; Miller et al., 2011). It is estimated that only 2.5 million acres of moderately wet bottomland forest, and over 0.6 million acres of very wet bottomland forest, remain in the lower part of the Mississippi River Alluvial Plain in Mississippi, Arkansas and Louisiana (Mississippi Museum of Natural Science, 2005).

It is likely that populations of both bat species have been substantially impacted by the loss in available roosting and foraging habitat (Gooding and Langford, 2004). Genetic studies on Rafinesque's big-eared bat (Piaggio and Perkins, 2005; Piaggio et al., 2011) have found limited support for the existence of two subspecies (*C. rafinesquii rafinesquii* and *C. r. macrotis*) proposed by C. O. Handley (1959), so it is plausible that the historical abundance, continuity and geographic extent of bottomland hardwood forests that once existed along the Mississippi Alluvial Valley and much of the southeast coastal areas facilitated gene flow among populations of Rafinesque's big-eared bat north to south and east to west keeping the species monotypic across its distribution.

Loss of bottomland hardwood forest has been primarily attributed to conversion of land to agricultural production and expanding urbanization (Smith et al., 2009; Miller et al., 2011). Loss of mature forest removes foraging opportunities and alters prey species diversity, abundance and availability (Burford et al., 1999; Hayes and Loeb, 2007). For at least Rafinesque's big-eared bat, it is hypothesized that foraging behavior and abundance of prey populations are closely tied to mature forest canopies with a relatively open understory (Lacki and Dodd, 2011). Continued fragmentation of remaining bottomland hardwood forests and the juxtaposition of residual habitat fragments will alter travel corridors to and from roosting sites, and likely affect bat movements and foraging patterns (Duchamp et al., 2007; Hein et al., 2009). Timber management practices that incorporate short rotations, often of altered tree species composition, lead to the development of stands with canopies that are less complex, relatively uniform in shape, and with a dense layer of vegetation in the understory (Guldin et al., 2007). These forests do not provide the same type of foraging sites, travel corridors and water accessibility for bats as do older-aged forests (Hayes, 2003; Patriquin and Barclay, 2003; Wigley et al., 2007). Use of selective cutting practices associated with longer rotation lengths is becoming increasingly common across the southeast and may help in improving suitable roosting and foraging conditions for these bats in bottomland hardwood forests (D. Miller, pers. comm.).

Remaining bottomland hardwood forests continue to be fragmented due to drainage, levee construction, reservoir creation, improved road access, increased agricultural use, and urban development (Wilson et al., 2007; Miller et al., 2011). Many fragmented parcels may be limited in their capacity to provide flood water storage, nutrient trapping, groundwater recharge, and wildlife habitat (Mississippi Museum of Natural Science, 2005). Fortunately, conservation of

bottomland hardwood forest is occurring in some cases because of increasing value for outdoor recreation. In part, due to the difficulty of converting these forests to other uses because of frequent flooding events, and due to conversion of these sites to greentree reservoirs which are popular locations for hunters and wildlife enthusiasts (Gosselink et al., 1990a). Additionally, conservation programs, such as the wetlands reserve program (WRP) of the USDA Natural Resources Conservation Service, are working with landowners to help conserve, restore and improve wetlands on private property. Given that private landowners own 87% of the forested lands in the southeastern United States (Miller et al., 2011) these types of programs have tremendous potential for sustaining and possibly increasing foraging and roosting sites of Rafinesque's big-eared bat and southeastern myotis.

Tropical storms and hurricanes have contributed to habitat loss and change for Rafinesque's big-eared bat and southeastern myotis. For example, two state parks in east Texas lost every known roost tree used by both species of bats during Hurricane Rita in 2005 (R. Maxey, pers. comm.). When bottomland hardwood forests were widespread and common along the southern and eastern ranges of these species, habitat damage from storm events was not likely a significant threat to bat populations. Given that current availability of bottomland hardwood forest is much reduced, the proportional effect of storm damage has likely increased. Some evidence indicates that violent weather events appear to be increasing in frequency and intensity due to climate change (Peterson, 2000; Chambers et al., 2007; Zeng et al., 2009), and could pose a threat to remaining habitat fragments in vulnerable areas. However, the Intergovernmental Panel on Climate Change (IPCC) report on extreme weather events indicates that currently there is weak evidence and low confidence of increases in frequency and intensity of storm events (IPCC, 2012).

4.2 Altered Hydrology

Understanding effects of altered water quality and hydrology in bottomland hardwood forests is complicated due to the synergistic interactions of physical and biological forces that impact wetland systems (Gosselink and Lee, 1989; Gosselink et al., 1990b). For example, water pollution from pesticide use, toxicant applications, sedimentation, and nutrient loading have all been demonstrated to affect plant species composition and abundance of arthropod prey (Scott et al., 1990; Mitsch and Gosselink, 2001). The diet of southeastern myotis is reliant on aquatic insects, especially Dipterans and Trichoptera (Zinn and Humphrey, 1981; Whitaker and Hamilton, 1998; Feldhamer et al., 2009) suggesting southeastern myotis may be particularly vulnerable to changes in aquatic prey communities. Contaminants may bioaccumulate in bats through consumption of prey species and, thus, could affect these bats both physically and behaviorally (Menzie 1980; Clark, 1981; Clark et al., 1988; O'Shea and Clark, 2002). Forest structure and composition might also be affected by changes in hydrologic patterns and shifting trends in tree mortality and survival (Megonigal et al., 1997; King and Antrobus, 2001). The ecologies of most tree species used for roosting by Rafinesque's big-eared bat and southeastern myotis in bottomland hardwood forests are closely tied to hydrologic patterns, depending on cyclic-flooding events for survival and recruitment (Hosner and Minckler, 1963; Dickson et al., 1965; Conner and Day, 1976). Change in distribution, abundance and quality of water sources might also affect bat populations, as both species of bats likely drink while in flight.

4.3 Climate Change

Climate change and the possibility of drought present additional, yet unknown, challenges to managing populations of Rafinesque's big-eared bat and southeastern myotis. Presently, the IPCC suggests medium confidence that some regions of the globe have experienced more prolonged and severe droughts due to climate change, but indicate that this is not the case for central North America (IPCC, 2012). Regardless, the projection of "virtual certainty" in global increases in temperature extremes equaling 2–5°C by the end of the 21st century (IPCC, 2012), suggests that some changes are imminent but unknown due to limitations of existing climate models and insufficient empirical data. Should prolonged drought conditions emerge, previously inaccessible wetlands and bottomland hardwood forests would become available for timber harvest, land development and conversion to agriculture, or may be more susceptible to some natural disturbance agents (e.g., fire; Burkett and Kusler, 2000). Further, the recruitment of important tree species, such as black gum, water tupelo and baldcypress, are impacted during drought conditions (Hosner and Minckler, 1963; Megonigal et al., 1997; McLeod et al., 2000), potentially leading to future shifts in forest tree species composition and loss of suitable roost trees. Climate change has been documented to alter insect availability and vegetation diversity, producing negative effects on songbird communities (Strode, 2003; Both and Visser, 2005). As predators of night-flying insects,

Rafinesque's big-eared bat and southeastern myotis occupy a similar ecological niche and are potentially susceptible to changes in insect communities. Climate change is already projected to modify the distributions of other bat species that overlap the ranges of Rafinesque's big-eared bat and southeastern myotis (Humphries et al., 2002; Kalcounis-Rüepell et al., 2012; Loeb and Winters, 2013).

4.4 Loss and Degradation of Mature Upland Forest

Mature upland forests play pivotal roles across many portions of the distributions of Rafinesque's big-eared bat and southeastern myotis in providing areas for foraging and commuting to and from roosting sites. As with bottomland hardwood forests, upland forests have also been extensively fragmented, altered by timber harvesting practices, and reduced in extent and functionality (Noss et al., 1995; Wear and Greis, 2002). Data are equivocal regarding loss or gain of upland forests in the southeastern United States, with increases in acreage of oak-hickory and loblolly-shortleaf pine forests and decreases in oak-pine and longleaf-slash pine forests between 1977 and 2007 (USDA Forest Service, 2009a). Construction and operation of flood control structures, reservoir creation, surface mining, urban development, fires, and exotic insect pests are negatively affecting the amount and suitability of upland forests (Oak et al., 1988; Noss et al., 1995; Ellison et al., 2005; Albrecht and McCarthy, 2006). Mature hardwood, pine-hardwood, and pine forests are used by these two bats for foraging and commuting to and from roosting sites during the summer maternity season (Schmidly et al., 1977; Hurst and Lacki, 1999; Menzel et al., 2001b; Miller, 2003; Medlin and Risch, 2008). In upland forests, both species of bats roost more commonly in non-tree structures, such as caves, buildings, cisterns and bridges, than in bottomland hardwood forests (Harvey et al., 1991; Best et al., 1992; Gore and Hovis, 1994; England and Saugey, 1999; Harvey et al., 1999; Sasse et al., 2011); thus, the dependency on cavity trees in upland forests is far less important for these bats than in bottomland hardwood forests. Regardless, upland forests are important to the ecology of these bats during fall swarming and spring staging, as these two species hibernate in caves and buildings in upland settings, and, therefore, are reliant upon adjacent mature forests for foraging as they enter and emerge from hibernation (Boyles et al., 2006; L. Dodd, unpubl. data).

The ability of upland forests to provide suitable foraging conditions for *Corynorhinus* bats depends on forest structure (foraging space) and the diversity of woody and herbaceous plant species (moth prey base) (Dodd et al., 2008; Lacki and Dodd, 2011). Moths are the predominant prey of *Corynorhinus* bats, including Rafinesque's big-eared bat (Hurst and Lacki, 1997; Lacki and LaDeur, 2001), and plant species diversity is fundamental to supporting rich and abundant communities of Lepidoptera (Summerville et al., 2003; Summerville and Crist, 2003, 2008; Dodd et al., 2008, 2012b). Silvicultural systems that are consistent with sustaining plant diversity are likely to foster habitat conditions of these bats, whereas practices which promote simple, monotypic stands are likely to reduce the abundance of moth prey and lower the overall foraging success of these bats (Summerville and Crist, 2002; Lacki and Dodd, 2011). The importance of forest structure to Rafinesque's big-eared bat is less clear as studies have documented this species feeding on moths that fly at canopy heights (Hurst and Lacki, 1997) and on insect prey near ground surfaces (Ellis, 1993; Tuttle and Kennedy, 2005). The ability to catch prey off the surface of objects (gleaning) likely permits these bats to feed effectively in a variety of forest canopy structures and heights, as long as sufficiently exposed surface area for gleaning prey exists (Lacki et al., 2007; Lacki and Dodd, 2011).

Data on the importance of upland forests for southeastern myotis are equivocal. Although diet studies on this species are few (Zinn and Humphrey, 1981; Whitaker and Hamilton, 1998; Feldhamer et al., 2009), the reliance of these bats on Dipterans and aquatic insects suggests a less significant role of upland forests in providing an adequate prey base, except in the vicinity of roosts and along riparian corridors. The integrity of riparian forests is most certainly important to enhancing water quality by minimizing sedimentation, providing coarse woody debris for benthic insect larvae, and sustaining cooler water temperatures through shading effects (Gilliam, 1994; Broadmeadow and Nisbet, 2004; Anbumozhi et al., 2005). Data on foraging behavior of southeastern myotis are few, but it is believed that these bats make use of stream corridors and open-bodies of water when capturing insects in flight (Harvey et al., 1999; Menzel et al., 2005). Protecting older-age forests within stream-side management zones (SMZs), especially along stream orders ≥ 2 , will likely provide suitable foraging conditions for these bats on landscapes dominated by upland forests. The SMZ width needed and the extent of corridor fragmentation permissible, without harming the functionality of foraging sites of southeastern myotis in upland forests, remains unclear.

The importance of fire to the ecology and health of upland forests in eastern North America is no longer debated (Abrams, 1992; Stanturf et al., 2002; Patterson, 2005; Ruffner, 2005). The proliferation of studies and management efforts centered on use of prescribed fire as a tool to exact desired changes in forest composition and structure (Stanturf et

al., 2002; Dickinson, 2005), speaks to the importance of fire in sustaining or re-storing forests to historical plant species compositions, canopy structures and ecosystem functionality. The likelihood that wildfires have affected populations of Rafinesque’s big-eared bat and southeastern myotis at some point in the past is high; however, we still know very little about how these two bats respond to fire, positively or negatively, or whether prescribed fire can be used as a tool to enhance habitat quality of either of these two species.

4.5 Loss of Natural Roosting Habitat

The historical abundance of large, hollow trees in bottomland hardwood forests is unclear, but the consensus of biologists and managers contributing to this conservation strategy is that these natural roosting structures are disappearing at a rate faster than they are being recruited into existing bottomland forests. Studies demonstrate that occurrence of cavity trees increases with increasing stem diameter (Allen and Corn, 1990; Fan et al., 2003), with stand age and tree size important indicators of cavity abundance. Fan et al. (2004) found a greater abundance of cavity-prone species in old-growth stands than in younger-aged stands in Missouri forests, and suggested that all timber harvesting systems evaluated resulted in declines in cavity tree abundance compared to older-age, no-harvest stands. Thus, to prevent shortages of suitable cavity trees for Rafinesque’s big-eared bat and southeastern myotis in managed forests of southeastern United States, the allocation of sufficient older-aged trees across forested landscapes, both spatially and temporally, must be considered part of existing habitat prescriptions that accompany scheduled timber harvests in these forests.

Density of cavity trees varies widely among forests of the same age, regardless of whether the data are from upland or bottomland forests (Fan et al., 2003). The frequency distribution of cavity trees follows a negative-exponential, Weibull probability density function, suggesting stands with high densities of cavity trees to be rare on the landscape, but that as stand age increases so does the likelihood of cavity tree formation (Fan et al., 2003). Successful management of roost-trees of Rafinesque’s big-eared bat and southeastern myotis, particularly in bottomland hardwood forests, will depend on an ability to promote development of patches or stands of older-aged forest with high densities of large-diameter cavity



Figure 13. Roost trees of Rafinesque’s big-eared bat possessing bole entrances in western Kentucky. High water levels prevent access to basal cavities.

trees (Mirowsky, 1998; Cochran, 1999; Hoffman, 1999; Reed, 2004; Sherman, 2004; Stevenson, 2008; Johnson and Lacki, 2011).

Land conversion to agriculture, urbanization or development, and commercial timber harvesting has removed large numbers of mature, hollow trees in many portions of forested landscapes in the southeastern United States (Gooding and Langford, 2004; Wilson et al., 2007). Regardless, opportunities exist to retain older-aged, hollow trees as roosting sites for bats in SMZs in forested landscapes managed for commercial tree species (Menzel et al., 2001a; Miller, 2003; Miles et al., 2004; Wigley et al., 2007), and this may be one of the best management tools for providing natural summer roosting sites for Rafinesque's big-eared bat and southeastern myotis across many portions of their distributions. Tree species most commonly identified as roosts [black gum (pulp and pallet wood), water tupelo (pulp and pallet wood), baldcypress (valuable wood products), American sycamore (pulp and low-value pallet wood), American beech (limited timber value), oak (high value lumber), hickory (moderate value lumber), and tulip poplar (moderate value lumber)], have not always been encouraged in replanting efforts (Haynes et al., 1988; Haynes, 2004; USDA NRCS, 2012). Moreover, altered hydrology and associated logging operations have often changed the community composition of tree species, discriminating against the preferred tree species that Rafinesque's big-eared bat and southeastern myotis use for roosting sites (Hosner and Minckler, 1963; Dickson et al., 1965; Conner and Day, 1976; Wilson et al., 2007). In some instances roosting opportunities occur on the landscape, but roosts are inaccessible to bats. Flooding cycles can render roost trees with ground-level openings inaccessible at various times of year due to heavy rainfall events and shifting hydrologic patterns (Hofmann et al. 1999; Clark, 2000; Fig. 13).

Roosts may become unacceptable to bats for a variety of other reasons. Most commonly, cave and karst roosts are altered by human disturbance, entrance modification, or alteration of surrounding vegetation (Pierson, 1998; Racey and Entwistle, 2003). Disturbance of hibernacula during winter months can lead to more frequent arousals, depleting fat reserves of hibernating bats (Thomas et al., 1990; Thomas and Geiser, 1997; Willis, 2007; Jonasson and Willis, 2011). Human disturbance has negatively affected cave-roosting populations of southeastern myotis across its distribution (Best et al., 1992; Harvey et al., 1999), and disturbance at maternity roosts has been associated with abandonment by Rafinesque's big-eared bat (Clark, 1990; Lacki, 2000; J. MacGregor, pers. comm.). In general, Rafinesque's big-eared bat forms smaller populations in roosting sites than does southeastern myotis, both in winter and summer (Barbour and Davis, 1969; Harvey et al., 1999); thus, disturbance at any one particular roost may not have the same threat of impact to the species-wide population of Rafinesque's big-eared bat as it does with the largest colonies of southeastern myotis. Climate change may play a new, yet still unclear, role in altering vegetation and available roosting conditions for bats if regional temperatures rise and precipitation patterns are modified as some climate models predict (Prentice et al., 1991; Kareiva et al., 1992; Gates, 1993; Giorgi et al., 1994; Hanson and Weltzin, 2000; Renneberg et al., 2006; Allen et al., 2010).

