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Cave- and Crevice-Dwelling Bats on USACE Projects: Gray Bat (*Myotis grisescens*)

by W. A. Mitchell and C. O. Martin

Figure 1. Gray bat (photo by John Lamb, Arnold Air Force Base, TN)

PURPOSE: This document is one in a series of technical notes produced by the U.S. Army Engineer Research and Development Center (ERDC) under the Ecosystem Management and Restoration Research Program (EMRRP). The technical notes identify sensitive species potentially impacted by U.S. Army Corps of Engineers (Corps) reservoir operations and are products of the EMRRP work unit entitled "Reservoir Operations – Impacts on Habitats of Target Species" (Dickerson, Martin, and Allen 1999; Kasul, Martin, and Allen 2000). This document is one of a group of technical notes that provide information on selected bat species that have the potential to occur on Corps projects in the eastern United States and be impacted by Corps activities. It is linked to a technical note (ERDC TN-EMRRP-SI-24), which presents an overview of general habitat requirements, impacts, and management needs for these species. For management purposes, the endangered gray bat (*Myotis grisescens*) (Figure 1) is considered a riparian species because it may forage over water or in riparian zones surrounding streams and lakes on Corps lands during summer months. This technical note describes the distribution, legal status, ecology, potential impacts, and management guidelines for the gray bat.

DISTRIBUTION: Gray bat populations are concentrated in caves of Alabama, Arkansas, Missouri, Tennessee, and Kentucky (U.S. Fish and Wildlife Service (USFWS) 1980, Harvey 1992). Summer

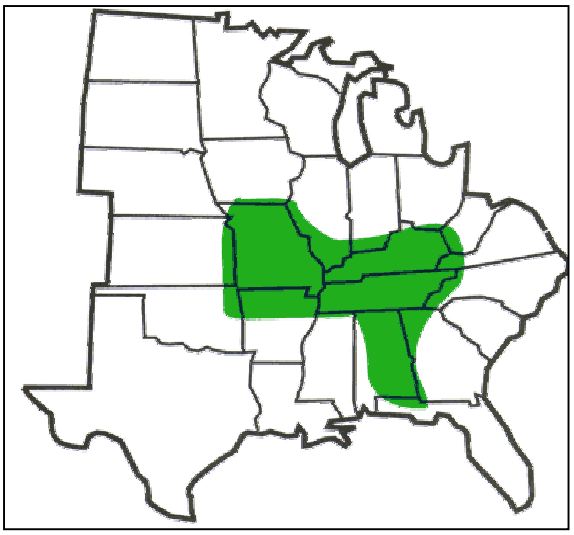

Figure 2. Approximate geographic range of the gray bat (after Harvey, Altenbach, and Best (1999))

and winter ranges are similar, but not identical, because different caves are occupied seasonally (Humphrey 1982). The summer range extends eastward from eastern Oklahoma and Kansas to southwestern Virginia and western North Carolina and southward from southern Illinois and Indiana to northern Florida (USFWS 1980) (Figure 2). The major winter caves are located primarily in Tennessee, Missouri, Kentucky, Alabama, and Arkansas (Tuttle 1976a).

STATUS: The gray bat was listed as Federally endangered throughout its range in April 1976 (41 FR 17740). The states in which the gray bat is endangered are Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Kansas, Kentucky, Mississippi, Missouri, North Carolina, Oklahoma, Tennessee, and Virginia. In the late 1970s, the total population was estimated at approximately 2 million bats (Tuttle 1979). It was estimated at only 1.6 million in the early 1980s (Brady et al. 1982) and at 1.5 million within the next 10 years (Harvey 1992). Recent population data compiled from cold hibernating caves (hibernacula) listed in the Recovery Plan (Brady et al. 1982) indicate that the gray bat population using these caves has increased by 16.5 percent over the 1982 estimate (Harvey 2001). When bat numbers from additional hibernacula are included with this data, the total population shows an increase of 40.4 percent from 1982 and is now estimated at approximately 2.3 million gray bats.

