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March 1998

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Species Profile: Gray Bat (*Myotis grisescens*) on Military Installations in the Southeastern United States

by *Wilma A. Mitchell*

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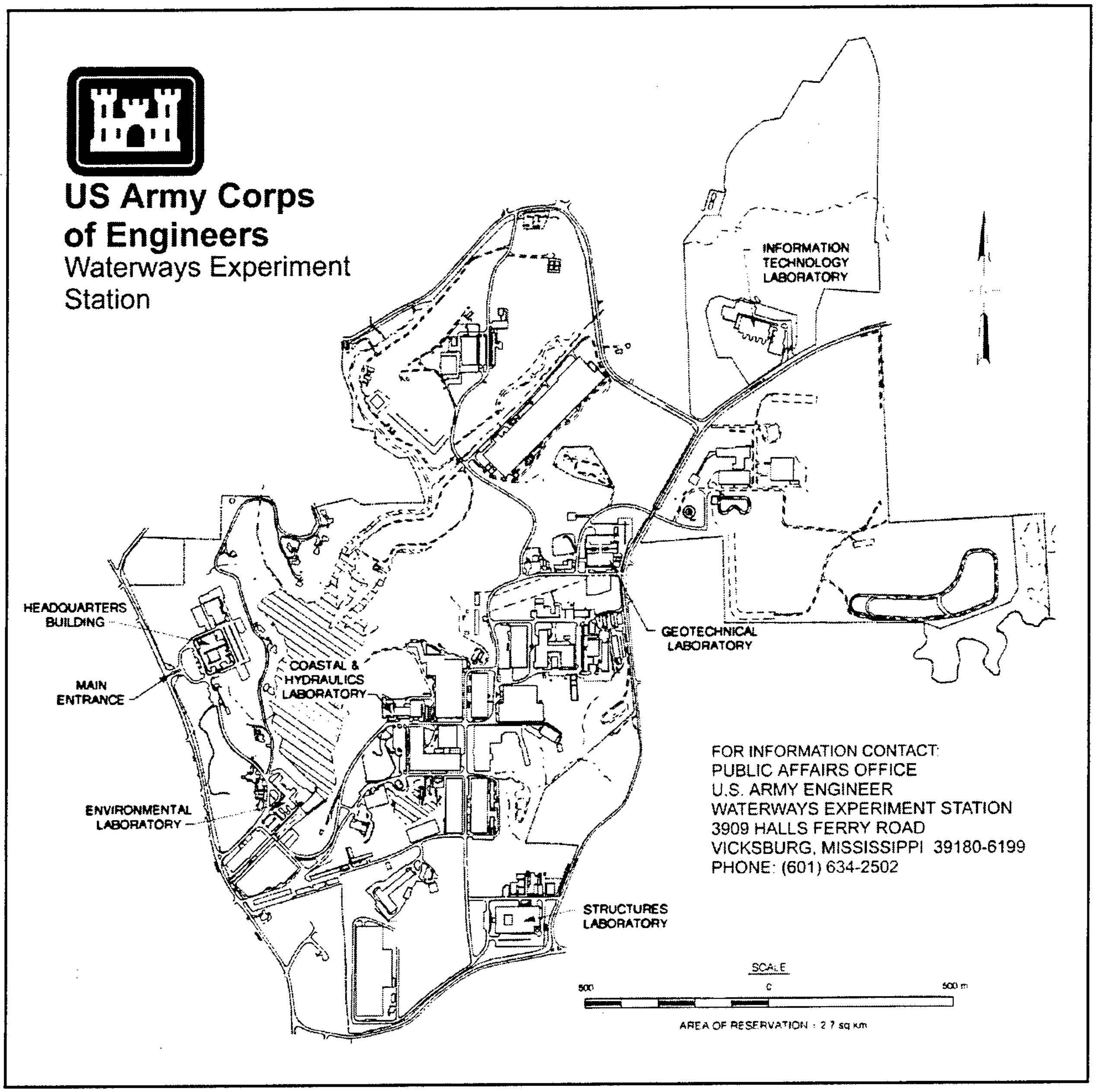

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Preface

The work described herein was authorized by the Strategic Environmental Research and Development Program (SERDP), Washington, DC. The work was performed under the SERDP study entitled "Regional Guidelines for Managing Threatened and Endangered Species Habitats." Mr. Brad Smith was Executive Director, SERDP.

This report was prepared by Dr. Wilma A. Mitchell, Natural Resources Division (NRD), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. Mr. Chester O. Martin, EL, WES, and Ms. Ann-Marie Trame, Land Management Laboratory, U.S. Army Construction Engineering Research Laboratories (CERL), were Principal Investigators for the regional guidelines work unit. Dr. Richard A. Fischer, EL, WES, managed and coordinated preparation of species profiles for this study. Report review was provided by Dr. Troy Best, Auburn University, Auburn, AL. WES technical review was provided by Mr. Martin and Dr. Fischer. Mr. Larry Reynolds and Ms. Tiffany Cook, EL, provided valuable assistance in assembling species information.