4.6 Loss of Anthropogenic Roosting Habitat

Unfortunately, anthropogenic structures suitable for bats have finite life spans, especially when compared with caves. Thus, their maintenance or replacement with suitable alternate structures that provide similar microclimate conditions on landscapes where they are historically used by these two species needs to be a management objective. Buildings deteriorate with neglect and are commonly removed or destroyed to avoid liability (Clark, 1990). Unused mines, cisterns and wells are often collapsed, filled in, capped, bulldozed or removed to prevent accidents (Sherwin et al., 2009; Sasse et al., 2011). Bridges can provide roosting sites that are more temporally stable, but these are typically renovated every 50–75 years and bridges of suitable design for bats are often replaced with more modern steel-beam or flat-bottom designs (Keeley and Tuttle, 1999), eliminating or inhibiting occupation by colonies of bats, including Rafinesque's big-eared bat and southeastern myotis.

The importance of forests surrounding anthropogenic structures cannot be ignored and removal or degradation of adjacent vegetation can limit the value and suitability of building structures for roosting by Rafinesque's big-eared bat (Clark, 1990). The situation can be reversed with bridge roosts, as surrounding vegetation can potentially block solar radiation, effectively insulating bridges from temperature maximums and reducing the suitability of bridge microclimates for roosting bats (Keeley and Tuttle, 1999). Vegetation surrounding anthropogenic roosts can provide seclusion, limit human disturbance, and potentially offer alternative microclimates inside roosts due to shading effects on the roosting structure (Clark, 1990).

Forest fragmentation likely compromises the suitability of roosting sites, both anthropogenic and natural, as increased flight distances to foraging sites and water resources can lead to long-term declines in the size of bat colonies or

abandonment of the structure altogether (Clark, 1990; Hurst and Lacki, 1999; Adams and Hayes, 2008). Data are equivocal, however, regarding the threat and impact of habitat fragmentation to bats, as studies suggest that some degree of forest fragmentation is often associated with increased bat activity and foraging success (Grindal and Brigham, 1999; Gorresen and Willig, 2004).

4.7 Disturbance at Roosting Sites

Vandalism, disturbance, and roost alteration have the potential to directly kill large numbers of bats, especially during hibernation (Tuttle, 1979; Pierson, 1998; Racey and Entwistle, 2003). Limiting vandalism to roosting bats, especially populations in caves and mines, has been a universal problem for land owners, managers, and state and federal officials. In Alabama, the largest colony of southeastern myotis was reportedly extirpated by vandals and careless cave explorers (Mount, 1986), and a colony discovered by Best et al. (1992) was perceived to be at high risk from human traffic. Rice (1955) reported 11,000 southeastern myotis in Mud Cave, Florida, but the site became a dump and was filled with trash (Humphrey and Gore, 1992). Cave gating, fencing, and signage have been used to avoid losses of bats to disturbance (Tuttle, 1977; MacGregor, 1991; Currie, 2002; Sherwin et al., 2009), but these do not keep out all violators. Regardless, ensuring gates or fences are erected and signs placed at the entrances to all caves and mines occupied by the largest populations of Rafinesque's big-eared bat or southeastern myotis should be a conservation objective (Ludlow and Gore, 2000).

Flooding during severe storms may be relatively rare, but can account for massive losses, especially as growing numbers of southeastern myotis are concentrated into fewer caves, such as in lowland areas of Florida (Gore and Hovis, 1992; 1994). Flooding complicates the issue of cave gating, discussed above, as the gates themselves can be an added problem if they become blocked with debris and accelerate the rise of water inside caves housing populations of roosting bats (Tuttle, 1977; White and Seginak, 1987; Currie, 2002). Gore and Hovis (1994) found potential for 10 of 19 nursery caves of southeastern myotis in Florida to be threatened by flooding and documented the 1989 drowning of >6,500 juvenile bats in one of the largest southeastern myotis nursery caves in Florida. They also documented the drowning of at least 57,000 individuals in a second flooding incident at another major nursery cave in 1990. Flooding also represents a mortality threat to tree-roosting colonies of Rafinesque's big-eared bat and southeastern myotis. Hofmann et al. (1999) reported flooding of an important roost tree in Illinois, and Clark (2000) expressed concern regarding the impact of depleted roost-tree resources in all but the lowest habitat areas. She postulated that vulnerability to flooding might increase as bats become trapped inside because of insufficient alternatives for shelter.

4.8 Disease: White-nose Syndrome

Until the emergence of WNS, diseases of eastern North American bats were not considered a significant threat to long-term survival of any species, including Rafinesque's big-eared bat and southeastern myotis (Rice, 1957; Bigler et al., 1975; Jones and Suttkus, 1975). That perception changed when the fungus, *Pseudogymnoascus destructans*, appeared in winter 2005-2006 in Howes Cave, New York (Fig. 14). By the following winter the fungus had caused noticeable bat mortalities in several proximally-located caves (Foley et al., 2011). Since then WNS has produced devastating effects on hibernating populations of cave-dwelling bats, resulting in mortality levels of bats of 90-100% in many infected hibernacula (Hallam and McCracken, 2010; USFWS, 2012). WNS is now estimated to have killed between 5.7 and 6.7 million bats (USFWS, 2012), and the *Pseudogymnoascus* fungus has been detected on 11 species including southeastern myotis (Foley et al., 2011). The fungus has reached 26 states and 5 Canadian Provinces and, as of 2013, has entered a large expanse of the distributions of Rafinesque's big-eared bat and southeastern myotis (Figs. 5 and 10), including the states of Indiana, Kentucky and Missouri to the west, West Virginia, Virginia and North Carolina to the east, and Tennessee and Alabama to the south (Fig. 14). Continued expansion of the disease, with further mortalities and the likely infection of additional cave-roosting bat species should be anticipated in forthcoming years. The recent addition of the endangered gray bat to the list of species affected by WNS supports this perception (Foley et al., 2011).

The fungus is the etiologic agent of this fatal disease and infects wing membranes and skin tissues of hibernating bats (Blehert et al., 2009; Meteyer et al., 2009). At optimal temperatures, fungal hyphae grow and spread across skin surfaces of hibernating bats creating lesions and eroding and replacing skin structures, such as sebaceous glands, hair follicles and apocrine glands (Cryan et al., 2010). The wing pathology hypothesis suggests that increased mortality of hibernating bats is driven by the "disruption of wing-dependent physiological functions (Cryan et al., 2010)." An

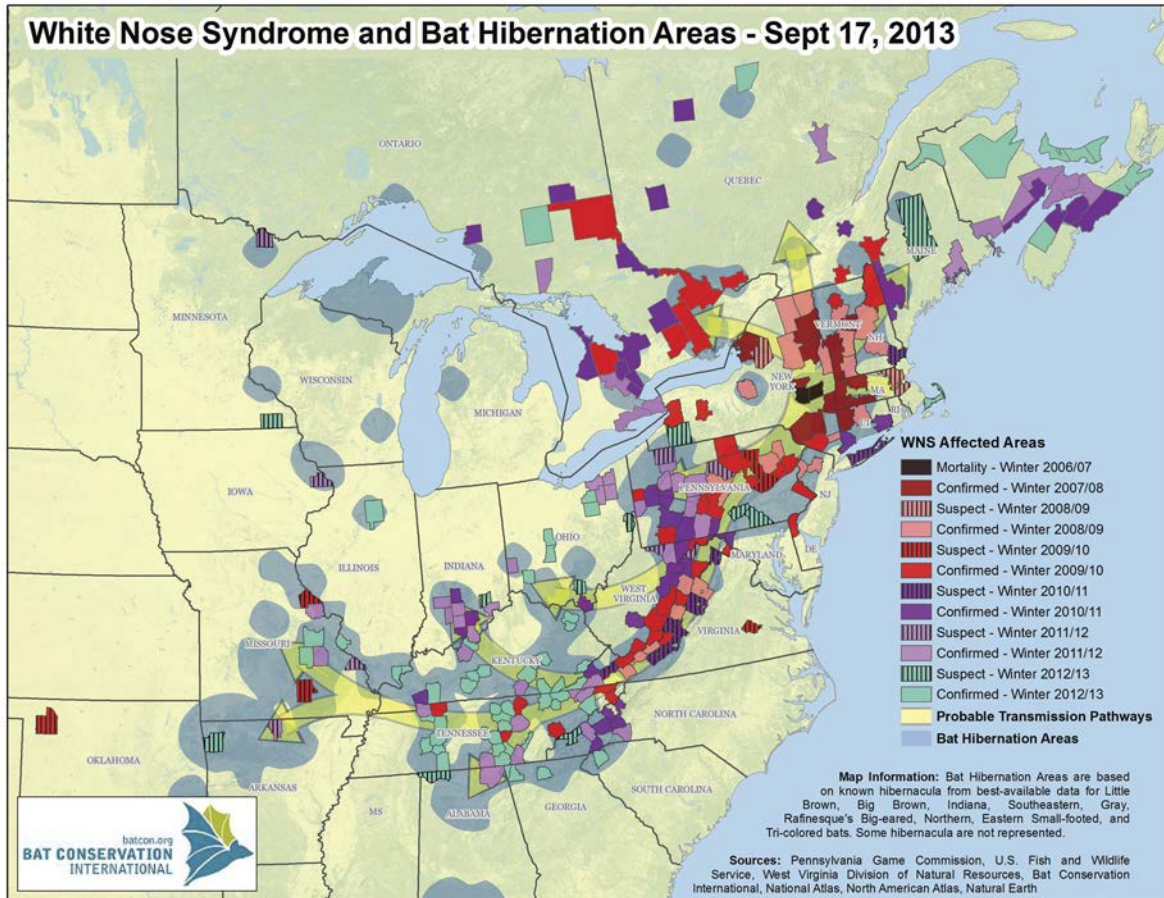


Figure 14. The temporal spread and geographic distribution of WNS in eastern North America.

alternate explanation for high mortality rates of hibernating bats from WNS is increased evaporative water loss from the fungal infection of wing membranes, or the dehydration hypothesis (Willis et al., 2011). Experiments demonstrated a significantly higher level of normothermic evaporative water loss in the little brown bat, a species vulnerable to WNS, when compared to a European bat species, Natterer's bat (*Myotis nattereri*), that overlaps the distribution of the fungus in Europe without significant mortalities (Willis et al., 2011). A third explanation, increased arousals, suggests that bats awakened more frequently during winter hibernation due to fungal infection depleting fat reserves needed to successfully hibernate until emergence in spring (Reeder et al., 2012). Regardless of these explanations, overall behavioral and histopathological responses of hibernating bats to the fungus include increased frequency of arousal, depleted fat stores, reduced immune response, and late-winter mortality (Warnecke et al., 2012). Evidence is accumulating that suggests dispersal of a single *Pseudogymnoascus destructans* genotype across eastern North America (Rajkumar et al., 2011), with a likely origin in Europe (Wibbelt et al., 2010; Warnecke et al., 2012).

Although the fungus is already known to affect hibernating southeastern myotis in Virginia (Foley et al., 2011), the southern most populations of this species, particularly in Florida, do not hibernate for as long a duration as other species of *Myotis* and occupy caves with temperatures warmer than those preferred by the fungus (Gore et al., 2012); thus, it is plausible that populations of this species in Florida may ultimately be spared from the severe population declines associated with this fungus (J. Gore, pers. comm.). Presently, the fungus has not been observed in Rafinesque's big-eared bat or in any other bat of the genus *Corynorhinus*. Populations of Virginia big-eared bats (*C. townsendii virginianus*) hibernate in several fungal-infected caves in West Virginia without any sign of infection or mortality (Stihler, 2011). *Corynorhinus* bats often hibernate closer to cave entrances in many winter roosts of the species (Mumford and Whitaker, 1982; Hurst, 1997), and have been found hibernating at temperatures from 4 to 11°C (MacGregor, 1997) and 0.6 to 8.9°C (Webb et al., 1996). A hibernaculum of Rafinesque's big-eared bat in Kentucky reached a low of 0°C in late January and sustained temperatures below 5°C from early January through early March (Hurst and Lacki, 1999). Thus, hi-

berating microclimates of these bats are sometimes cooler and possibly less humid than conditions needed for optimal growth of the fungus, which does best at a temperature range of 12.5 to 15.8°C (Chaturvedi et al., 2010; Verant et al., 2012) and at high humidity (>90%; Blehert et al., 2009). This explanation is partially supported by the absence of WNS on Virginia big-eared bats in West Virginia caves, as this species was observed roosting in less humid sections of hibernacula than fungal-infected species of bats (Stihler, 2011).

Studies of Rafinesque's big-eared bat during winter hibernation in Kentucky have demonstrated the use of shallow torpor in this species, with torpor bouts of short duration and considerable movement among hibernacula by these bats during winter months (Johnson et al., 2012b). These behavior patterns during hibernation may indirectly aid in periodically re-setting immune response in Rafinesque's big-eared bats, while simultaneously hindering fungal growth as these bats do not remain in the same roosting site for more than a few days (Johnson et al., 2012b). Data for all *Corynorhinus* species/subspecies will be needed to fully evaluate these possibilities. Regardless, the threat of WNS to these bats will likely become clearer in the next few years as the disease expands deeper into the geographic distributions of North American *Corynorhinus*.

4.9 Wind Energy Development

Growth in use of wind as a source of renewable clean energy has accelerated in recent years and the trend is expected to continue, as concerns mount over climate change, increasing energy demands, and environmental impacts from use of fossil fuels (McLeish, 2002; Inkley et al., 2004; Arnett et al., 2008). Despite the widespread perception, wind energy production is not environmentally neutral (The Wildlife Society, 2007), and impacts on wildlife habitats (Arnett et al., 2007; Kuvlesky et al., 2007) and populations of birds (Erickson et al., 2001; Smallwood et al., 2007; Smallwood and Thelander, 2008; Smallwood and Karas, 2009) and bats (Arnett et al., 2008, 2011; Rydell et al., 2010) have accelerated with the growing number and size of wind energy facilities and the increase in size and diameter of wind turbines. Placement of wind energy facilities on the landscape requires locations with high wind speeds; thus, high-elevation mountain tops, wide-open plains, and coastal areas have been the preferred choices for wind energy facilities (Johnson, 2010). These conditions exist in many geographic locations across the distributions of Rafinesque's big-eared bat and southeastern myotis, and Federal Aviation Administration data bases indicate numerous wind energy facilities are proposed for construction across the southeastern United States, including multiple locations in Arkansas, Tennessee, North Carolina, and Florida (C. Willis, pers. comm.). Most of these proposed locations are outside of the distribution of the endangered Indiana bat (*Myotis sodalis*), potentially avoiding policy and regulations that might limit facility operations or require mitigation measures as can occur at sites when EIS surveys demonstrate the Indiana bat to be present. Future regulations surrounding wind energy development may be dictated, in part, by the need to minimize impacts on this endangered bat from wind turbines where the two are in conflict (Arnett, 2012), and these regulations may ultimately benefit Rafinesque's big-eared bat and southeastern myotis.

Numerous bat species are vulnerable to fatality at wind energy facilities, with foliage- and tree-roosting lasiurine species exhibiting the highest mortality rates at wind energy facilities in North America (Barclay et al., 2007; Kunz et al., 2007; Arnett et al., 2008; Johnson et al., 2011). Studies indicate that wind turbines likely kill bats through direct strikes from blades (Kunz et al., 2007), and through changes in air pressure leading to 'barotrauma' and damage to lung tissues (Baerwald et al., 2008). Other species killed by wind turbines include several in the genus *Myotis* (Kunz et al., 2007; Arnett et al., 2008), suggesting that southeastern myotis is vulnerable should facilities be developed in close proximity to colonies of these bats. Effects of wind turbines on *Corynorhinus* bats remain unclear, with no evidence of mortalities reported in the literature. As with other *Corynorhinus*, Rafinesque's big-eared bat is a slow, agile flier that can glean insects from substrates and uses echolocation calls of low intensity and frequency (Lacki and Dodd, 2011). This flight and echolocation strategy may contribute to a reduced vulnerability to wind turbines of *Corynorhinus* bats, but data are needed to support or refute this possibility.

4.10 Air Strikes

Although all species of bats are potentially subject to collisions by aircraft, no strike involving Rafinesque's big-eared bat or southeastern myotis has been documented in the literature. According to records maintained by the United States Air Force, bat species most commonly killed by military aircraft were lasiurines (*Lasiurus* spp.), Brazilian free-tailed bats, silver-haired bats (*Lasionycteris noctivagans*), big brown bats, and pipistrelles (*Perimyotis* sp.) (Peurach, 2004). However,

some data maintained by the military listed bats struck as “vesper bats” and many were only identified as “bats.” Martin et al. (2005, 2008) examined use of airstrip culverts by bats at Naval Air Station Meridian, Mississippi, and potential collisions of bats with training aircraft. The base supported a large population of southeastern myotis that used culverts as maternity roosting sites, and there was concern for potential of serious bat-aircraft collisions. Based on material examined during post-flight inspections from 2000 through 2008, neither southeastern myotis nor Rafinesque’s big-eared bat was documented as struck by aircraft. Rather, eastern red bat (*Lasiurus borealis*) was the species most often reported as struck, primarily during the fall months; other species struck were tri-colored bats, evening bats, and a hoary bat (*L. cinereus*) (Martin et al., 2008).