HABITAT: Gray bats are year-round cave residents, occupying cold hibernating caves (hibernacula) in winter and warm caves in summer (Tuttle 1976a, Gore 1992) (Figure 3). However, less than 5 percent of available caves provide gray bat habitat (Tuttle 1979). Caves used by gray bats must have temperatures appropriate for necessary metabolic processes; i.e., warm caves for digestion and growth in summer and cool caves for torpor and hibernation in fall and winter (Twente 1955). Few caves in the northeastern United States are warm enough for rearing young, and few in the Southeast are cold enough for successful hibernation (Tuttle 1976a).

Both males and females hibernate in the same caves. Suitable winter caves are typically deep and vertical (Brady et al. 1982) with multiple entrances, good airflow, and temperatures ranging from 5 to 11 ºC (42 to 52 ºF) (Harvey, Altenbach, and Best 1999). These caves are already cold when gray bats arrive in September (USFWS 1980). On the summer range, colony members disperse in groups among several different caves with only females and young occupying the maternity cave and other groups using more peripheral caves (Tuttle 1976a). Colonies select summer caves with temperatures that range from 14 to 25 ºC (57 to 77 ºF) (Brady et al. 1982). The maternity cave is usually the warmest cave in the summer range because it contains structural heat traps (Tuttle 1976a). Nursery populations succeed because these heat traps capture the metabolic heat from a large number of clustered individuals. Typical cave configurations that trap heat include small chambers and domes (Dwyer 1963), high places in domed ceilings (Davis, Herreid, and Short 1962), depth of etching, and porosity of the rock surface (Tuttle 1975).

Figure 3. Blowing Wind Cave in northeastern Alabama is used as a roost site by gray bats (photo by Chester Martin)

Gray bats may roost at man-made sites that simulate summer caves, such as abandoned barns (Gunier and Elder 1971) and storm drains (Hayes and Bingham 1964, Elder and Gunier 1978, Timmerman and McDaniel 1992). These drains have high humidity and clear running water, which are characteristics of natural caves used by gray bats. A few maternity colonies have been known to use man-made structures as maternity roosts. Lamb (2000) described a maternity colony using a gate-room at Woods Reservoir Dam at Arnold Air Force Base (AFB), Tennessee; this site was listed as a priority two maternity colony in the USFWS Gray Bat Recovery Plan (Brady et al. 1982). Another gate room of the dam is used by a bachelor colony (Lamb 2000). Corps personnel should be aware of the potential for gray bats and other bat species to use reservoir dam facilities as roost sites.

Gray bats forage primarily over water where flying insects are abundant (Tuttle 1976b, 1979; LaVal et al. 1977). Summer colonies inhabit areas in which open water and the banks of streams, lakes, or reservoirs are within foraging distance of roosting sites and caves suitable for rearing young. Summer colonies, especially maternity colonies, prefer caves that are within 1 km (0.6 mile) of a major river or lake and are rarely found in caves located at distances greater than 4 km (2.5 miles) (Tuttle 1976b). Factors closely correlated with distance traveled to feeding areas include growth rate and survival, condition of young bats, and adult mortality. For newly volant (flying) young, growth rates and survival are inversely proportional to the distance from the roost to the nearest overwater foraging habitat. Forested areas surrounding caves or located between caves and foraging habitat are important for gray bat survival (Tuttle 1979). These areas serve as corridors for travel and as protective feeding cover for newly volant young (Brady et al. 1982). Results of surveys conducted at Arnold AFB, Tennessee, indicate that wetland depressions are also important foraging sites for gray bats (Lamb 2000).

BEHAVIOR: Bats emerge from hibernation in spring and move to the summer range, where colony members disperse among several caves (Tuttle 1976a). Adult females migrate to the breeding range in late March or early April, and most adult males and juveniles migrate between mid-April and

mid-May. On the summer range, hundreds to thousands of reproductive females congregate in one preferred maternity cave to bear and rear young, while adult males and yearlings of both sexes form smaller bachelor groups that occupy peripheral caves (Harvey 1992). After the young become volant, gray bats are more transient within the home range and frequently use alternate roost sites (Thomas 1994). Thomas and Best (2000) reported that gray bats foraged over large areas and appeared to have large individual home ranges (average minimum size 7 × 24 km; 97 km^2 (4.3 × 15 miles; 37.5 $miles^2$)) in the Guntersville Reservoir area of northern Alabama. Their data indicated that gray bats might have a greater affinity for foraging areas during the breeding season and during and shortly after young become volant than later in the year.