This report was prepared under the general supervision of Dr. Michael F. Passmore, Chief, Stewardship Branch, NRD; Dr. Dave Tazik, Chief, NRD; and Dr. John Harrison, Director, EL.

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Species Profile: Gray Bat

(Myotis grisescens)

Photo by Merlin Tuttle, Bat Conservation International

Taxonomy

Class	Mammalia
Order	Chiroptera
Family	Vespertilionidae
Genus/species	*Myotis grisescens*
Other Common Names	None known

Description

The gray myotis is a medium-sized bat with a forearm length of 40 to 46 mm (1.6 to 1.8 in.) and a wingspread of 275 to 300 mm (10.8 to 11.8 in.) (Barbour and Davis 1969). Weight ranges from 7 to 16 g (0.25 to 0.56 oz) (Gore 1992); it usually falls between 8 and 10 g (0.28 to 0.35 oz) during the summer but may increase to 16 g (0.56 oz) just before migration (U.S. Fish and Wildlife Service (USFWS) 1980). The wing membrane is attached to the foot at the ankle (Gore 1992). The calcar, a cartilaginous rod behind the ankle, lies along the free edge of the wing membrane and is not keeled. The skull has a distinct sagittal crest (Hamilton and Whitaker 1979, Gore 1992).

The fur of the gray bat is woolly and uniform in color from the base to the tip of the hair (Burt and Grossenheider 1976). The fur is gray immediately following the molt in midsummer but may bleach to chestnut-brown or bright russet by the following May or June, especially in reproductive females (USFWS 1980, Gore 1992).

Similar Species

The gray bat is most likely to be confused with other species of *Myotis* that inhabit its range (Barbour and Davis 1969, Burt and Grossenheider 1976). These include the southeastern myotis (*M. austroriparius*), little brown myotis (*M. lucifugus*), Indiana myotis (*M. sodalis*), small-footed myotis (*M. subulatus*), and Keen's myotis (*M. keenii*). The gray bat has uniformly colored dorsal fur, whereas the other species have bicolored or tricolored fur with the bases and tips of the hairs in contrasting shades (Barbour and Davis 1969, Hamilton and Whitaker 1979). The gray bat can also be distinguished from these species by the attachment of the wing membrane to the foot at the ankle, rather than at the base of the toe (Barbour and Davis 1969, Gore 1992). The gray bat is larger than all these species except Keen's myotis, which also has large ears.

Status

Legal designation

Federal. The gray bat was listed as endangered throughout its entire range on 28 April 1976 (41 FR 17740).

State. The gray myotis is listed as endangered in Arkansas, Florida, Georgia, Mississippi, Tennessee, Indiana, Illinois, Kentucky, Missouri, and North Carolina.

Military installations

Table 1 represents the known status of the gray bat on military installations in the southeastern United States.

Table 1
Known Status of Gray Bats on Military Installations in the Southeastern United States

Status	Installation	Status on Installation
AL	Anniston Army Depot	Potential.
	Fort McClellan	Documented onsite (Tom Steerhof, Personal Communication, 1996).
	Redstone Arsenal	Potential.
GA	Fort Benning	Potential.

Distribution and numbers

The gray bat occurs in cave regions of the midwestern and southeastern United States. Populations are concentrated in Alabama, Arkansas, Missouri, Tennessee, and Kentucky, with occasional colonies and individuals in adjacent States (USFWS 1980, Harvey 1992) (Figure 1). Summer and winter ranges are similar but not identical,