4.11 Loss of Genetic Diversity

As highlighted in this conservation strategy, numerous threats exist to Rafinesque’s big-eared bat and southeastern myotis that have the potential for magnitudes of population decline capable of isolating remaining sub-populations and inflicting distribution-wide losses in genetic diversity. The extensive losses of mature bottomland hardwood forests in the Mississippi Alluvial Valley and the Gulf Coast Regions have, almost certainly, already fragmented populations of these bats to some degree in both north-south and east-west directions. Population genetic assessments of Rafinesque’s big-eared bat already demonstrate evidence of low genetic diversity, low colony connectivity, and the existence of population bottlenecks in some colonies (Piaggio et al., 2009; 2011). Habitat loss, disjunct populations, and overall declines in numerical abundance were postulated as reasons behind the patterns observed (Piaggio et al., 2011). The authors found evidence for two major evolutionary lineages in Rafinesque’s big-eared bat with a sequence divergence of 4% between them, and suggested that future management efforts of this species emphasize conservation of these divergent lineages.

Comparable assessments of population genetics in southeastern myotis are needed. The species is believed to be monotypic because of variation in appearance among demes (LaVal, 1970), but no recent evaluation of population genetics of southeastern myotis has been completed. Baseline data and studies on mitochondrial and nuclear DNA sequencing in this species are essential to evaluate existing and future patterns in genetic diversity at the metapopulation level. Variation in morphological appearance of southeastern myotis has contributed to historical errors in identification from little brown bats, producing inaccuracies in the historical distribution of the species from collected specimens (Davis and Rippey, 1968). Capturing the extent of this genetic variation at the species level is critically important to conservation efforts of southeastern myotis. Future loss of roosting sites and declines in connectivity of remaining habitat blocks has potential for further altering dispersal patterns and gene flow, leading to genetic drift, low effective population sizes, and reduced evolutionary potential in both Rafinesque’s big-eared bat and southeastern myotis (Cornuet and Luikart, 1996; Lacy, 1997; Altizer et al., 2003; England et al., 2003).

The recent emergence of new threats, e.g., WNS and wind energy development, is an indication of just how rapidly environmental conditions can change, and how conservation efforts at the species-level must remain inherently flexible and pro-active (Halbert, 1993; Irwin and Wigley, 1993), especially in addressing fluctuating patterns in the severity of existing and newly-emerging threats and how these changes affect genetic diversity and gene flow in Rafinesque’s big-eared bat and southeastern myotis. Use of captive bat management is being evaluated as a strategy for responding to losses of cave-roosting bats to WNS, with emphasis currently being placed on endangered bats and species already experiencing significant population losses (Coleman, 2012). Regardless, bats in both the *Corynorhinus* and *Myotis* genera are being evaluated and progress in this approach may eventually aid in conservation of genetic diversity of these two bat species.

4.12 Insufficient Conservation Planning

The dramatic loss of bottomland hardwood forest in the past century demonstrates a need for unified conservation efforts of Rafinesque’s big-eared bat and southeastern myotis, especially in the Lower Mississippi River Alluvial Valley, where substantial amounts of habitat of these bats have been lost and where millions of acres of potentially suitable habitat still exist but have never been surveyed. Appropriate steps are now beginning to take place with the coordinated efforts of conservation groups such as the Lower Mississippi Valley Joint Venture, Forest Resource Conservation Working Group (Wilson et al., 2007) and the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative (GCPO LCC). The latter is a conservation partnership of federal agencies, states, universities, regional organizations, tribes, and NGOs, who wish to develop a unified approach to management of natural resources in the southeastern states

(<http://gcpolcc.org>; accessed June 2012). The cooperative is part of a national network with a goal of coordinated action in meeting shared conservation priorities across large landscape areas. Goals of the GCPO LCC are consistent with sustaining and restoring existing bottomland hardwood forests in the southeastern United States and to manage these forests for biodiversity conservation. These types of efforts, if coordinated properly, can be a major boost to habitat management for both Rafinesque's big-eared bat and southeastern myotis in bottomland hardwood forests.

The different goals and objectives of public and private sectors for land management, however, create unique challenges for protecting and enhancing ecosystem diversity while maintaining economic stability across eco-regions (Yarrow, 2005; Wigley et al., 2007). Additional cooperative ventures will most certainly be needed if habitats of Rafinesque's big-eared bat and southeastern myotis are to be sustained into the future. The recent trend toward land divestment by large timber holding companies has led to a large number of individual and corporate landowners (e.g., timberland investment management organizations -TIMOs) across the southeastern region, creating even more challenges for regional and local biologists in terms of communication and coordination (Block and Sample, 2001; Stein et al., 2010; Miller et al., 2011). It will likely be difficult to disseminate information and promote habitat continuity for bats when habitat parcels are fragmented into smaller tracts, each with a different landowner and different management goals, and where goals may not consider long-term ownership or management to sustain forest resources (Miller et al., 2011). Public response to bat management will likely vary among locations, ranging from informed and enthusiastic support for bats to apathy and lack of knowledge about bats and their habitats.

Although considered species of special concern by the U.S. Fish and Wildlife Service (USFWS, 2010), the absence of formal protected status at the federal level for both Rafinesque's big-eared bat and southeastern myotis has limited the ability to implement conservation measures across the distributions of these two species. The U.S. Forest Service classifies these bats as sensitive species (USDA Forest Service, 2009b) and many states provide status recognition (Bayless et al., 2011; Appendix 1); however, few enforce these in legal matters, such as conflicts between land use practices and bats, or when vandalism occurs at roosting sites. The adoption of a comprehensive and widely-agreed upon approach to the management of habitats and populations of Rafinesque's big-eared bat and southeastern myotis across the southeastern region is warranted, and the justification for the development of this conservation strategy. Establishing federal protected status (i.e., threatened) for these two bat species, distribution-wide, might help in implementing measures and allocating funds to their conservation; however, with listing comes additional impediments that can also hinder progress in some aspects due to potential for extensive amounts of oversight, as is currently evident in the ongoing debate over how to best manage for the endangered Indiana bat in the northeast and central states (Kurta and Kennedy, 2002; USFWS, 2007). Thus, taking proactive steps for these bats in lieu of federal listing may in the long term be more cost effective, efficient, and politically acceptable.

5. CONSERVATION ACTION PLAN

The remaining sections of this conservation strategy for Rafinesque's big-eared bat and southeastern myotis delineate critical areas of need from both a management and research perspective and cover both short-term and long-term issues and goals (see Appendices 5 and 6). Highlighted are significant concerns for the protection of these bats, including: protection and creation of roosting sites, providing suitable foraging sites, establishing safe protocols for monitoring, development of range-wide population estimates and trends, and tracking threats and the responses of these bats to environmental stressors. Key areas of research need are identified, and the importance of communication and cooperation among stakeholders is addressed. Acceptable research and monitoring protocols as identified by the Technical Advisory Group are described in Section 6. The final section closes with a series of ten phases that outline a step by step approach to the conservation of these bats that delineate immediate actions needed, long-term concerns, and the need to periodically update and revise this strategy based on new information on the biology of these species and the emergence of new or increases in existing threats to these bats and their habitats.

5.1 Identify Occupied Habitat

Areas of high priority for conservation of Rafinesque's big-eared bat and southeastern myotis should be identified for conservation as Important Bat Conservation Areas (IBCA). IBCAs would include roosting sites with significant colonies, both hibernacula and maternity sites, and include sites that are protected and not protected. Determination of significant colonies of each species would be based on data from population monitoring efforts and how relative estimates of size compare with counts at other known colonies of the species. Initial conservation efforts would emphasize roosting sites that represent the largest populations (top 10-15% in size) of each species. Maximum population sizes of southeastern myotis are considerably larger than that of Rafinesque's big-eared bat. Geographic location of a colony relative to the distribution of the species should also be a consideration, as more isolated colonies at peripheral points in the distribution would be given consideration as an IBCA even with smaller estimates of population size because they may represent important pools of genetic variation (Piaggio et al., 2009, 2011).

IBCAs would also consider priority habitats of Rafinesque's big-eared bat and southeastern myotis, including those situated in landscapes threatened by fragmentation and or land conversion, such as parcels of bottomland hardwood forest in the southeastern United States (Twedt and Loesch, 1999; Wilson et al., 2007). Size of habitat patches and their spatial arrangement, juxtaposition, and connectivity would be important considerations when identifying an IBCA. Suitable habitat patches, both bottomland and upland, would be classified into large (>1,000 ha), medium (500-1000 ha), and small (<500 ha) categories, with initial conservation emphasis placed on identifying and protecting the largest habitat patches. Landscape connectivity will be an important consideration and patches smaller in size that can facilitate connectivity of larger patches would also receive priority emphasis. Potential connectivity would be evaluated in the context of distances moved by these bats when foraging and when switching roosting sites (e.g., Trousdale et al., 2008; Johnson and Lacki, 2011, 2013).

Determining the "suitability" of a habitat patch remains only partially clear and there are no data to suggest a minimum patch size necessary to support colonies of Rafinesque's big-eared bat or southeastern myotis over an extended time frame. Two habitat elements are important to this determination, especially for bottomland hardwood forests: availability of large-diameter roost trees and quality of existing foraging sites. Data on the size of cavity-trees sufficient for use as roosting sites exist (Carver and Ashley, 2008; Hoffman, 1999; Trousdale, 2011), but there is a paucity of data on densities of roost trees across geographic locations, both spatially and temporally. Surveys for cavity-roost trees of these bats, primarily Rafinesque's big-eared bat, on Noxubee National Wildlife Refuge, Mississippi, found 622 cavity-trees on 1,250 ha of bottomland hardwood forest, with 49 trees found to support these bat species (Stevenson, 2008). Roughly, this equates to 3.92 suitable roost trees/100 ha. This represents a starting point but far more data are needed across the distributions of these bat species to assess a modal value for roost-tree density and to evaluate the variation in roost-tree density across large landscapes. Currently, there are limited data to indicate a minimum number of roost trees required to support a local population of either of these two species in bottomland hardwood forests. Recent studies on Rafinesque's big-eared bat in bottomland hardwood forests in western Kentucky demonstrate "fission-fusion" behaviors by maternity colonies with bats moving among multiple hollow trees (Johnson et al., 2012a), so multiple trees are needed and the numbers will likely vary among locations.

Studies on foraging behavior and habitat use of Rafinesque's big-eared bat are few (Hurst and Lacki 1999; Menzel et al., 2001b; Johnson and Lacki, 2011, 2013), but even less is known about foraging in southeastern myotis (Miller, 2003; Menzel et al., 2005; Medlin and Risch, 2008). Future research efforts need to target foraging behavior and habitat selection of these two species to ensure a clearer understanding of the spatial and temporal aboveground habitat needs of these bats and to more fully assess the suitability of existing habitat patches on the landscape.

Once an IBCA is identified, a local plan involving appropriate stakeholders would be developed to implement conservation actions that promote long-term population stability of either or both of these bats at the IBCA. Development of a distribution-wide GIS data base that delineates the location and extent of IBCAs should be a goal of the conservation effort of these two bat species. This data base will need to be regularly updated in order to track temporal changes in pattern and extent of habitat gain or loss (e.g., Twedt and Loesch, 1999). A list of IBCAs could be maintained by the Southeastern Bat Diversity Network in their range-wide database (www.sbdn.org) and updated in partnership with Bat Conservation International (www.batcon.org) or included in the emerging Bat Population Data (BPD) project that is being upgraded to a web-based application (http://www.fort.usgs.gov/Research/research_tasks.asp?TaskID=2217).

5.2 Protect Existing Roosting Sites

Bats spend most of their lives in roosts (Kunz, 1982; Kunz and Lumsden, 2003). Roosts are important to the survival and social organization of bats; therefore, understanding roosting requirements is imperative for the management and conservation of any bat species. Concern for bat conservation has led to the overarching recommendation that bat roosts be protected from all forms of human disturbance (Fenton, 1997). Disturbance can alter activity patterns of breeding colonies (Shirley et al., 2001; Mann et al., 2002), or force hibernating bats to use energy stores critical for survival to spring emergence (Speakman et al., 1991; Thomas, 1995; Fenton, 1997; Johnson et al., 1998). Bats may also abandon traditional roosts when disturbed (Pearson et al., 1952; Kunz, 1982); thus, roosting habitat of Rafinesque's big-eared bat and southeastern myotis should be protected to the extent possible. Existing, large cavity-producing trees need to be maintained on landscapes as part of management actions, and the provision of future roost trees should be considered as part of forest management planning and, to the extent possible, integrated into landowner objectives both federal and private.

Initial conservation efforts should focus on maintaining existing roosting sites of Rafinesque's big-eared bat and southeastern myotis, and sheltering these roosts from inadvertent disturbance or outright vandalism by implementing gates, fences, or signs as appropriate and financially feasible (Tuttle, 1977; Currie, 2002; Sherwin et al., 2009). Cave, karst, and other subterranean roosts of these species should not be sealed off, altered, or destroyed. Subterranean hibernacula should be closed to recreational activities to avoid disturbing maternity colonies or waking hibernating bats. Where liability or safety is a concern, fencing and gating underground entrances will also enhance human safety and reduce landowner liability. Where bats roost in tree hollows, species of trees that produce basal cavities (e.g. bald cypress, sycamore, sweet gum, water tupelo, black gum) should be encouraged in forest management actions, and younger, developing trees of these species should be allowed to mature to promote recruitment of future roost trees. SMZs should be managed to promote retention of roost-tree species, especially in landscapes actively managed for timber production (Wigley et al., 2007). Although neither Rafinesque's big-eared bat nor southeastern myotis is currently protected at the federal level, other legislation does exist to enable protection of sites surrounding caves and along riparian corridors and should be enforced in locations adjacent or near roosts of these bats when applicable (e.g., Cave Protection Act 1988; Clean Water Act, Section 404). All landowners should be encouraged to implement BMPs when managing forests in areas supporting populations of Rafinesque's big-eared bats and southeastern myotis, and recommendations for wider SMZ buffers should be suggested as habitat enhancements for these bats.

When bats roost in anthropogenic structures (Fig. 15), accommodations should be made to retain those structures or replace them with equally suitable roosting opportunities. Liability can be a concern when bats roost in deteriorating buildings, open wells, cisterns, or beneath bridges, and funding is not always readily available to stabilize structures or restrict human access. Nevertheless, every reasonable effort should be made to retain (or enhance) anthropogenic roosts of Rafinesque's big-eared bat and southeastern myotis (Clark, 1990; Martin et al., 2011). Funds to stabilize structures and reduce liability threats should be pursued and construction of artificial roosts appropriate to these species considered when loss of existing roost sites is imminent (Roby et al., 2011). Partnerships with state and local departments of transportation (DOTs) should be established to encourage replacing bridges along highways and forest or county roads with bat-friendly designs (Keeley and Tuttle, 1999). Guidelines for bridge design and maintenance for sites where bats are roosting exist, and a strategy for outreach and education to the Federal Highway Administration and state DOTs should be developed as part of this conservation strategy to facilitate good stewardship in situations involving roosting colonies of these two bat species beneath bridges.



Figure 15. Examples of structures used for roosting by bats.

5.2.1 Cave and Mine Roosts

Site conservation should be linked closely to both the importance of the site (i.e., colony size) and its role in protection of the species. Due to limited resources, intrusive, expensive or complicated protection measures should be implemented at high-priority hibernacula, maternity, or swarming and staging sites. The range of conservation measures from least to most expensive includes: 1) doing nothing, which often keeps the site anonymous; 2) installing signs which deter access; 3) installing fences, road closures, and other means to restrict access; and 4) installing cave and mine gates that permit bat access through horizontal steel bars, but control human access through locked entrances.

Signs which deter access should include information about why the site is restricted and provide contact information for additional inquiries. Signs should be placed inside cave entrances so that they do not attract potential violators to the cave, but should be placed so that they do not block airflow or movement of bats into and out of the cave. Road closures can be a sufficient deterrent on public lands, combined with other protection measures. Cameras used at sensitive sites or sites with repeated disturbances have been shown to be successful deterrent and surveillance tools (M. Baker, pers. comm.). Even imitation camera systems can be a cost effective deterrent, particularly when coupled with signs indicating penalty for entry. Fences that limit access to a cave or mine site can provide a reasonable level of protection. Fences should be set out a sufficient distance from the underground cave or mine entrance to prevent interference with airflow and emergence behavior of bats. Distances will vary depending on the topography of the site and bat behavior, but sufficient distances typically exceed 15 m (50 ft); distances within 5 m of an entrance should be avoided if possible. No-climb chain link or other small-mesh fences over 3 m (10 ft) high with a smooth top wire angled away from the entrance are most effective for deterring trespassers (Ludlow and Gore, 2000). Smooth wire should be used rather than barbed wire to prevent bats from becoming entangled as they fly over the fence, although this becomes less important if the fence is far from the cave entrance and barbed wire does add an additional deterrent to trespassers. Fences are most effective in areas where the site is easily monitored (e.g., on private property or in a state park), and are advantageous because they can be safely, cheaply and correctly installed by local contractors. This makes them practical solutions for private landowners, small colony roosts and multiple entrance caves. While popular because of their lesser expense, fences offer significantly less protection from disturbance than cave gates, because they are relatively easier to breach by determined individuals. Consultation with an individual experienced in cave protection prior to installing any protection measures, including fences, is recommended.