In autumn the summer colonies disband and migrate to colder caves for hibernation (Gore 1992). Fall migration occurs in approximately the same order as spring emergence, with adult females leaving by early September and juveniles departing last, usually by mid-October (Tuttle 1976a). Because of limited hibernacula, bats from wide areas migrate to common hibernation sites (Hall and Wilson 1966). Tuttle (1976a) found that one-way distances regularly traveled in migration ranged from 17 to 37 km (10.5 to 23 miles); bats that summer in Florida migrate as far as 500 km (310 miles) to hibernation caves in central Tennessee and northern Alabama.

Copulation occurs upon arrival at winter caves, after which females immediately enter hibernation, usually by early October (Brady et al. 1982). Males may remain active for several more weeks, but most juveniles and adult males are hibernating by early November. During hibernation the gray bat becomes torpid, and the body temperature drops almost to the ambient temperature (Henshaw 1970). This allows the body to conserve fat reserves that must last through six or seven months of hibernation and spring migration (Tuttle and Stevenson 1977). Bats hang from cave ceilings in compact clusters composed of several thousand individuals in densities of more than 1800 bats per m^2 (170 bats per ft^2) (Gore 1992). Indiana bats (*Myotis sodalis*) may hibernate in the same caves with gray bats but usually select slightly different areas of the cave with different temperature ranges (Hall 1962). Hibernation lasts for approximately six months (Barbour and Davis 1969). Gray bats demonstrate strong loyalty to both summer and winter ranges (Tuttle 1976a). They may use as many as six different caves in the summer range but show no significant movement within the winter range after hibernation has begun.

REPRODUCTION: Gray bats require two years to reach sexual maturity (Tuttle 1976b). Females store sperm in the uteri (Guthrie 1933) but do not ovulate until they have emerged from hibernation (Saugey 1978). Fertilization and pregnancy occur soon after females leave the hibernaculum (Guthrie and Jeffers 1938). Gestation lasts for 60 to 70 days (Saugey 1978), and parturition occurs in late May and early June (Tuttle 1976b). The single, naked young cling to adult females for about a week, then remain in the nursery cave while females forage (Burt and Grossenheider 1976). Most young become volant by four weeks of age, which is usually late June to mid-July (Saugey 1978). For newly volant young, growth rates and survival depend on the commuting distances between roosts and foraging areas (Tuttle 1976b). Excessive commuting distance slows weight gain during weaning and prior to autumn migration. Although juvenile mortality is low (Saugey 1978) and potential longevity is high (up to 17 years), survival to maturity is only about 50 percent (USFWS 1980). Therefore, approximately five years are required for a female gray bat to produce two surviving offspring.

FOOD HABITS: Gray bats are insectivorous and consume a variety of insects that comprise at least 55 families (Clawson 1984, Best et al. 1997). Insect orders important to the diet are flies (Diptera), beetles (Coleoptera), caddisflies (Trichoptera), moths (Lepidoptera), wasps (Hymenoptera), stoneflies (Plecoptera), leafhoppers (Homoptera), and mayflies (Ephemeroptera) (Rabinowitz and Tuttle 1982; Clawson 1984; Brack 1985; Lacki, Burford, and Whittaker 1995; Best et al. 1997). Best et al. (1997) found that the most common prey, in decreasing order of dietary presence, were moths, flies, and beetles. Gray bats were highly selective of prey for these three taxa, which represented almost 50 percent of the total diets of gray bats at Blowing Wind Cave, Alabama. Studies by Clawson (1984) and Barclay and Bingham (1994) found that dietary components of insectivorous bats are strongly correlated with prey abundance in the habitat. Both aquatic and terrestrial species are eaten, most of which are less than 10 mm (0.4 in.) in length (Clawson 1984). Larger prey are soft-bodied insects with poor flying ability, while the smallest prey are swarming insects.

In early evening, gray bats emerge from summer roosts and fly to foraging sites associated with water or wetland vegetation (Rabinowitz and Tuttle 1982, Clawson 1984, Brack 1985). They usually follow a direct route to feeding areas (Tuttle 1976b) but may fly overland to reach the main river channel or tributary systems that lead to open-water foraging sites (Thomas 1994, Best and Hudson 1996). Gray bats typically forage over streams, reservoirs, lakes, and adjacent riparian vegetation, with both large and small perennial streams providing suitable foraging habitat (LaVal et al. 1977). Newly volant young often forage in forested areas surrounding the maternity cave. Gray bats may fly considerable distances during nightly foraging trips (Brady et al. 1982). Distances of 19 to 34 km (12 to 21 miles) have been recorded (Tuttle 1976a, LaVal et al. 1977, LaVal and LaVal 1980, Goebel 1996). Gray bats feed by continuous pursuit and remain in the air during most of the foraging period (Vaughn 1959). Feeding usually occurs within 5 m (16 ft) of the water surface (Harvey 1992). In riparian areas foraging occurs below treetop height, sometimes only 2 m (6.6 ft) above the water (LaVal et al. 1977, Brack 1985). During peak insect abundance in early evening, gray bats forage in slowly traveling groups; when insect numbers decrease after sunset, bats become territorial with 1 to 15 bats occupying a single territory (Brady et al. 1982). Gray bats maintain territorial fidelity for areas of productive foraging (Goebel 1996).

IMPACTS: Although natural factors such as flooding, cave-ins, freezing, and disease occasionally impact gray bats, population decline has been attributed chiefly to human disturbance of bats and alteration of their habitat (Barbour and Davis 1969, Mohr 1972, Harvey 1975, Tuttle 1979, Brady et al. 1982). The gray bat congregates in larger numbers at fewer hibernacula than any other North American bat (Brady et al. 1982). Approximately 95 percent of all gray bats hibernate in 11 caves, with 31 percent wintering in a single cave in northern Alabama (Harvey 2001). Each human entry into a hibernaculum causes all bats within range of sound or light to arouse at least partially from hibernation and use energy reserves that cannot be replenished before spring emergence (Tuttle 1979). Colonies are extremely loyal to single caves or groups of caves (Tuttle 1976a) and usually have limited ability to move to alternate caves to rear young (Tuttle 1979). Disturbance at maternity caves is most harmful from late May through mid-July when nonvolant young are on the roosts; thousands may die from a single disturbance (Brady et al. 1982). Gray bats may also abandon summer caves because of human intrusion (Barbour and Davis 1969). Human activities that have resulted in major impacts to bat colonies include cave exploration (Harvey 1975), cave commercialization (Brady et al. 1982), and vandalism (Tuttle 1979). Intentional vandalism includes

the shooting of bats by youth (Tuttle 1979), cave bombing with gasoline bombs (Harvey 1975), and extermination by property owners because of unsubstantiated fears of bats and rabies (Fredrickson and Thomas 1965). Although bats can contract and transmit rabies, fewer than 40 people in the United States are known to have contracted rabies from bats during the past 40 years (Harvey, Altenbach, and Best 1999).

The most outstanding impacts caused by human environmental alterations probably result from deforestation, chemical contamination, and impoundment of waterways. Deforestation near cave entrances and between caves and rivers or reservoirs may cause adverse effects to bat populations, including decrease in prey availability, decrease in foraging efficiency, and increase in vulnerability to predators (Tuttle 1979). Tree canopy is used by gray bats for protection in the vicinity of roost caves and along corridors to foraging areas. Clearing of vegetation near cave entrances increases gray bat susceptibility to predators such as the screech owl (*Otus asio*), which has much greater difficulty capturing bats in forest canopy. The newly volant young receive greater protection in forest cover, as they are slow, clumsy fliers and often spend several nights foraging in the forested area around the nursery cave during the first week of flight.