At locations where less expensive measures are ineffective, or at highly sensitive or significant roosting sites, a cave gate is likely the most effective option for protecting bats from disturbance. It is extremely important to consult with professionals experienced in constructing cave gates during planning, designing and building cave gates. Kerbo (2004) offers this advice about installing gates: "Gates should only be used to protect caves [and mines] where the need is considered essential and a biologically neutral gate can be constructed. Gates can be deleterious to the ecology of a natural cave, especially if improperly designed. Even a bat-friendly gate is not as friendly as an un-gated entrance, though it may offer protection from external threats." Poor gate designs may impede or obstruct airflow and the movement of bats and other organisms into and out of the cave (Ludlow and Gore, 2000). Caves vulnerable to flash flooding should be carefully evaluated before a gate is constructed, especially when bats roost in micro-sites where they can be impacted should water be impounded by a gate. It is important to consider the possibility of debris accumulating against a gate that subsequently impedes airflow or blocks the entrance leading to rising water levels during flood events (USFWS, 2007).

Gates should be custom fit and constructed on site from steel angle iron, with 5 ¾" (14.6 cm) spacing between bars to permit flight of bats into and out of the cave (Powers, 2004; Kennedy, 2006). Current gate designs can incorporate windows, chutes, and flyover options for larger bat colonies, which may otherwise be restricted by standard gate rails (Powers, 2004; Kennedy, 2006). Care should be exercised during the construction process, as disturbance outside the cave or mine entrance can be problematic at sensitive roosts. Modification of the surface conditions and vegetation changes in surrounding habitats can potentially affect bat behavior. In addition to installing a gate at a cave or mine roost, a minimum of ¼ mile (400 m) habitat buffer surrounding priority cave and mine roosts is recommended to limit effects of management activities on the bats inside and to hinder detection by trespassers. Research is needed to evaluate whether this buffer dimension is sufficient for protecting roosting sites of Rafinesque's big-eared bat and southeastern myotis, as some have called for larger buffer zones (Clark, 1990; Hurst and Lacki, 1999).

5.2.2 Tree Roosts and Surrounding Habitat

The average lifespan of hollow tree roosts of Rafinesque's big-eared bat and southeastern myotis is unknown and long-term data are needed to produce estimates of survival for hollow tree roosts of bats in bottomland hardwood forests. These data are important to future management efforts that attempt to balance losses of existing roosts with replenishment of new roost trees. Data on survivorship of tree roosts of bats in forests of eastern North America are lacking, but patterns for western North America suggest longevity of snag roosts of bats to be less than randomly available snags in forested landscapes (Barclay and Brigham, 2001; Lacki et al., 2012). Regardless, longevity of hollow, live roost trees in bottomland hardwood forests is likely to exceed that of snag roosts of bats in upland habitats, and monitoring efforts have potential to ensure that roost trees remain standing for as long as possible, especially on state, federal, and private-industrial lands where personnel are available to monitor the roost trees and provide management oversight.

One aspect of habitat planning in bottomland hardwood forests involves active management of habitat immediately surrounding hollow tree roosts. Active management is defined as any activity that inhibits understory or mid-story development to facilitate access to the roost by bats. Hollow tree roosts of Rafinesque's big-eared bat and southeastern myotis are difficult to identify and relocate, especially in bottomland hardwood forests, so establishing protocols to maintain habitat surrounding roost trees will be difficult to implement across such landscapes, particularly on lands in private ownership where efforts to obtain cooperation from landowners will require effective communication of the importance of these bats. Regardless, for maternal roosts that have been discovered, the collection of GPS coordinates and the marking of trees for re-identification is encouraged. Management planning could then use this information to help ensure that known tree roosts are buffered from disturbances (e.g., removal of neighboring trees, creation of roads and trails at the roost site, changes in surrounding habitat structure) to avoid changes in roost microclimate and other disturbances that might alter roosting conditions and the suitability of these trees for bats. The size and extent of area surrounding tree roosts of bats that can and needs to be managed will vary by location, ownership, and management objectives, but in each case, management should consider local sources of potential disturbance (e.g., possibility of strong winds, accidental felling or vandalism) and species needs when determining the extent of area to be protected. Future research efforts are needed to evaluate the efficacy of buffers and how the amount and configuration of surrounding habitat influences longevity, use, and internal microclimate of roost trees of these two bat species.

Studies are now beginning to demonstrate that silvicultural prescriptions which produce more open woodland habitat (e.g., partial harvests, mid-story removal, controlled burning) may be beneficial to both foraging and roosting habitats of many bat species (Boyles and Aubrey, 2006; Hayes and Loeb, 2007; Perry et al., 2007; Perry and Thill, 2007). Because almost all of these studies have occurred in upland forests, caution should be exercised in applying these recommendations to cavity-roosting bats in bottomland hardwood forests. The bat species covered by the above recommendations typically occupy upland forests and roost under exfoliating bark or in small cavities high up on the bole where increased solar exposure of the roosting site may be beneficial. These roost trees are mostly snags (Carter and Feldhamer, 2005; Boyles and Aubrey, 2006; Miles et al. 2006; Lacki et al., 2009), as opposed to roost trees of Rafinesque's big-eared bat and southeastern myotis which are typically hollow live trees (Fig. 19). Another distinct difference is tree roosts of Rafinesque's big-eared bat and southeastern myotis are chosen in stand positions where direct exposure of the bole to sunlight is minimized following leaf-out, especially the lower half of the roost tree (Clark et al., 1997; Carver and Ashley, 2008). It should be expected that bat responses to silvicultural prescriptions are likely to vary between species living in upland versus bottomland hardwood forests. Studies evaluating suitability of different silvicultural prescriptions for bats in bottomland hardwood forests are much needed.

At present, no study has examined the effects of forest management on roost selection by either Rafinesque's big-eared bat or southeastern myotis in bottomland hardwood forests. Silvicultural practices that selectively remove the non-cavity and, therefore, non-roost trees within a stand of trees will leave roost trees standing and open up foraging space for bats, but could change characteristics of the forest in ways that reduces the likelihood of use by one or both of these two species of bats. For example, because cavity openings are commonly at ground level, any increase in forest floor cover resulting from opening up the canopy and mid-story vegetation layers, could potentially block access at the entrance, hindering use of these hollow tree roosts by bats. Further, the response of Rafinesque's big-eared bat and southeastern myotis to increased solar exposure of roost trees, and subsequent changes in roosting microclimates, is also unknown; thus, studies are needed to evaluate the effects of silvicultural practices, such as selective logging and thinning, on use of foraging areas and roost trees by Rafinesque's big-eared bat and southeastern myotis.

5.2.3 Building Roosts

Due to the unique conditions at each building roost of bats and the variation in configuration among building structures (Fig. 15), development of uniform prescriptions for management of building roosts, even for a single species of bat, will be difficult at best. Instead, scenarios based on adaptive management are more likely to succeed in protecting colonies of Rafinesque's big-eared bat and southeastern myotis occupying building structures. Building roosts of Rafinesque's big-eared bats are generally dilapidated, and the deteriorating conditions of building structures is a management concern, especially in regions where natural roosts are lacking and where these bats rely on buildings as primary roosting sites (Lowery, 1974; Saugey et al., 1993; England and Saugey, 1999). Additionally, in some areas, such as portions of Arkansas, abandoned buildings are accompanied by water wells, with these accessory structures frequently used by Rafinesque's big-eared bat for roosting, especially in winter months (Sasse et al., 2011). Thus, to the extent feasible, management efforts should try and sustain building roosts of these bats, at least until alternate roosting structures can be constructed (Clark, 1990) or accessory structures made suitable to bats for long-term roosting opportunities (Sasse et al., 2011). Conversely, southeastern myotis often inhabits buildings that are structurally sound and not in an advanced stage of decay, so approaches to exclude these bats that are not harmful need to be developed, including the possibility of placing bat houses nearby to facilitate roost switching in this species.

5.2.4 Bridge Roosts

Coordination between state DOTs, county public works departments, state wildlife departments or other appropriate agencies (e.g., USFS) is essential to success of any bridge-roost protection project. In each case, the agency with bridge ownership should be contacted soon after bats are discovered using a bridge as a roost. If an agency is unaware of bats roosting beneath the bridge, they will not have an opportunity to consider bat-friendly maintenance alternatives. If the state DOT environmental office, local bridge maintenance engineer, and state wildlife agencies work closely in the process, a good working relationship will facilitate meaningful discussion when repair or replacement decisions are underway. When evaluating alternatives, it is important to understand that activities designed to protect bats and their roosting sites will also increase costs, future obligations or delays in project completion date and are likely to be more difficult to gain support for implementation. Conversely, proactive conservation may aid in the effort to stabilize rare or declining populations of bats, including Rafinesque's big-eared bat and southeastern myotis, eventually reducing the likelihood of federal listing. This is important because once a species is federally protected delays, costs, and obligations in bridge repair and replacement will become inevitable. Thus, voluntary conservation measures ultimately have the potential to save time and money in the long-run. In many cases, hosting a field visit to the site can be a more effective communication tool than phone or email correspondence. Developing and effectively communicating incentives to DOTs and other agencies, which voluntarily incorporate considerations for roosts of these bats into their bridge maintenance schedules, is recommended.



Figure 16. A bridge with a construction design suitable for roosting bats.

Bats roosting in highway structures are already habituated to vibrations and sounds associated with normal traffic and will be minimally disturbed by activities that create these conditions (Fig. 16). Structural maintenance to bridges, therefore, should only affect bat colonies if the roost beneath the bridge is suddenly exposed or if foreign materials (water, tar, gravel, etc.) are introduced (Keeley and Tuttle, 1999). Maintenance activities underneath the bridge near the roosting site can cause disturbance to bat colonies, so scheduled maintenance on the underside of bridges housing summer bat colonies should not occur when pregnant or lactating females and flightless young are present. Exact dates will vary depending on geographic location, but approximate dates for southeastern United States range from 15 April through 1 August (Harvey et al., 1999). Both Rafinesque's big-eared bat and southeastern myotis are occasionally observed using bridges during winter months in southeastern states (Ferrara and Leberg, 2005b; Gore and Studenroth, 2005), thus, caution should be exercised in conducting maintenance on the underside of bridges housing winter bat colonies. Loeb and Zarnoch (2011) found less use of bridges by Rafinesque's big-eared bats in winter as temperatures declined, suggesting that colder winter periods may be more suitable times to do bridge maintenance. Before working near known bat roosts, relevant information should be provided to promote safety for both bats and workers. Maintenance workers should be discouraged from handling bats, and provided with respirators capable of filtering 2 to 3 micron-sized particles (protection factor at least 10) when dust from bat droppings cannot be avoided (CDC, 2005). No structural damage has been attributed to bats at bridges housing colonies (M. Bloschock, pers. comm.); however, organic materials that retain moisture, such as bat droppings, can potentially facilitate oxidation of unprotected metal bridge parts. Thus, bat roosts above exposed metal components should be discouraged (Keeley and Tuttle, 1999). The possibility exists that DOT agencies may decide to exclude bats from bridges and, if so, they should be encouraged to follow proper exclusion methods. Some states, such as Florida, have rules that delineate protocols for bat exclusion from bridges including seasons and methods.

Once constructed, the life of a DOT bridge is typically 20–50 years (Keeley and Tuttle, 1999). Involvement by the DOT, county highway department, or other appropriate agency during planning prior to bridge replacement will benefit all stakeholders involved. Planning should begin at least a full year prior to replacement. This allows for pertinent information regarding bat roosting locations to be communicated to the DOT environmental division, local bridge maintenance engineer, state wildlife agency, and other appropriate ownership agencies (e.g., USFS) at the beginning of the planning process. Replacement priorities should take into consideration current or past use by bats. Bridges with documented bat observations and surrounding vegetation suitable for foraging are the most likely candidates for successful partnerships. When bridges occur on public lands, collaboration with the land ownership agency to incorporate bat foraging habitat and future roosting opportunities will contribute to the long-term sustainability of the bat colony. Agencies who manage adjacent lands (e.g., USFS, NPS, state lands) may have the ability to require bat-friendly, bridge construction designs if bats are known to be in the existing bridge, in a nearby bridge, in the surrounding area, or if the road or bridge project is likely to cause forest fragmentation or other adverse impacts to a species. When the bridge cannot be replaced with a structure similar enough in design to allow continued roosting by bats, other options are available. For example, southeastern myotis may roost in crevices provided by post-construction bat boxes placed beneath or nearby the bridge (M. Bayless, pers. comm.). Both Rafinesque's big-eared bat and southeastern myotis have been documented occupying large cement, artificial roosts that mimic hollow trees when they are installed near bridges with adequate canopy cover (M. Bayless, pers. comm.).

5.3 Identification and Creation of New Roosting Sites

One aspect of this conservation strategy is to inform landowners and land managers in the southeastern United States of the current conservation status of Rafinesque's big-eared bat and southeastern myotis, and to educate them on the importance of searching previously un-surveyed public and private lands to confirm the presence/absence of these species and to locate maternity roosts and hibernacula. Assuming expanded survey effort, we should anticipate an increase in the number of known roosts over time. This outcome has two implications. First, as more roosts are discovered our awareness of the overall population status of these bats improves. Second, as more roosts are discovered, the effort and difficulty in sustaining a comprehensive monitoring effort increases accordingly. Limited resources already exist to sustain monitoring efforts and these will only be stretched as newly discovered roosts of these bats are added to the list of known roosts to be surveyed. This dichotomy should be considered in advance of developing distribution-wide survey strategies.

Densities of hollow tree roosts in bottomland hardwood forests of the southeastern United States can vary substantially among locations due to site history, stand age, and tree species composition (Hosner and Minckler, 1963; Dickson

et al., 1965; Conner and Day, 1976; Megonigal et al., 1997; King and Antrobus, 2001), and it is unclear what density and distribution of suitable roost trees is necessary to support populations of either Rafinesque's big-eared bat or southeastern myotis at the landscape-scale, both temporally and spatially. Recent studies have shown that variation in density of tree roosts influences "fission-fusion" behavior of maternity colonies of Rafinesque's big-eared bat (Johnson et al., 2012a), so we should expect these two species of bats to occur in habitats with a wide range of tree roost abundance and to do so at varying levels of colony size or bat densities (Bogan et al., 2003; Weller, 2007). These patterns in variation make conducting exhaustive surveys of tree roosts across existing bottomland hardwood forests both unrealistic and unnecessary. Instead, survey efforts that sub-sample habitat parcels within the matrix of bottomland hardwood forests are needed to help produce maps of the densities of total and used hollow trees. Correlating these density estimates to habitat metrics should permit GIS assessments of the amount of existing habitat with high, moderate, and low densities of hollow tree roosts of these bats. Subsequent studies that generate estimates of bat abundance associated with varying densities of hollow tree roosts could then be used in models to predict population estimates of bats at the landscape-level. A recent study in Georgia found colony densities of Rafinesque's big-eared bat across eight study areas to range from 0.07 to 0.47 colonies/ha in saturated and semi-permanent wetlands, respectively (Clement and Castleberry, 2013). Advances in this area would greatly enhance management of these bat species by identifying habitats that are occupied or degraded and in need of enhancement, and would lead to a more comprehensive understanding of distribution-wide population numbers of these bat species.

The placement of artificial structures suitable for use by roosting bats has been an ongoing effort for decades and much progress has been made in identifying design features that enhance or promote use of these structures by bats (M. Bayless, unpubl. data). The importance of buildings and other anthropogenic structures to bats in Europe has been known and studied for decades (Bat Conservation Ireland, 2010). Efforts to design structures suitable for roosting by Rafinesque's big-eared bat and southeastern myotis in locales where natural roosts are in short supply have met with some success, but have not consistently produced the kind of response in use by these bats as observed in many abandoned anthropogenic structures such as wells, cisterns or barns (Martin et al., 2011; Sasse et al., 2011; M. Bayless, unpubl. data). Carefully designed experiments are needed to evaluate the interplay of placement, associated habitat conditions, and structural features in rendering artificial structures suitable or not suitable for use by these two species. Existing studies have confirmed the importance of microclimate inside structures (i.e., temperature and humidity) to use by Rafinesque's big-eared bat (Clark, 1990; Ferrara and Leberg, 2005b; Roby et al., 2011; Johnson and Lacki, 2012), but data are needed for southeastern myotis as published studies of preferred roosting microclimates inside artificial structures are lacking.