Agricultural pesticides have been implicated in the decline of North American bats, especially in curtailing the prey base (Reidinger 1976; Clark and Prouty 1976; Geluso, Altenbach, and Wilson 1976). Clark, LaVal, and Swineford (1978) documented mortality in gray bats and probable population decline resulting from routine insecticide use. Since mayflies, a major dietary item of gray bats, are sensitive to aquatic pollutants, declines of these and other insects eliminated by insecticides could prove disastrous for bat populations (Tuttle 1979).

The preference of gray bats for caves near rivers has made caves particularly vulnerable to inundation by man-made impoundments (Tuttle 1979). M'Murtrie (1874) described a heavily used bat cave in Alabama that was flooded by a reservoir, and Tuttle (1979) received accounts from longtime residents in Alabama and Tennessee about other bat caves that became submerged when waterways were impounded. A cave at Nolin River Lake, Kentucky (USACE Louisville District) was inadvertently inundated during storage of floodwaters during the summer of 1995, and a large number of gray bats were killed (Mitchell, Martin, and Dickerson 2000). The Corps now coordinates closely with USFWS to aggressively manage for the bats and prevent flooding of the cave. A colony may survive if timing of initial flooding is offset from the use of caves; however, strong roost site fidelity may render survival of a displaced population questionable, even if it escaped initial destruction (Tuttle 1979). The presence of reservoirs in gray bat home range can also be detrimental to colonies because people visiting reservoirs for recreational purposes can disturb quality foraging habitat.

MANAGEMENT: Any cave used by gray bats for roosting or hibernation must be protected from human disturbance (Brady et al. 1982) with efforts concentrated during the periods of cave residence (Tuttle 1977). Disturbance should be avoided at maternity caves between early April and the end of July, and at hibernacula between mid-August and mid-May. The physical structure of roost sites must be maintained or restored, and entrances and subsurface areas that have been adversely modified should be rehabilitated (Brady et al. 1982). Warning signs should be designed with proper wording to engage cooperation from potential cave users, and properly constructed gates or fences may be erected at cave openings. Gating and other entrance alterations should not be attempted

without knowledge of the potential impact upon the movement of both bats and air currents (Tuttle 1977). Ludlow and Gore (2000) examined emergence patterns of gray bats and southeastern myotis (*Myotis austroriparius*) before and after removal of a steel-bar gate at a cave in northern Florida and determined that gates can inhibit the use of cave entrances. These authors recommended perimeter fencing as an alternative to steel-bar gates at caves where trespassing and vandalism are not chronic problems. Multiple nongated entrances were considered to be important to bats, especially when the colony is large, predators are regularly present, and floods or rockfalls might close the primary entrance. Gray bats west of the Mississippi River will not tolerate some full gates at single-entrance maternity caves, and they will avoid gates if possible (White and Seginak 1987).

Gating has become the chief management tool for prevention of human entry into bat caves and mines. The Gray Bat Recovery plan outlined recommendations for the construction of gates at caves housing gray bats (Brady et al. 1982). However, this gate design has gradually developed into a basic design that can accommodate most cave-dwelling species (Tuttle and Taylor 1998). Angle iron replaced round steel bars, and gate dimensions have been altered to provide more flight space. Bat Conservation International recommends this basic gate design, which is officially called the American Cave Conservation Association (ACCA) gate. The ACCA provides general information on constructing bat gates and detailed designs that are updated annually. These designs are illustrated in Tuttle and Taylor (1998) with construction specifications for a typical bat gate used at vertical entrances and for a cage assembly placed over a mine shaft.

Foraging habitat should be protected by preserving the water quality of foraging sites, leaving forested areas associated with foraging habitat intact near roost caves, and maintaining the vegetation surrounding cave entrances to provide protection during nocturnal emergence (Brady et al. 1982). Any activities that might adversely affect foraging habitat within 25 km (15.5 miles) of gray bat caves should be carefully evaluated and modified to protect the habitat. For example, forested corridors, river edges, and reservoir shorelines should be left intact near summer caves, and the vegetation surrounding cave entrances should be maintained to provide protection from predators during nocturnal emergence.

Gray bat populations and habitats should be monitored periodically. Tuttle (1979) recommended an annual census of summer colonies between late July and mid-August. Brady et al. (1982) recommended a biennial census of hibernacula. Census methods have historically consisted of visual estimation of gray bats emerging from summer colonies and examination of cave evidence such as areas of staining and measurements of guano deposits (Tuttle 1979). Sabol and Hudson (1995) used infrared imaging to estimate numbers of emerging bats at caves in northern Alabama. Gray bats have also been monitored using radiotelemetry (Thomas and Best 2000) and ultrasonic sound detectors (e.g., the Anabat II detector) (Lamb 2000). Mistnetting may be used to help determine presence or absence, but project personnel should be aware that appropriate permits are required for the capture of protected species. Habitat can be evaluated by visual estimates of forest cover in travel corridors and at cave sites (Brady et al. 1982). The adequacy of foraging areas can be determined by sampling for appropriate food items, water quality, and chemical residues. Insects, guano, and bats should be checked for toxic chemicals if unexplained numbers of carcasses are found or if the population decreases after stabilization.

Several surveys show that the Corps has had opportunity to protect and manage gray bats on its projects in the eastern United States (Allred 1996; Kasul, Martin, and Allen 2000). Records maintained by Headquarters, USACE, show that gray bats and/or their habitats are being managed as part of recovery plan efforts on 15 projects in Kentucky, Tennessee, Missouri, Arkansas, and Kansas.[1] An assessment of Corps activities for threatened and endangered species found that several Corp projects actively manage for gray bats and at least 15 projects manage potential habitat (Mitchell, Martin, and Dickerson 2000). Caves used by summer colonies of gray bats have been managed to control flooding at Beaver Lake, Arkansas; Harry S. Truman Lake, Missouri; and Nolin River Lake, Kentucky. An artificial cave entrance was built at Beaver Lake to replace the natural entrance, which was below the flood control pool, and pumps were used at Harry S. Truman Lake to transfer storm and spring drainage away from a cave containing a maternity roost. At Nolin River Lake, a large nursery colony is located in a cave that opens onto a cliff on the edge of the summer pool. When floodwaters have to be stored, the Louisville District coordinates closely with the USFWS to affect appropriate protective measures.

SUMMARY: The gray bat was listed as Federally endangered throughout its range in April 1976 (41 FR 17740). In the late 1970s, the total population was estimated at approximately 2 million bats and it was estimated at only 1.6 million in the early 1980s. Although natural factors such as flooding, cave-ins, freezing, and disease occasionally impact gray bats, population decline has been attributed chiefly to human disturbance of bats and alteration of their habitat. The most outstanding impacts caused by human environmental alterations probably result from deforestation, chemical contamination, and impoundment of waterways. Gating has become the chief management tool for prevention of human entry into bat caves and mines. Bat Conservation International recommends a basic gate design, which is officially called the American Cave Conservation Association (ACCA) gate. The ACCA provides general information on constructing bat gates and detailed designs that are updated annually. Although recent population data indicate that the gray bat population has increased by 16.5 percent over the 1982 estimate, populations and habitats should continue to be monitored periodically. Census methods have historically consisted of visual estimation of gray bats emerging from summer colonies and examination of cave evidence such as areas of staining and measurements of guano deposits.

POINTS OF CONTACT: For additional information, contact Dr. Wilma A. Mitchell (601-634-2929, *wilma.a.mitchell@erdc.usace.army.mil*), Mr. Chester O. Martin (601-634-3958, *chester.o.martin@erdc.usace.army.mil*), or the manager of the Ecosystem Management and Restoration Research Program, Mr. Glenn R. Rhett (601-634-3717, *Glenn.G.Rhett@erdc.usace.army.mil*). This technical note should be cited as follows:

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[1] Personal Communication, July 2000, Denise White, Headquarters, U.S. Army Corps of Engineers (HQUSACE), Washington, DC.

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