5.4 Population Inventory and Monitoring

Statistically robust estimates of population size are difficult to achieve for bats, particularly for species that exhibit low fidelity to roosting sites and switch roosts frequently (Weller, 2007). Unique problems exist depending upon the type of roosting structure, including caves and mines (Tuttle, 2003), buildings (Kunz and Reynolds, 2003), and tree crevices and cavities (Bogan et al., 2003). Habitat-associated issues in estimating population sizes of bats also exist, especially for bats that occupy bottomland hardwood forests, where monitoring is difficult due to logistical constraints and fluctuating hydrologic conditions that render access to roosts by both bats and investigators difficult during some periods of the year (Clark, 2003). These problems can and will affect efforts to assess the population status of Rafinesque's big-eared bat and southeastern myotis, as these species differentially occupy caves, mines, buildings, and tree cavities in bottomland hardwood forests depending on the time of year and geographic location. Moreover, Rafinesque's big-eared bat exhibits "fission-fusion" behavior when inhabiting tree cavities in bottomland hardwood forests (Johnson et al., 2012a), further complicating an ability to produce reliable population estimates. Data are needed to confirm whether these same behavior patterns occur in southeastern myotis. Bridge surveys of both Rafinesque's big-eared bat and southeastern myotis indicate considerable fluctuations in population sizes within bridge roosting sites and presumed movement of bats to alternate roosts (McDonnell, 2001; Trousdale and Beckett, 2004; Ferrara and Leberg, 2005a; Gore and Studenroth, 2005; Bennett et al., 2008).

Because roosting preferences of Rafinesque's big-eared bat and southeastern myotis vary seasonally and geographically, obtaining reliable population estimates will require that a range of methods be used to census populations depending on the type of roosting structures being surveyed (Kunz, 2003). Further, combining data generated using various survey methods, each with their own sources of sampling error and anticipated levels of variation, will require predictive models to be developed that can use and integrate data from different sources (Clark, 2003). Developing a statistically-

robust sampling strategy for estimating population sizes of these two species that uses both counts of bats during winter hibernation and the summer maternity season should be a long-term goal of this conservation strategy.

There is currently insufficient information about Rafinesque's big-eared bat and southeastern myotis to comprehensively map species distributions or adequately assess distribution-wide population status. Both habitat and roost site inventories should be conducted on a repeated basis to provide baseline data on population sizes for long-term planning and monitoring efforts (Fig. 23). Geographic Information Systems (GIS) should be used to develop predictive models that identify areas of higher bat concentrations and to prioritize future survey efforts. Inventories will need to incorporate statistically valid sub-sampling at multiple spatial scales across the range of these bat species to ensure reasonable inference of model outcomes. Surveys should include natural habitats (caves and trees) and man-made structures (mines, bridges, buildings, cisterns, wells, etc.). Guidelines for roost surveys should be developed across agencies to ensure, to the extent possible, consistent, reliable and comparable data collection procedures. Results from a coordinated range-wide inventory of both species will be fundamental to developing a statistically-sound monitoring program.

Among the considerations that need to be addressed in monitoring efforts include survey measures that can be related back to habitat management prescriptions, account for differing seasons (i.e., maternity, hibernation, or both), address differences across habitat types (bottomlands, karst, uplands), estimate variation due to roost-switching behavior and use of multiple roosts by colonies, and are based on sufficient replication in data collection to allow for evaluation of demographic changes at multiple spatial scales. Further, shifts in species distributions, either increases or decreases in range, must be carefully monitored. A key step in coordinating monitoring efforts across the ranges of these two bat species will be establishing a centralized location for storage of population data, with the most likely possibility being the BPD project of the U.S. Geologic Service (USGS). These data will not be exhaustive, however, as it will be difficult in some instances for monitoring and data collection to be permitted at roosting sites on private lands if landowners suspect data could be used by the USFWS as part of an effort to petition these bat species for listing as threatened or endangered.

Monitoring programs for Rafinesque's big-eared bat and southeastern myotis will always be challenged by limited resources and the possibility of long-term commitments by organizations. Species conservation, however, is likely to be less costly in the long run if agencies, landowners, and conservation groups begin investing in survey efforts. Lack of baseline data, inconsistent methodology, diverse jurisdictional boundaries, variable habitat use, low levels of detection, and decentralized data reporting will continue to hinder conservation efforts of these bat species as long as they lack federal designation, because no centralized agency is authorized to lead the conservation effort. Perhaps just as important, an absence of clear objectives and adequate planning will render interpreting the biological significance of any observed change in population levels difficult (Ellison et al., 2003). Critical to future population assessments of these two bat species will be development of approaches to define and detect biologically meaningful differences (e.g., power analyses, statistically-robust sampling sizes, and derivation of confidence intervals about population means). In subsequent subsections, specific issues related to surveys of populations in caves, mines and buildings are discussed relevant to Rafinesque's big-eared bat and southeastern myotis.

5.4.1 Caves and Mines

WINTER: Timing: Range-wide surveys of hibernacula of Rafinesque's big-eared bat and southeastern myotis are recommended, with as many hibernacula as possible surveyed annually to monitor temporal changes in population size. Surveys should use methodology that results in minimal disturbance to hibernating bats. Given the expansion of WNS into the distributions of these two bat species, all survey protocol at hibernacula should adhere to guidelines set forth by the USFWS regarding entry and monitoring of hibernating bats in eastern United States (USFWS, 2011a). It should be anticipated that guidelines will evolve over time as our understanding of the impact of WNS becomes clear. Currently cave entry is allowed in some states by permitted biologists within the distribution of the *Pseudogymnoascus* fungus, but not others. Thus, systematic distribution-wide surveys of the same approach may not be feasible for assessing long-term numerical changes in the abundance of these two bat species, unless a collective agreement can be reached across states to unite in a common monitoring approach at hibernacula of these bats. More realistically, population monitoring efforts will have to use a varied set of approaches to assess population trends at hibernacula of these bats. For example, use of beam-break systems offers potential for estimating the number of bats at hibernacula (M. Baker, pers. comm.), and may be well suited to hibernacula where a single bat species is present. These systems have costs involved in materials, placement, maintenance, repair, and data processing; thus, they may only be suited to caves and mines on public lands as private landowners will not likely be willing to absorb any cost associated with operating a beam-break system.

Additionally, novel alternatives may be used to track populations of these bats in caves and mines, and repeated emergence counts during swarming and staging may be useful in assessing long-term trends in hibernating populations.

Methodology: Direct counts are the traditional method of surveying hibernating bats. Individual bats and clusters are enumerated, and where clusters are large, estimates of cluster size are often re-checked using photographs of the cluster. Sub-sampling of direct counts of larger clusters (>25 bats) with high-resolution photographs is recommended. Photographic sub-sampling (i.e., limited to a % of cluster counts to minimize disturbance to bats from flash photography) can provide error estimates of direct counts and a permanent record of the activity (Meretsky et al., 2010). Minimum camera specifications and photography methods should follow Indiana bat survey protocols for consistency (USFWS, 2007). When possible, camera systems should include a single lens reflex (SLR) digital camera with a minimum resolution of 8 megapixels, a zoom lens, adequate flash and flash extender (for high ceilings), and spot metering capabilities for survey photographs. Many cameras require light to focus; laser pointers can improve camera autofocus and ensure the correct bat cluster is photographed (Hicks et al., 2009). Where clusters are exceptionally large, a measure of scale in the photograph or measure of the area covered by the clusters should be included. A steel tape, folding engineering ruler or laser caliper (for high ceilings) may be required to accurately measure cluster sizes.

Survey teams should be limited in size to reduce disturbance, but consist of up to four individuals for effective bat counts. Surveyors should be skilled in standard caving techniques, including vertical survey experience. New surveyors are encouraged to conduct multiple surveys under supervision by an experienced observer to ensure consistency among surveyors. Each survey report should include a map of each hibernaculum with survey sections clearly labeled. If no map is available, a detailed sketch of the surveyed sections should be prepared to facilitate future surveys and provide baseline information for subsequent surveys. During each survey, bat roosting locations should be identified on an accurate map of the cave or mine, so that future surveyors can locate roosting sites and document changes in roosting behavior. Identification of evidence of past roosting locations is encouraged. Roosting sites should be sub-sampled to collect microclimate information using a non-contact infrared laser thermometer. The temperature on the wall adjacent to bat clusters should be recorded soon after reaching the cluster and away from the influence of the body heat of the observer. The thermometer should be calibrated prior to each survey. Records of the location and height above the floor where measurements are taken should be made. Data loggers which record environmental conditions inside the roost (i.e., temperature, humidity, and disturbance events) should be installed to monitor roost conditions at important hibernation and maternity sites. Survey reports should include a site name, county, state, geographic coordinates, survey date, list of surveyors, the time spent surveying (start and end times) and a clearly labeled cave or mine map. Notes on numbers of other species, condition of cave gates and fences, evidence of human and other disturbance, and evidence of predation should be noted on the survey form. In all locations surveyors should spend the least amount of time possible in each hibernaculum. Activities should be coordinated with the appropriate state agency, and state and Federal permits should be in the surveyor's possession if required.

SUMMER: Timing: Colonies of both species can be sensitive to disturbance during the maternity season. If possible, surveys each year are recommended. Surveys should be conducted at the cave or mine entrance when the young are flightless and then soon after volancy commences to assess the increase in colony size and index the reproductive success of the maternity colony. Survey dates will vary by geographic range and seasonal phenology. When time or resources prevent completing both surveys, completing the post-volancy survey is recommended.

Methodology: Bats should be surveyed using entrance counts at sunset that continue through to the completion of the nightly emergence, typically from 1-2 hrs post-sunset. A sufficient number of surveyors should be involved to ensure that all entrances are surveyed. Night vision equipment should be compliant with Gray bat survey protocols (USFWS, 1982; typically a Sony video camera with IR lights and nightshot capabilities). Infrared lighting is preferred over visible red light for emergence counts. Use of thermal imaging cameras and image analysis with tracking software will likely be the best approach for estimating size of large maternity colonies of southeastern myotis. Under no circumstances should entry inside maternity roosts to count or photograph bats be permitted, as this will likely lead to fatalities of juvenile bats and possible abandonment of maternity roosting sites. If necessary, monitoring inside caves of maternity colonies should be done only with red lights or nightvision equipment. For specific research or monitoring projects the use of marking techniques such as passive integrated transponder (PIT) tags or bands may be explored. Survey reports should include a site name, county, state, geographic coordinates, survey date, list of surveyors, and the time spent surveying (start and end times). Notes on weather conditions, moon phase, numbers of other species, condition of cave gates and fences, evidence of human and other disturbance, and evidence of predation should be noted on the survey form.

5.4.2 Buildings and Bridges

Direct counts are the most common method to survey bat colonies in buildings and bridges. We recommend surveying buildings, bridges, and other man-made structures for bat occupancy during summer months. Available research indicates the frequency of use of anthropogenic structures by both Rafinesque's big-eared bat and southeastern myotis peaks during summer months when maternity colonies form (Felts and Webster, 2003; Trousdale and Beckett, 2004; Ferrara and Leberg 2005a,b; Bennett et al., 2008). Bats roosting in buildings, bridges, and other human-made structures tend to be more tolerant of visitation than those roosting in caves and mines, perhaps due to their increased tendency for roost switching (Trousdale and Beckett, 2004; Ferrara and Leberg, 2005a; Bennett et al., 2008). Regardless, maternity colonies with flightless young are sensitive to disturbance, particularly in the first few weeks post-parturition, so no more than one survey is recommended between the time when young are born and when they become volant (early May to mid-July).

When resources are limited, bridge surveys for both species should be limited to concrete bridge designs which trap heat and retain stable temperatures for roosting bats (Ferrara and Leberg, 2005b). For Rafinesque's big-eared bat, surveys should prioritize bridges with open compartments such as T-beam or multi-beam bridges. For southeastern myotis, bridges with crevices should be surveyed. Because of the roost-switching behavior employed by both Rafinesque's big-eared bat and southeastern myotis, bridges should be inspected 3–5 times in a given year to determine with reasonable confidence whether or not they are being used (Ferrara and Leberg, 2005a; Bennett et al., 2008). Based on a 0.42 probability of absence of Rafinesque's big-eared bats from known roosts, at least 3 surveys are necessary to have a <10% chance of misidentifying a roost bridge as a non-roost (Ferrara and Leberg, 2005a).

When bats are found roosting in bridges, development of collaborative relationships is encouraged among the Federal Highway Administration (FHWA), state DOTs, county public works departments, land management agencies, and state wildlife agencies. This will facilitate creation of a memorandum of understanding that covers voluntary guidelines for assessing bat use, conservation actions, and bridge replacement strategies. Because of seasonal variation in bridge use by bats, monitoring programs need to involve summer and winter surveys to document all species of bats that use bridges. Surveys of bridge roosts are not known to cause roost abandonment, but care should be taken when monitoring larger groups and maternity colonies. Surveys during the day detected many more bats than surveys conducted at night (Ferrara and Leberg, 2005a).

5.5 Population Genetics

Critical to our understanding of the status of Rafinesque's big-eared bat and southeastern myotis is a determination of population connectivity across local and geographic distances. In locations where populations (roosts) are isolated due to limited dispersal and gene flow, bats will ultimately suffer from loss of genetic diversity, subsequent inbreeding depression, or susceptibility to disease or ecological catastrophes (Piaggio et al., 2011). The ability to estimate effective population sizes or changes in demography through use of genetic tools, such as mitochondrial or nuclear DNA sequencing and microsatellite loci, can inform management and conservation efforts. Mitochondrial DNA and nuclear DNA sequencing primers have been optimized for use in Rafinesque's big-eared bat (Piaggio and Perkins, 2005), with 15 microsatellite markers specific to this bat already developed (Piaggio et al., 2011). These tools along with appropriate population genetic theory and statistics are excellent methods for inferring population connectivity, genetic diversity, changes in population demographics, and effective population size. Genetic methods have also been used in mark-recapture analysis to estimate overall population size of Indiana bats in a study in Indiana (S. Oyler-McCance, unpubl. data). Genetics-based research studies require large sample sizes and will need the coordination of field investigators in the future to assess the distribution-wide status of bats. Presently, no study of genetic diversity and divergence exists for southeastern myotis and such studies are sorely needed for long-term conservation efforts of this species.

Samples for such studies are ideally tissues from wing biopsies. These samples provide the highest quality and quantity of DNA. Other sample types can be feces (guano) or saliva swabs, but, due to the nature of these tissues (low quality/quantity DNA), the number of samples that need to be processed is greater resulting in added time and costs for analyses (Clare et al. 2009; Clare et al. 2011; Zeale et al. 2011; Dodd et al., 2012a). Further, such sample types require additional statistical analyses to estimate genotyping error rate associated with allelic drop-out and false alleles that result from low quality/quantity DNA. Genetic assays in conjunction with ecological studies such as radiotelemetry or mark-recapture can provide a fairly robust picture of bat populations. Presently, only a single study has applied a population genetic approach to Rafinesque's big-eared bat (Piaggio et al., 2011), with no such study completed on southeastern myotis. A comprehensive understanding of the genetic status of these two bat species will require the collection of replicate data sets from multiple locations across their geographic distributions.

5.6 Manage Foraging Habitat

Long-term conservation of Rafinesque's big-eared bat and southeastern myotis will require diverse and healthy forest communities that provide quality foraging sites, functioning hydrologic systems, and sufficient roosting conditions. Without each component, populations of these two species will be difficult to sustain in bottomland hardwood forests. At our present state of understanding, management actions that retain late succession forests with high species diversity, structural complexity, and a relatively open understory appear desirable. Activities that dramatically alter forest structure or convert forest land to other land uses should be avoided in areas supporting significant populations of these bat species. The importance of woody plant diversity to sustaining healthy moth communities is well documented (Summerville et al., 2001, 2003; Summerville and Crist, 2002, 2003). Thus, management practices that maintain or increase woody plant diversity should enhance suitability of foraging sites for Rafinesque's big-eared bat by providing an abundant and diverse pool of available moth prey (Hurst and Lacki, 1997; Burford et al., 1999; Dodd et al., 2008; Lacki and Dodd, 2011). The possibility exists that a range of silvicultural practices, such as thinning or small-patch cuts, might enhance both foraging space for bats and the abundance and diversity of insect prey, including moths. However, studies examining bat foraging behavior and patterns in moth abundance and diversity associated with various timber management prescriptions are sorely needed for bottomland hardwood forests, as published data sets are largely from upland forests and responses of bats and moths to habitat changes in wetland ecosystems may not be identical to those in upland forests.

Efforts to ensure that land managers minimize impact of timber harvests by adhering to established guidelines for Best Management Practices (BMPs; Stringer and Perkins, 2001), which require functional stream buffers and maintaining diversity of woody plant species, will benefit bats and other wildlife dependent on riparian corridors. Presently, no data exist that compare habitat use (foraging and roosting) of Rafinesque's big-eared bat and southeastern myotis to stream buffer dimensions, so in the absence of data a more conservative approach that allows for wider buffer strips is encouraged, at least until habitat use of these bats can be evaluated at replicate stream corridors of varying widths and in different landscape contexts.

Guidelines need to be developed which provide for a range of options while still adhering to BMPs, so that land managers can select from a diverse set of choices in managing bottomland hardwood forests but in ways that meet the needs of bats simultaneous with other management priorities and objectives. It should be noted that BMPs vary with topographic and ecological conditions (Stringer and Perkins, 2001) and that variation in habitats along stream corridors across the distributions of these bats should be anticipated. Ultimately, a properly functioning hydrology is critical to conservation actions for these bats in bottomland hardwood forests and is a research need that is sorely lacking. Connectivity of wetlands and waterways should be a focus of management efforts attempting to bridge land parcels of different ownerships together, and research examining variations in connectivity and habitat block size in relation to colony size, patterns in movement among roosting sites, frequency of dispersal among relatively-isolated colonies, and gene flow in these bats, is also needed. Urban planning at local and regional scales should address water conservation and promote the use of pervious land surfaces to further support the hydrology of adjacent watersheds.

5.7 Monitoring Emerging Threats

The future of bats and their habitats is anything but clear. At the turn of the century effects of wind turbines on birds were just beginning to be studied (Erickson et al., 2001), and the emergence and debilitating effects of WNS on hibernating populations of North American bats were completely unforeseen. Logically, new, yet unknown, concerns should be expected to arise and any discussion of emerging threats to Rafinesque's big-eared bat and southeastern myotis is likely to be outdated within a short period of time. For example, high volume horizontal hydraulic fracturing, i.e., fracking, is expanding in use and the effects of this technology are only beginning to surface. Areas of concern include effects on wastewater and stream ecology, toxic air emissions, habitat fragmentation, and excessive lighting and noise (NYS-DEC, 2011). The loss of aquatic insects and excessive 24-hr noise levels are postulated to impact bats (Kiviat and Schneller-McDonald, 2011), but empirical evidence is lacking.

Regardless, the most recent issues of concern facing North American bats include mortalities associated with wind energy development and WNS infection. In both cases, legal and federal responses to the issues are evolving rapidly and this constant stream of change in policies and protocols will largely dictate how management of Rafinesque's big-eared bat and southeastern myotis will be handled relative to these threats (USFWS, 2011b; Arnett, 2012). Regardless, cooperative efforts

among state and federal agencies in providing oversight of placement and numbers of wind energy facilities across the southeast, and in monitoring the spread of the fungus to hibernacula of bats, is essential to understanding the cumulative effects of these threats to the global survival of Rafinesque's big-eared bat and southeastern myotis.

No assessment of emerging threats to bats is complete without some mention of climate change and the future it holds for species and their habitats. Effects of climate change on the potential distribution of summer maternity habitat of the Indiana bat has been examined (Loeb and Winters, 2013), but presently we can do little more than speculate on how changes in annual temperature extremes, amount and frequency of rainfall, and shifting weather patterns will affect Rafinesque's big-eared bat and southeastern myotis. Needed are models that evaluate changes in habitats, particularly distributions of important roost tree species (e.g., tupelo) based on various climate change scenarios (S. Loeb, pers. comm.), such as correlative models that use current and historical distributions. Better information on bat responses to high temperatures and the need for water would also help in predicting the effects of climate change on Rafinesque's big-eared bat and southeastern myotis.

Forest ecosystems are believed to exhibit non-linear responses to rising temperatures, with threshold limits that, if surpassed, leave subsequent forests permanently altered from current steady states in species composition, tree densities, and habitat structure (Parks and Bernier, 2010). Across North America rising temperatures and subsequent changes in forested habitats are projected to be severe in the southwest (Allen et al., 2010) and in the Midwest (Loeb and Winters, 2013), the western edge of the distributions of Rafinesque's big-eared bat and southeastern myotis. Less impact is anticipated in the southeastern region of the continent (Kalcounis-Rüeggell et al., 2012). Modeling results suggest some hope of resiliency of bottomland hardwood forests to climate change, as research has confirmed that increased levels of CO² will lead to greater productivity and increased water use efficiency of forests (IPCC, 2012). Regardless, we should proceed with caution and anticipate that even mild impacts to southeastern forests could alter hydrology or shift tree species composition and habitat structures in ways that are potentially harmful to these two bat species. Some suggest that global levels of CO² in the atmosphere have exceeded 380 ppm and are expected to reach 550 to 600 ppm, even with a relatively rapid planet-wide response to climate change (Hertsgaard, 2011; Stager, 2011); however, current estimates of the IPCC indicate less extreme responses in rising CO² levels (IPCC, 2012). Ultimately, changes in bottomland hardwood forests resulting from increases in CO² levels and temperature extremes are likely to be gradual and not necessarily easy to detect, so management for Rafinesque's big-eared bat and southeastern myotis needs to consider the possibility of effects as we move forward with our efforts to conserve these bat species into the foreseeable future.

5.8 Education, Extension and Outreach Campaign

A comprehensive outreach program must accompany any conservation action. The persistence of both Rafinesque's big-eared bat and southeastern myotis in their natural habitats will depend heavily on volunteer efforts of land managers and concerned citizens. Many river corridors, swamplands, anthropogenic roosts, caves, and underground formations within the distributions of these species are held and managed by public land agencies, and it is anticipated that other large-acreage landowners, such as commercial timber companies and developers, will have an increasingly crucial role in the long-term management of these bats throughout their ranges. The recent trend of property divestments by large landholders makes effective communication with numerous small private landowners also important in the overall conservation efforts of Rafinesque's big-eared bat and southeastern myotis.

Given the gaps in the existing data bases for Rafinesque's big-eared bat and southeastern myotis, it is likely that many land managers, both public and private, remain unaware of the needs of these bats in bottomland hardwood forests or in cave and mine roosts that they inhabit. Presently, there are few educational or outreach materials available to encourage effective and voluntary habitat management options for these two bat species. For this conservation strategy to be effective, clearly written guidelines for land management need to be developed and distributed to lawmakers, decision makers, enforcement officials, landowners, and the general public to foster pro-active habitat management. These guidelines should include strategies for recruiting roost tree species, options for sustainable timber management practices, information about laws and legal issues affecting bats, and tools for protecting bat roosts from disturbance and alteration, while reducing landowner liability (e.g., leaving caves open and abandoned buildings standing). Partnerships should be developed between state and federal agencies and private landowners to promote materials and management ideas at the local level to engender public support for these bat species in the surrounding communities. One untapped resource is Cooperative Extension Programs at land grant universities across the southeast. Such institutions have the expertise, technology, facilities, software, distribution infrastructure, and staffing necessary to develop effective outreach products and could be an extremely useful partner in the conservation efforts of these two bat species.

5.9 Conservation Incentives

Bats do not recognize land ownership boundaries and consequently, regardless of actions of public agencies, range-wide conservation of these species will require voluntary stewardship by private landowners. Private lands will play a critical role in providing sustainable habitat and stable bat populations. Critical habitats or IBCAs should be prioritized to ensure effective distribution of resources and habitat connectivity throughout the ranges of these species. Existing wetlands and riparian corridors should be conserved, especially where bat roosts have been identified or important foraging areas occur. Conservation goals for managing bat habitat often coincide with other forest and wetland species. Public and private landowners will need to work in partnership to ensure landscape connectivity and provide corridors for movement between larger patches of suitable habitat.

Barriers to private land stewardship are lack of awareness and concern that species presence will impact proposed activities on properties. Partnerships should be established in the planning stage, whenever possible, to minimize impacts of land use activities and foster sound stewardship of the resources needed by Rafinesque's big-eared bat and southeastern myotis. Incentives should be created to encourage ecologically diverse landscapes and healthy hydrologic processes. Where possible, partnerships should be developed to promote more inclusive conservation incentives to private landowners, in combination with other conservation organizations. Examples of these types of programs and arrangements exist for many wildlife species (e.g., Ducks Unlimited, Rocky Mountain Elk Foundation, Partners in Flight), and similar efforts for these two species of bats are realistic and achievable goals of this conservation strategy. The use of joint ventures and the involvement of LCCs in the conservation efforts of these bats are fundamental to their successful conservation. Conservation-friendly tax structures that reward sustainable forestry practices, habitat protection, and water conservation should be encouraged. A variety of incentives should be made available that promote diverse and healthy forests for bats and other wildlife. Landowner partnerships, stewardship agreements, management agreements, conservation easements, and means of financial assistance should be created to influence land management planning. Several state and federal programs already exist to manage forests, wetlands, and roosting resources of bats and should be promoted as part of this conservation strategy.

6. RESEARCH RECOMMENDATIONS OF THE TECHNICAL ADVISORY GROUP

6.1 Research Priorities

One of the current barriers to conservation of Rafinesque's big-eared bat and southeastern myotis is gaps in our understanding of basic life history, demography, distribution, and habitat needs. Consequently, there is insufficient information on distribution and populations to properly assess status and long-term trends of these two species and existing knowledge gaps make specific conservation recommendations difficult to develop, requiring biologists and land managers to set guidelines based on incomplete information. Research on both species has accelerated in the past 10 years, and many of the priorities are currently under investigation. The recent publication of the big-eared bat symposium proceedings (Loeb et al., 2011) has contributed significantly to our understanding of the biology and management of Rafinesque's big-eared bat and to this conservation strategy; however, no equivalent document covering southeastern myotis exists.

Research needs of the Technical Advisory Group are presented in Appendix 2, with specific priorities listed in Appendix 6. Most of the identified research priorities should be investigated at multiple spatial scales and incorporate study sites from across the range of habitats and regions that these bats occupy. For example, both inland and coastal populations of Rafinesque's big-eared bat should be included and compared to ensure a comprehensive assessment of habitat suitability in this species. Fortunately, Rafinesque's big-eared bat and southeastern myotis are listed as species of concern in most State Wildlife Action Plans (SWAP) within their range, facilitating local research priorities and offering grant opportunities to conduct research and monitoring activities that are consistent with the priorities outlined in individual SWAPs.

Prior to initiating any new bat research or monitoring efforts, federal, state and agency non-game wildlife permits will need to be obtained. These regulations are enforced to ensure that the methods being used lead to no harm or take of the species of bat in question, and that methods and approaches are consistent with current mandates to minimize the spread and exposure of bats to WNS infection (USFWS, 2011a). In the case of federal permitting, the process is lengthy and can take anywhere from 3 months to more than a year for approval, so adequate planning to ensure authorization by study start date is important. The American Society of Mammalogists publishes recommended research protocols for use with wild mammals, including bats (Sikes et al., 2011), and adhering to these recommendations should help in getting proposed research activities approved. Further, research projects involving academics or research on federal lands (e.g., National Park Service) will also have to pass Institutional Animal Care and Use Committee (IACUC) reviews of methodology to assure that: the animal model under study is appropriate, the sampling effort proposed is both necessary and sufficient to complete the work, and the possibility of alternative methods discounted as less suited to achieving study objectives.

6.2 Research Methodology

The following text derives from ideas and issues raised by the Technical Advisory Group in advance of developing this conservation strategy for Rafinesque's big-eared bat and southeastern myotis. They are not meant to necessarily be a comprehensive list of methodologies and priorities for research, but do encompass issues that the Group felt needed more immediate attention or represented more significant shortcomings in our understanding of the biology, habitat requirements, and management needs of these two bat species. Numerous excellent sources describe recommended research methods for use with bats (Kunz, 1988; Brigham et al., 2002; O'Shea and Bogan, 2003; Kunz and Parsons, 2009), including Rafinesque's big-eared bat and southeastern myotis (Clark, 2003; Clement and Castleberry, 2011), so the following section of this conservation strategy is meant to serve as a supplement to these sources and ideas.

Methodology should be repeatable and clearly understood so that studies can be compared across the range of each species. There is a need to develop commonalities in research and survey protocols that include a standardized list of data to be collected that permit comparisons across populations. For example, establishing a minimum number of standardized habitat variables to be measured at and surrounding hollow tree roosts of these species would facilitate our understanding of geographic variation in summer roosting habitat. Meta-analyses could then be completed that assess how differences in roosting habitats relate to measures of colony health and fitness, such as trends in population size, reproductive rates, survivorship, effective population size, sequence divergence, and genetic diversity. Additionally, studies of occupancy should be required to use a combination of multiple techniques for a robust assessment of use, including

acoustic monitoring with Anabat and Sonobat technologies, mist-netting, harp trapping, and roost searching. Issues specific to methodological areas are addressed below.

6.2.1 Acoustic Monitoring

The use of acoustic monitoring to address questions regarding species presence has permitted insights into the natural history of bats that are non-intrusive and repeatable and can be implemented with minimal personnel and costs (Brigham et al., 2002). Although limitations exist, such as an inability to estimate population size (Hayes, 1997, 2000), the development of call libraries has increased the effectiveness of these methods (Britzke et al., 2011), with the USFWS now requiring them in surveys for the endangered Indiana bat. Currently, use of acoustic methods appears to be effective in monitoring presence/absence of southeastern myotis across habitat types (Menzel et al., 2005; Stuemke et al., 2009), but problems exist with use of acoustic techniques in surveying Rafinesque's big-eared bat.

Rafinesque's big-eared bat uses echolocation call signatures with a structure, frequency, and intensity that render them less easily detected by existing acoustic methods (Figs. 3 and 4; M. Kalcounis-Rüepell, pers. comm.), requiring individual bats to be much closer to detection devices to be recorded. In fact, the species has been referred to in the literature as a "whispering" bat (Fenton, 1990), because it emits calls of low intensity for navigating. Additionally, Rafinesque's big-eared bat is a gleaning species that uses passive-listening (i.e., hearing prey-generated sounds) to identify moths on the surfaces of vegetation or other objects (Lacki and Dodd, 2011). Therefore, this bat likely spends less time emitting echolocation calls during foraging bouts than do other bat species; amplifying the difficulty in recording these bats with acoustic methods. There is a current perception of relatively low confidence in identifying the calls of this species consistently and accurately using acoustic techniques, and the sampling effort needed to achieve resolution of presence/absence of these bats remains unclear (E. Britzke, unpubl. data; M. Kalcounis-Rüepell, unpubl. data). More progress in acoustic sampling of Rafinesque's big-eared bat would be helpful in developing future monitoring efforts.

6.2.2 Mist Nets and Harp Traps

Mist net and harp trap survey protocols for Rafinesque's big-eared bat and southeastern myotis should, at a minimum, adhere to guidelines outlined for all bat species as detailed by the USFWS to reduce the exposure and spread of the *Pseudogymnoascus* fungus among bats from the capture process (USFWS, 2011a). Otherwise, Kunz and Kurta (1988) provide a good overview of mist-netting techniques and methods appropriate for most bat species. Researchers experienced in capturing Rafinesque's big-eared bat and southeastern myotis advise that mist net survey protocols should include netting late into the night to ensure sufficient capture effectiveness for presence/absence studies. This consideration is especially important for Rafinesque's big-eared bat, due to the limited application of acoustic methods for monitoring this species.

When capturing in front of hollow tree entrances, caves, and building roosts researchers should avoid placement of nets too close to the roost entrance, and setting nets so taut as to result in bats deflecting off and out of net bags. A more appropriate strategy is to place nets a short distance from the roost entrance, with nets set more loosely so that bats contacting the net are not lost before capture and processing. Mist netting in front of a roost entrance which contains a potentially large population of bats is not recommended without prior assessment of the numbers emerging, the timing of emergence, and the pattern of emergence of the resident colony of bats (Carroll et al., 2002). Large, unexpected emergences can overwhelm nets and field personnel, resulting in an excessive number of bats captured and increasing the time bats spend in the net, the chance of injury to bats, and the potential for bat to bat contact and, thus, possible exposure to spores of the *Pseudogymnoascus* fungus. This problem is less likely to occur with harp traps because these devices are typically used at cave and building entrances and, thus, can be reached quickly and closed upon capture of multiple bats, avoiding issues of harm and limiting prolonged exposure of an individual bat to other bats in the capture device. For this to occur, multiple trained investigators are required to extract bats from the harp trap as rapidly as possible, and to clean the catch bag periodically using a USFWS recommended cleaning solution to minimize spread of fungal spores. Use of hand nets, such as H-nets, is another approach to capture bats that is often used at bridges and sometimes at hollow trees, but care must be taken to minimize disturbance associated with use of this technique.

6.2.3 Radiotelemetry

Use of the “5% rule” is generally accepted as the standard to judge the effectiveness and efficacy of placing transmitters on bats for studies of foraging behavior, movement patterns, and identification of new roosts (Aldridge and Brigham, 1988; Sikes et al., 2011). Based on body mass and weights of available transmitters, meeting this expectation is less of a concern with Rafinesque’s big-eared bat (7–13g body mass) than with southeastern myotis (4–9g). Regardless, both mass of transmitter and glue should be considered in assessing whether an individual bat should be radiotagged under the 5% cutoff. This means that use of juvenile bats should be avoided, especially of southeastern myotis. Good overviews of telemetry techniques and analysis for bats are available (Wilkinson and Bradbury, 1988; Amelon et al., 2009).

6.2.4 Pit Tags

Passive integrated transponders are increasing in use with wildlife species, including bats (Kerth and König, 1996, 1999; O’Shea et al., 2004; Neubaum et al., 2005). Pit tags allow for individual identification of bats in the hand or at roosting sites using pit tag readers and have been successfully used with captive bats (Barnard, 1989), and to monitor bat movements (Kerth and König, 1996, 1999), describe activity patterns (Brooke, 1997; Horn, 1998), and estimate survivorship (O’Shea et al., 2004; Wimsatt et al., 2005). Thus, their use with Rafinesque’s big-eared bat and southeastern myotis is likely to increase in the future. Pit tags are implanted subcutaneously and, therefore, are a more intrusive means of collecting data on bats, with a number of potential problems such as tags extruding shortly after insertion (Kunz and Weise, 2009). Consequently, use of this technique requires investigators to be properly trained beforehand. An ongoing study of Rafinesque’s big-eared bat at roosting sites in Mammoth Cave National Park is demonstrating pit tags to be an effective technique for monitoring colony numbers and movement patterns (Johnson et al., 2012b; S. Thomas, unpubl. data).

6.2.5 Banding

An overview of the breadth of scientific knowledge gained during the USFWS bat banding program (1932 to 1972) and a description of injuries and population declines documented during that period are provided by Ellison (2008). This source highlights the contentious issues associated with banding bats, assessing the information gained versus potential for harm and injury to banded individuals. Progress has been made, however, in the design and diversity of bands easing concerns over injuries and mortalities of bats (Kunz and Weise, 2009). Although some bat species commonly develop injuries when banded, researchers believe that Rafinesque’s big-eared bat and southeastern myotis accept bands without complications if attached correctly. Concern has been expressed over banding injuries in Townsend’s big-eared bat (Pier-son and Fellers, 1993), but researchers experienced with banding Rafinesque’s big-eared bat are comfortable with attaching bands provided they are lightweight and filed to remove any sharp edges. Both commonly available plastic split-ring bands and the new lightweight aluminum alloy lipped bat bands (bat rings) used in Europe, are recommended for use with Rafinesque’s big-eared bat and southeastern myotis. Older issued USFWS metal bands are not appropriate for either species due to their heavier weight and tendency to cause injury. Narrow 2.9 mm bands are the recommended band size for both Rafinesque’s big-eared bat and southeastern myotis, although bands of smaller dimensions, e.g., 2.4 mm, are now available and may prove more suitable, especially for southeastern myotis. Sources are available that discuss the intricacies of banding a variety of bat species and provide techniques for minimizing risk to bats (Barclay and Bell, 1988; Kunz and Weise, 2009).

Long-term monitoring of Rafinesque’s big-eared bat and southeastern myotis would be enhanced by consolidating bat banding records into a comprehensive region-wide database. This would facilitate flow of information when banded bats are captured and recorded outside their original capture area. The SBDN has maintained a regional database designed for this purpose (S. Loeb and E. Britzke, pers. comm.), but costs and personnel issues exist with data entry and file management and these data are now being incorporated into the BPD project of the USGS. Data confidentiality was addressed by SBDN to protect proprietary rights to data, but many researchers, agencies and consulting firms in the southeastern United States still do not contribute to the data base. All investigators banding bats in the field are encouraged to contribute their information to the new BPD project, especially those with data on Rafinesque’s big-eared bat and southeastern myotis.

6.2.6 Emergence Counts and Thermal Imagery

Counting bats emerging at dusk is a long-established technique for monitoring roosting populations of bats (Kunz et al., 2009). Depending on conditions and the location of roost entrances, counts sometimes can be made at dusk through direct observation of bats against the evening sky; however, more often counts are made with night vision equipment (goggles or scopes) with image enhancement provided by illumination of roost entrances with the aid of infrared or ultraviolet light. Supplemental lighting is essential for counting species of bats that emerge after dark, behavior typical of Rafinesque's big-eared bat (Hurst, 1997; Hurst and Lacki, 1999). Emergence counts can be complicated by bats that roost in structures with multiple openings, requiring several personnel and equipment to ensure accurate estimates (Kunz et al., 1996; Kunz and Anthony, 1996). Additional concerns include the emergence of volant young later in the evening, requiring counts to be extended in time during the post-lactation period to ensure a complete census of the roosting population (Kunz et al., 2009). Several authors have recommended that emergence counts be repeated multiple times across the growing season to assess intra-colony variation in population size (Hoying and Kunz, 1998; Hristov et al., 2010).

Thermal Infrared imagery (TIR) is gaining popularity as a survey technique for bats and has been used to obtain more accurate counts of gray bats during emergence events (Sabol and Hudson, 1995). Studies using state-of-the-art TIR imagers have shown this technology can be used to quantify bat activity, including emergence from roosts, and flight and feeding behavior (Martin et al., 2004; Melton et al., 2005). Kirkwood and Cartwright (1991) used TIR to examine behavioral characteristics of roosting big brown bats. Melton et al. (2005) developed a TIR videograph technique that involved an automated digital image process to detect, track, and count bats in flight. The technique was successfully used to record evening emergences of several thousand southeastern myotis from abandoned cisterns in southwestern Mississippi (Sherman, 2004). The key to successful use of TIR is contrast between the desired target and the background. Thermal contrast depends on the temperature and thermal variability of the background, and the surface temperature of the target animal (Melton et al., 2005). Drawbacks include the relative expense of TIR equipment and the specific environmental conditions that must be met for TIR to be effective (Havens and Sharp, 1998; Butler et al., 2006). However, less expensive TIR cameras are being tested and have high potential for use in bat surveys (B. Sabol, pers. comm.). Clearly, use of TIR imagery is likely to aid in future survey efforts and behavioral studies of Rafinesque's big-eared bat and southeastern myotis.

6.2.7 Roost Searches

Determining bat roosting locations is critical for effective species conservation, comprehensive distribution information, and understanding habitat associations. New bat roosts can be identified through systematic search efforts. For cave and mine roosts, searches typically result from identifying potential suitable karst features and targeting surveys during either maternity or hibernation seasons. Systematic bridge searches have been conducted in Louisiana, South Carolina, and Florida to effectively locate roosts of Rafinesque's big-eared bat (Lance et al., 2001; Gore and Studenroth, 2005; Bennett et al., 2008). In the South Carolina study, researchers obtained lists of potentially suitable bridges from the state Department of Transportation and systematically visited each bridge looking for roosting bats (Bennett et al., 2008). Considerable temporal variation exists in use of bridges by bats, with June through July recommended as the optimal period of time to survey bridges for Rafinesque's big-eared bat (Ferrara and Leberg, 2005a).

In bottomland hardwood forests, where both species are commonly found using hollow trees, roost searching is a complicated process for several reasons. First, Rafinesque's big-eared bats using tree roosts demonstrate roost switching behaviors which decrease the detection rate for a colony in any one roost, requiring multiple counts to assess the mean and range in colony size (Johnson et al., 2012a). Second, the density of potential tree roosts can be quite high, rendering comprehensive surveys difficult to complete (Stevenson, 2008; J. Jones, unpubl. data). Third, access to available tree roosts can be difficult due to flooding or distance from roads (Johnson and Lacki, 2011). And, fourth, identifying available tree roosts is not always obvious to the observer. Probability of detection of roost trees improved from 92% to 99% when multiple observers were used as opposed to a single individual (Fleming et al., 2013b).

Stuemke and others (2009) developed a protocol for successful roost searching in bottomland hardwood forests. In their study, they used a random sampling of 100-ha parcels from a predefined grid to evaluate potentially suitable habitat. Selected parcels were searched thoroughly for roost trees in conjunction with other methods to document presence of Rafinesque's big-eared bat. Stuemke and others (2009) are refining this protocol to include transects and more efficient roost searching techniques. In Mississippi, Stevenson (2008) sampled 10% of her study area by searching 40m x 200m (0.8 ha) plots for cavity trees. In general, researchers working with these two bat species agree that a standardized

sampling method should be identified that would facilitate meta-analysis and comparisons of results across studies. Successful efforts to estimate density of roosts of Rafinesque's big-eared bat demonstrate that progress in this area has been made (Clement and Castleberry, 2013). Low sample sizes in individual study areas make pooling data across studies attractive for modeling purposes, but inconsistent methodology makes this type of analysis complicated to interpret (Clement and Castleberry, 2013). Established protocols should be based on transects of standardized length and width and address how often hollow trees should be surveyed and monitored. Field investigators must also recognize sampling biases (e.g., only checking trees with basal hollows) and incorporate steps to reduce bias.

Disturbance continues to be a concern when establishing protocols for roost searching and monitoring, regardless of the type of roost structure. Guidelines for acceptable levels of disturbance should be developed and included in recommended protocols. At a minimum these guidelines need to emphasize that close inspection or disturbance by investigators at maternity and hibernating colonies of bats should be avoided or greatly minimized. Noise and white lights should be avoided. Potential roosts can be checked for bat occupancy in a variety of ways. Cameras or a handheld mirror coupled with infrared lights can be used to inspect the interior cavities of trees with basal openings. Evening emergence counts, bat detectors, thermal imaging cameras, and video probe cameras (i.e., peeper cams) can be used to assess bat occupancy of roosts, especially those with multiple entrances or entrances not easily accessed, such as broken tops or cavities on the side of the stem of roost trees. Use of digital infrared imagery was superior to visual inspection of cavities in enumerating bats, as visual inspection typically underestimated the size of colonies inside roost trees (Fleming et al., 2013b). Staff of the USFWS have at times cut replaceable "windows" in the side of roost trees to facilitate monitoring (Richardson, 2007), but the practice has not been assessed and is not widely used or recommended by the USFWS because the disturbance associated with use of this technique remains unclear. Commonly, buildings, bridges, and caves can house larger colonies of bats than trees, especially colonies of southeastern myotis, so disturbance by biologists at these roosting sites could be especially harmful if monitoring is not done properly.

6.2.8 Euthanasia and Safety Concerns

In some instances (incidental injury, research objectives, etc.) bats must be euthanized. The current recommended euthanasia procedure requires the use of inhalant anesthetics halothane or isoflurane (Sikes et al., 2011). Both anesthetics are commonly available in automotive "starter cleaners," and are thus easily accessible to field investigators. These inhalants are among the most humane techniques approved for bats (Sikes et al., 2011), and are easy to administer under field conditions. The American Veterinary Medical Association (AVMA) does not recommend other inhalants (e.g., CO₂) for use with bats due to mucosal irritation and ventilatory stimulation effects, and because many bat species exhibit a high tolerance for elevated concentrations of compounds such as CO₂. Physical methods such as cervical dislocation or decapitation are also not recommended, unless they are used following induction with anesthetic inhalants or when recommended inhalants are unavailable and the need to euthanize is immediate (e.g., presence of WNS spores, etc.).

Field investigators of bats can often become so focused on achieving their objectives that they become less vigilant in observing safety considerations for both the bats they are studying and their personal health. Constantine (1988) provides a good overview of safety considerations for bat researchers, including exposure to rabies. However, the recent advance of WNS into the southeast region suggests that further consideration of health and safety of bats and humans is warranted. Compliance with existing USFWS protocols relative to WNS spread and infection is a must and these protocols are likely to continue to be updated as we learn more about the ability of the *Pseudogymnoascus* fungus to spread among populations of hibernating bats. Given the fragility of cave environments, adequate training by biologists in safe cave exploration is warranted prior to entering these roosting sites. The National Speleological Society is a potential source of information and trained personnel that could help in facilitating investigator training in proper cave exploration.

7. EVALUATE AND UPDATE CONSERVATION STRATEGY

The following implementation schedule has been developed to reflect phases or steps in the conservation process of Rafinesque's big-eared bat and southeastern myotis, understanding that specific timelines involved in organizing a coordinated conservation effort cannot be easily anticipated. Initial start up and organization is a critical hurdle that can either expedite or hinder the conservation process, and having immediate participation of all states within the distributions of these bats would greatly accelerate the implementation of this conservation strategy. Regardless, the phases listed below encompass a range of timelines. Some phases should be expected to begin earlier than others as the conservation effort for these bats unfolds. Of critical importance is identifying and designating leadership roles in the implementation of this conservation strategy. The most likely candidates for this role include the USFWS, BCI, and SBDN, although other organizations, such as private industry, LCCs, and other state and federal agencies, could contribute significantly in this partnership.

7.1 Cooperation and Organization – Bringing Partners Together

This phase must come first and represents the collective effort of SBDN, BCI, USFWS, state and other federal agencies, LCCs, tribes, private landowners, university researchers, and environmental consultants to meet and develop an organizational structure under which activities associated with this conservation strategy can be coordinated and undertaken. Clearly identifying the roles of each partner will be important early on if the planning process is to proceed smoothly. Disagreements and debate among partners should be anticipated and considered part of the planning process and not an impediment to progress. Should either Rafinesque's big-eared bat or southeastern myotis eventually receive federal listed status, i.e., threatened or endangered, the USFWS will by default become the lead partner in the recovery effort.

7.2 Initial Planning Effort – Assessing Personnel and Financial Support

This phase represents the follow up to initial organization and addresses the roles that each partner is willing to contribute to the conservation effort, such as data base management, field personnel for monitoring, providing research expertise, or financial support, among others. Identifying and attracting short- and long-term sources of financial support is critical to the success of this conservation strategy, as without funds many of the activities planned or suggested cannot be undertaken. Reaching out to financially-sound environmental organizations with large memberships could be an effective avenue for acquiring some of the needed funding. This will be no easy task in the current economic climate and will probably require novel approaches to maximize information gained relative to dollars spent. This phase identifies the most important roosting sites of each species, and rank prioritizes them for protection using gates and fences.

7.3 Baseline Data and Management Needs – Monitoring and Research Planning

In this phase partners identify the immediate data needs to begin conservation efforts, and establish an initial framework for monitoring known roosting sites across the distributions of these bats, with separate approaches developed for different roosting structures (e.g., hollow trees, buildings, bridges, caves). This phase also identifies an initial set of IBCAs to target with initial conservation actions, such as key roosting sites and significant, large blocks of suitable habitat, with an emphasis in the latter on bottomland hardwood forests. This phase also begins the research planning process by identifying lists of important short- and long-term research projects, and prioritizes these projects by need and temporal and financial considerations.

7.4 Short-Term Monitoring – Current Status Assessment

This phase represents the initial monitoring efforts identified in Phase 3, some of which will continue as part of long-term monitoring after the first 5–6 years of sampling. Short-term monitoring includes roost surveys designed to estimate initial population sizes of bats, and assesses condition and status of known roosting sites to identify those sites that are in decline

and in need of restoration, repair or replacement. Monitoring also includes periodic assessments of important habitat areas and forest structure and composition at multiple spatial scales. Included in this phase is development of survey strategies for sub-sampling tracts of bottomland hardwood forests to assess density and use of hollow tree roosts by bats.

7.5 Research Studies ≤3 Years in Length

This phase implements short-term research projects designed to answer specific questions about the biology and habitat needs of these bats as identified by the Technical Advisory Group and highlighted in this conservation strategy. Research projects will be initiated based on funding resources and the perceived need of the anticipated product. Possibilities for initial short-term projects include, but are not limited to: roost microclimates, population genetics, foraging habitat use, dietary analyses, hydrology, and water quality.

7.6 Outreach Program – Educating Landowners and Land Managers

The development of outreach programs and materials are vital to this conservation strategy. Fortunately, the infrastructure exists to accomplish this task in a reasonable time frame and it is recommended that this phase be acted upon as soon as possible, as the education process takes time and repeated contacts to achieve public awareness of conservation-related issues. For years BCI and other organizations have emphasized the need for sustaining populations of bats in achieving healthy ecosystems and this message has reached a large audience, including elected officials. In the case of Rafinesque's big-eared bat and southeastern myotis, however, now is the time when educational outreach efforts should focus as much or more on what the bats actually need to survive, emphasizing where they live, their life histories and their habitat requirements. Materials should target landowners, land managers, and school systems. If interested leadership can be identified, the potential exists for this phase to achieve impact and success in a very short frame of time (4–6 years).

7.7 Long-Term Monitoring – Trajectories in Population Size and Distribution

Long-term monitoring is fundamental to assessing population trends and patterns, and is essential to activities proposed with long-term research and management actions. Important to this phase is an understanding of the extended commitment in personnel time and costs that will be required of conservation partners performing monitoring activities. Because of the numbers of known roosts of these bats, especially in bottomland hardwood forests, it will be difficult to consistently and repeatedly monitor all sites over decades of sampling. Emphasizing a subset of sites for more concentrated survey effort across the distributions of these species may prove to be more fruitful and result in stronger and more consistent temporal data sets.

7.8 Research Studies >3 Years in Length

This phase implements longer-term research directed at: landscape-scale habitat and population studies; metapopulation studies at the regional level, including assessments of gene flow and population connectivity; and distribution-wide studies examining trends in global population sizes, and temporal-changes in geographic distribution and abundance of these bats. These subject areas are all important to assess as part of this conservation strategy; however, specific studies will need to be prioritized and implemented as financial support permits.

7.9 Conservation Incentives – Easements, Agreements and Protecting Roosts

This will be one of the most difficult phases to develop and implement, as it requires landowners and land managers to prioritize the protection of populations of rare bats. Cooperation can often be achieved through education of the importance of bats to healthy ecosystems and environments. Efforts to develop dialogue and effective means of communication can often produce significant results and support. Sustaining populations of Rafinesque's big-eared bat and southeastern myotis is an ethical, legal, and financially acceptable conservation management practice and most

landowners and land managers can be made to understand this concept with open and non-threatening channels of communication. Successfully educating individuals that a conservation need of high importance exists on their land is an extremely important step in the phase. It should be anticipated that many, but not all, landowners are going to become partners, and that our ability to manage and protect some populations of these bats will remain limited. Because of the intricacies involved in establishing conservation easements, this phase will require considerable documentation and need for legal services by both landowners and state and federal agencies, as appropriate.

7.10 Plan Revision – New Concerns and Directions for Management

It is unclear at this time when a revision to this strategy should begin, but a minimum of 10 years is likely needed to gain a sense of progress in the conservation of these bats as some phases should not be anticipated to achieve momentum for at least a few years. Obviously, should the listing process change the status of either or both species, the recovery plan will serve as the plan revision and update. That said, this phase will require an evaluation of success and failure of policy, management, research, and monitoring efforts as outlined in this conservation strategy. This phase will also allocate more time and attention to new and emerging threats, which by 10 years from the publication of this document will have manifested as a more (or less) negative effect on populations of these bats.



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APPENDIX I

State-level Status of Rafinesque's Big-eared Bat and Southeastern Myotis. Data from Bayless et al. (2011) and BCI^a.

State	Rafinesque's big-eared bat	Southeastern myotis
Alabama	SGCN; S2; P1	SGCN; S2; P2
Arkansas	SGCN; S3	SGCN; S3
Florida	SGCN; S2	SGCN; S3
Georgia	SGCN	SGCN; S3
Illinois	Endangered	Endangered
Indiana	SGCN	SGCN; S1
Kentucky	SGCN; S3	SGCN; S1
Louisiana	Not listed	SGCN
Mississippi	SGCN; S3	SGCN; S1
Missouri	SU	SGCN; S1
North Carolina	Threatened	SGCN; S2
Ohio	SGCN	-
Oklahoma	SGCN; S1	SGCN; S1
South Carolina	Endangered	SGCN; S1
Tennessee	SGCN; S3	SGCN; S3
Texas	Threatened	SGCN; S3
Virginia	Endangered	SGCN; S2
West Virginia	SGCN; S1	-

^aAbbreviations are: *SGCN* (species of greatest conservation need), *S* (sub-national), and *P* (priority). Numbers are: 1 (critically imperiled); 2 (imperiled); 3 (vulnerable), and 4 (apparently secure).

APPENDIX 2

Priority Research Needs of the Technical Advisory Group for Rafinesque's Big-eared Bat and Southeastern Myotis.

RESEARCH PRIORITIES

BIOLOGY & BEHAVIOR

Life Cycles and Longevity:

Genetics:

Subspecies, genetic isolation, and population connectivity

Food Habits:

Prey preference and prey switching behaviors

Behaviors:

Mating and gender specific - karst vs. lowland habitats

Foraging Patterns:

Travel distances and habitat used

Pesticide Effects:

DEMOGRAPHY

Dispersal and Migration:

Timing elements, movement patterns, and barriers to movement

RANGE AND DISTRIBUTION

Distribution:

Seasonal patterns, gaps, and predictive modeling

Monitoring and Inventory:

Methodology used, timing /season of sub-sampling, and detectability

FORAGING HABITAT

Habitat Requirements:

Multiple spatial scales, forest age/composition, and source /sink habitats

Predictive Modeling:

Range-wide availability

Management Practices:

Timber harvesting, prescribed fire, and land use changes

Pollution Effects:

Pesticides, sedimentation, and toxicants

Prey Relationships:

Diversity and availability cycles

ROOSTING HABITAT

Habitat Requirements:

Multiple spatial scales, forest age/composition, and proximity to foraging habitat

Predictive Modeling:

Range-wide availability

Management Practices:

Timber harvesting, prescribed fire, cave gating, and artificial roosts

Roost Selection:

Fidelity, switching effects on fitness, gender differences, limiting factors, seasonal differences, regional differences, habitat differences, and microclimates

Species Relationships:

Competition and mutual selection

HYDROLOGY

Pollution Effects:

Pesticides, sedimentation, and toxicants

Water Requirements:

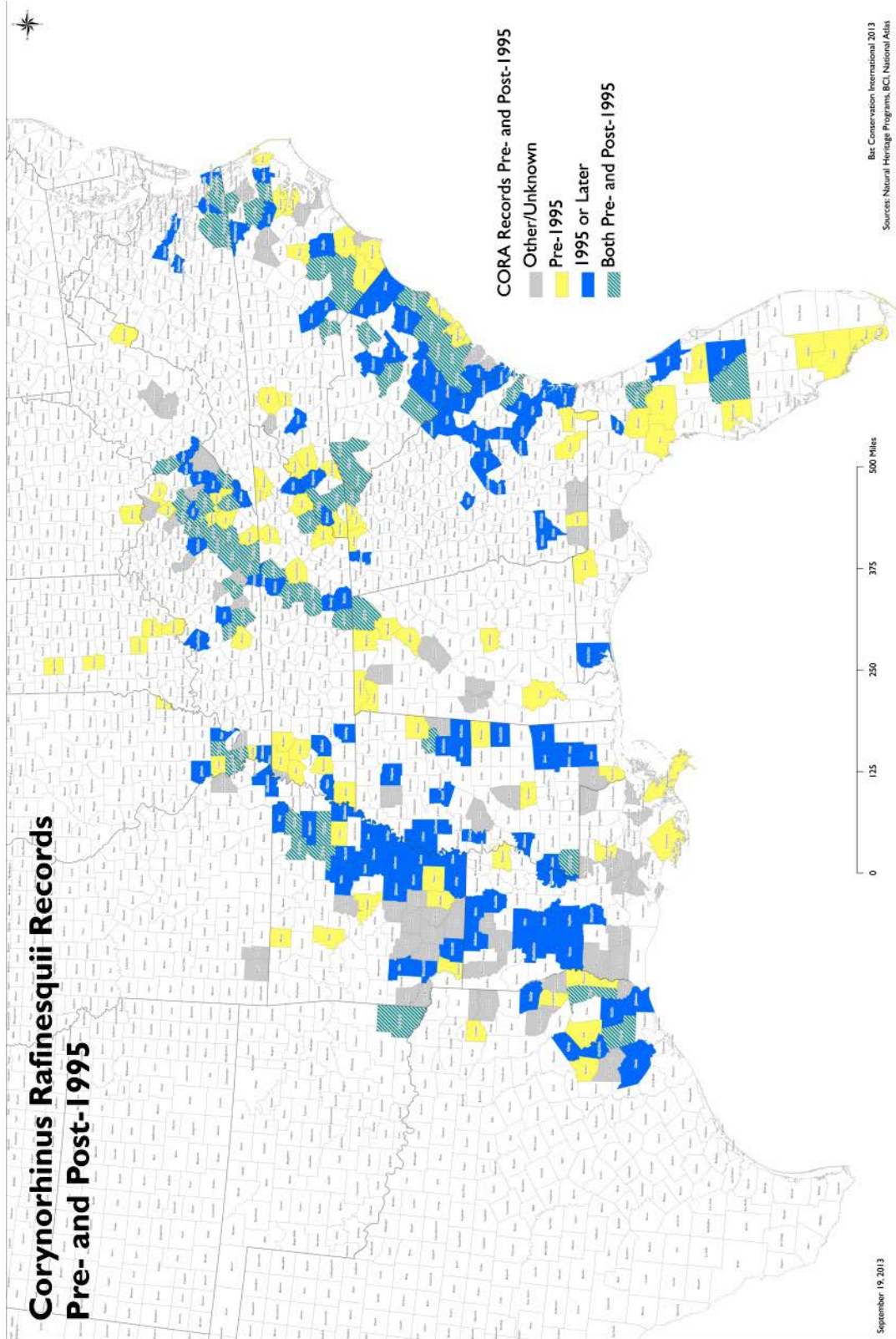
Foraging and drinking sites, habitat alteration, and prey abundance

Effects of Land Use:

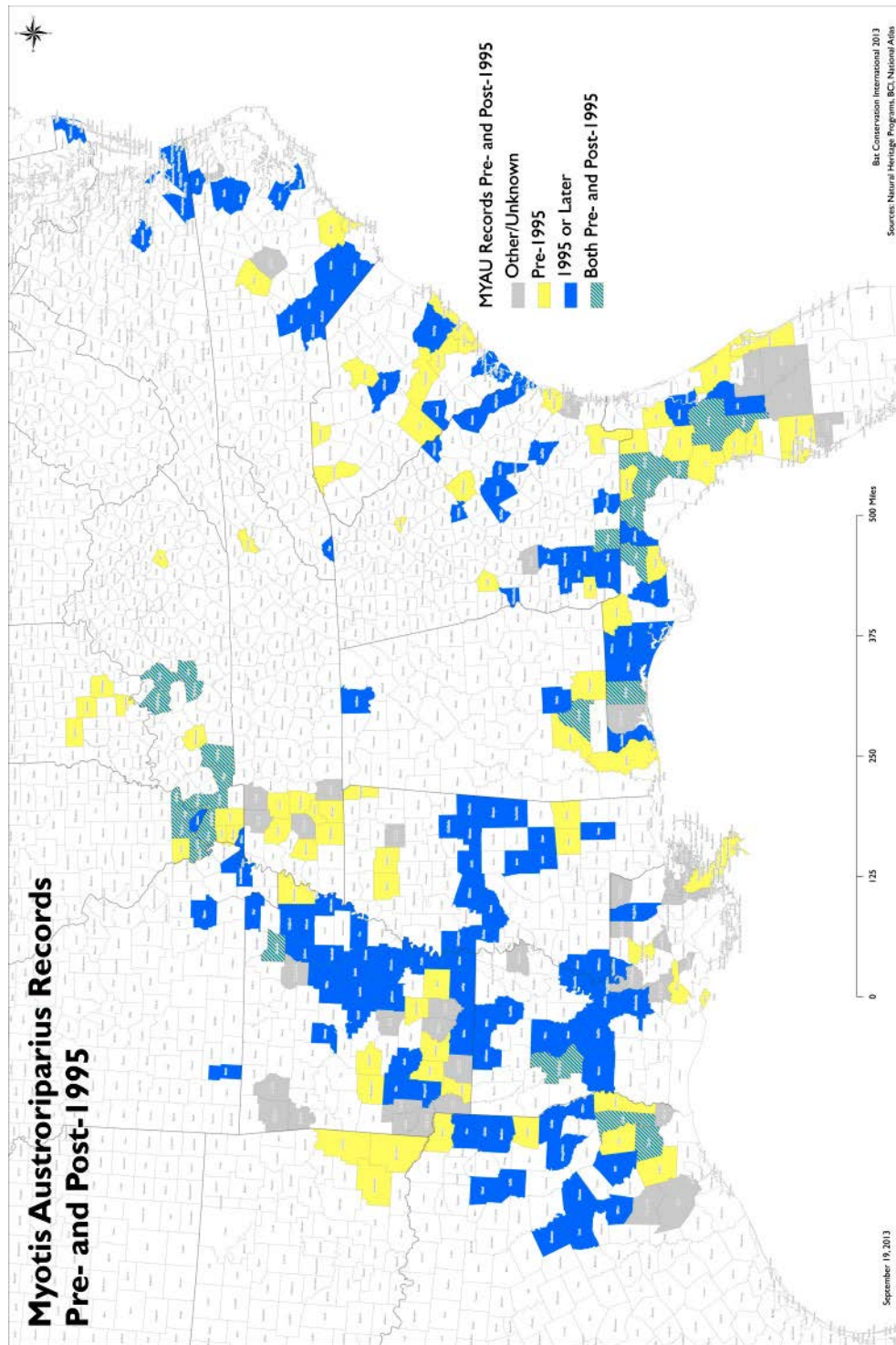
Water quality, quantity, and accessibility

APPENDIX 3

State and County Distribution of Rafinesque's Big-eared Bat (*Corynorhinus rafinesquii*).



APPENDIX 4
State and County Distribution of Southeastern Myotis (*Myotis austroriparius*).



APPENDIX 5

Priority Management Recommendations for Rafinesque's Big-eared Bat and Southeastern Myotis. Recommendations Listed in Order of First Appearance in Text.

Conserve remaining old-growth bottomland hardwood forests and reestablish corridors that connect these habitats. (2.17)

Provide artificial roosts in areas of depleted roosting resources. (2.17)

Protect important cave roosts to maintain ecologically significant populations of bats. (3.17)

Use silvicultural systems consistent with sustaining plant diversity. (4.4)

Protect stream-side management zones (SMZs) on landscapes dominated by upland forests. (4.4)

Allocate sufficient older-aged trees, both spatially and temporally, as part of existing habitat prescriptions that accompany timber harvests. (4.5)

Promote development of patches of forest with high-densities of large-diameter cavity trees. (4.5)

Maintain or replace anthropogenic roosts with structures that provide similar microclimate conditions. (4.6)

Erect gates or fences and place signs at entrances to caves and mines occupied by bats as financially feasible. (4.7)

Emphasize conservation of the two existing and divergent lineages of Rafinesque's big-eared bat. (4.11)

Designate areas of high priority as Important Bat Conservation Areas (IBCA). (5.1)

Maintain large, cavity-producing trees as part of management plans, and provide for future roost trees in forest management planning on federal and private lands. (5.2)

Manage SMZs to promote retention of roost-tree species on landscapes actively managed for timber production. (5.2)

Encourage landowners to implement BMPs when managing forests supporting populations of bats, and recommend wider SMZ buffers as habitat enhancements for bats. (5.2)

Develop guidelines for bridge design and maintenance where bats occur, and develop a strategy for outreach and education to the Federal Highway Administration and state DOTs. (5.2)

Buffer known roost trees from disturbances to avoid changes in roost microclimate that might alter roosting conditions and the suitability of trees for bats. (5.2.2)

Effectively communicate incentives to DOTs and other agencies to incorporate considerations for roosts of these bats into bridge maintenance schedules. (5.2.4)

Provide relevant information to promote safety for bats and workers when maintenance occurs at bat-inhabited bridges. (5.2.4)

Develop a statistically-robust sampling strategy for estimating range-wide population sizes of bats that uses both counts during winter hibernation and the summer maternity season. (5.4)

Establish a centralized location for storage of population data. (5.4)

Adhere to forest management actions that retain late succession forests with high species diversity, structural complexity, and a relatively open understory. (5.6)

Maintain wetlands and waterways that connect land parcels of different ownerships. (5.6)

Develop a comprehensive outreach program. (5.8)

Draft clearly written guidelines for distribution to lawmakers, decision makers, enforcement officials, landowners, and the general public that foster pro-active habitat management. (5.8)

APPENDIX 6

Priority Research Needs for Rafinesque's Big-eared Bat and Southeastern Myotis. Research Needs Listed in Order of First Appearance in Text.

Rafinesque's Big-eared Bat

- Development of reliable estimates of range-wide population sizes. (2.4)
- Improved resolution of patterns in social organization and behavior of colonies. (2.6)
- Estimates of temperature conditions inside winter roosts at southern end of the range. (2.11)
- Measures of relative humidity conditions inside winter roosts. (2.11)
- Quantify use of available foraging habitats across the range of the species. (2.13)
- Determine the relationship of forest structure to measures of foraging success. (4.4)
- Progress in improving acoustic sampling for use in future monitoring efforts. (6.2.1)

Southeastern Myotis

- Measures of temperatures inside roosting structures at the northern extent of the range. (3.11)
- Improved resolution of echolocation calls from sympatric *Myotis* species. (3.3)
- More complete data on distribution and abundance. (3.4)
- Current surveys of all historically occupied roosts. (3.4)
- Documentation of seasonal movements and long-distance migration. (3.5)
- Studies of roosting behavior of maternity colonies. (3.6)
- Description of characteristics of roost trees used in winter. (3.9)
- Estimates of home range size and spatial use of available foraging habitats. (3.13)
- Greater resolution of diet across the entire range. (3.14)
- Effect of SMZ width and extent of corridor fragmentation allowable in upland forests. (4.4)
- Assessment of population genetics based on mitochondrial and nuclear DNA sequencing. (4.11)
- Development of methods for exclusion from structures that facilitate roost switching to alternate sites. (5.2.3)
- Estimates of preferred roosting microclimates inside artificial structures. (5.3)

Both Species

- Estimates of longevity and age-related survival. (2.15; 3.15)
- Impacts of exposure to the *Pseudogymnoascus* fungus. (2.16; 3.16)

Effects of selective cutting, thinning, and extended rotation lengths in bottomland hardwood forests. (4.1)

Responses to wildfire and evaluation of prescribed fire for enhancing habitat quality. (4.4)

Determination of impact or benefit of varying amounts of forest fragmentation. (4.6)

Estimates of mortality rates at wind turbines proximally located to roosting sites. (4.9)

Quantify the minimum habitat patch size needed to support a colony over time (5.1)

Data on densities of roost trees across geographic locations, both spatially and temporally. (5.1)

Minimum number of roost trees required to support populations in bottomland hardwood forests. (5.1)

Determination of the size of buffers needed to protect roosting sites. (5.2.1)

Estimates of annual survival of hollow tree roosts in bottomland hardwood forests. (5.2.2)

Influence of habitat buffers on longevity, use, and internal microclimate of roost trees. (5.2.2)

Development of predictive models for estimating population sizes at the landscape-scale. (5.3)

Evaluation of placement, habitat conditions, and structural configuration on use of artificial structures. (5.3)

Derivation of approaches to detect biologically meaningful changes in population size. (5.4)

Comparisons of habitat use, both foraging and roosting, with stream buffer dimensions. (5.6)

Quantifying effect of habitat connectivity and patch size on colony size, movements, frequency of dispersal, and gene flow. (5.6)

Responses to higher temperatures and the need for water in predicting the potential effects of climate change. (5.7)

Predictive models that evaluate responses of roost tree species based on various climate change scenarios. (5.7)

Development of research and survey protocols that permit comparisons across populations and habitats. (6.2)