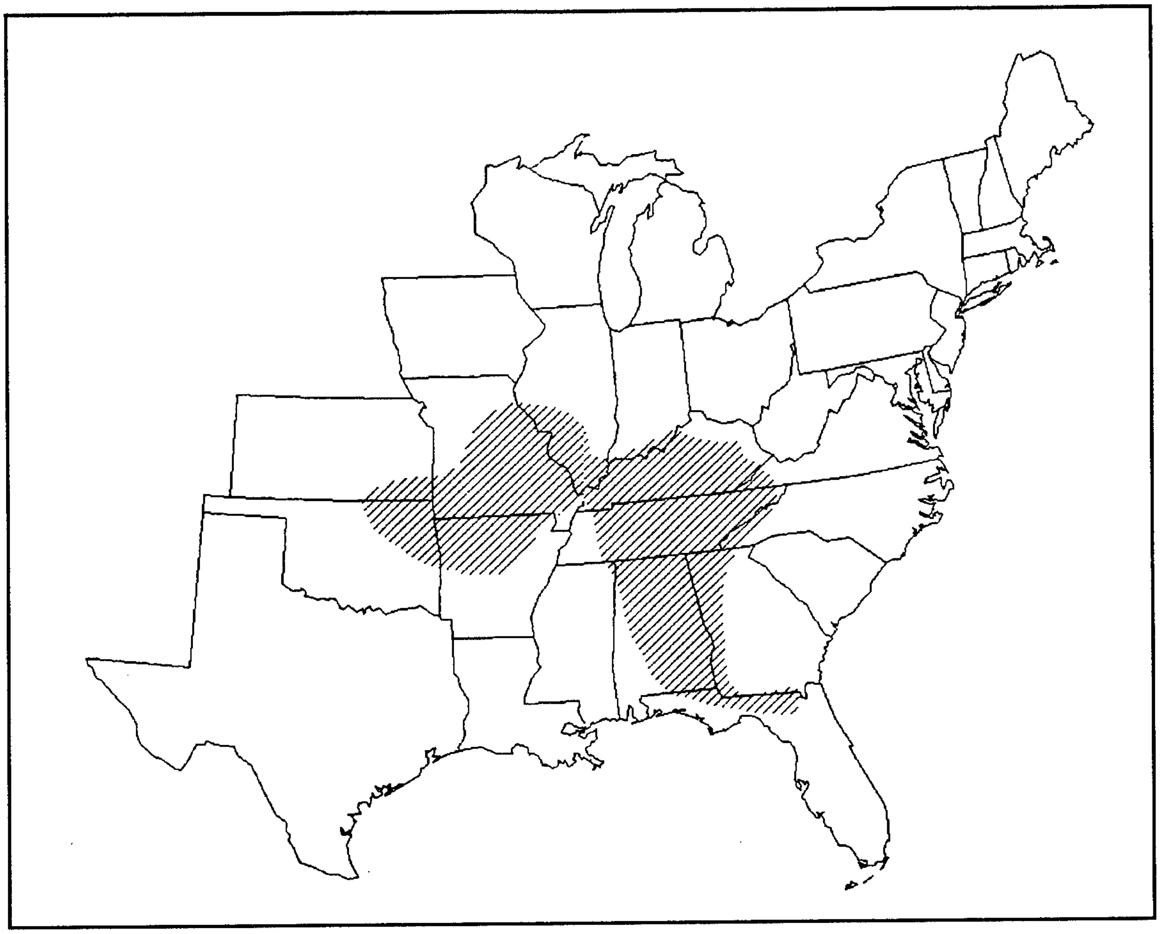

Figure 1. Approximate distribution of the gray bat (USFWS 1980)

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 south from southern Illinois and Indiana to northern Florida (Barbour and Davis 1969, Tuttle and Robertson 1969, Humphrey and Tuttle 1978, USFWS 1980, Martin and Sneed 1990, Gore 1992, Harvey 1992). Although summer colonies of gray bats in Florida are located far south of much of the species range, most of these bats hibernate in caves of northern Alabama and central Tennessee (Tuttle 1976a). The nine major winter caves are located primarily in Tennessee, Missouri, Kentucky, Alabama, Arkansas, and North Carolina.

It is difficult to accurately estimate the size of gray bat populations (Tuttle 1979). In the late 1970s, the total population of gray bats was estimated to be approximately 2 million. The present total population probably numbers between 1.5 million (Harvey 1992) and 1.6 million bats (Brady et al. 1982). About 95 percent of all gray bats hibernate in only nine caves (Tuttle 1979). Although gray bat numbers are still relatively high, their total population size has decreased significantly in recent years (Harvey 1992).

Life History and Ecology

Migration

Gray bats are year-round cave residents but occupy different caves in winter and summer (Gore 1992). Regardless of sex, age, or geographic location, all gray bats move between cold hibernating (winter) caves and warm summer caves each spring and fall (Tuttle 1976a). Adult females emerge from hibernation in late March or early April, followed by adult males and yearlings of both sexes. Most adult males and juveniles leave between mid-April and mid-May. In the summer range, adult females congregate in one preferred maternity cave to rear the young, and adult males and yearlings cluster in smaller groups in other caves. After the young are fledged, sex and age segregation are weakened, and individuals are more evenly dispersed throughout the summer range.

In autumn, the summer colonies disband to migrate to colder caves, where they hibernate for about 6 months (Barbour and Davis 1969, Gore 1992). Fall migration occurs in approximately the same order as spring emergence, with adult females leaving in early September and adult males and juveniles departing last, usually by mid-October (Tuttle 1976a). Gray bats travel in flocks between summer and winter sites, with some caves serving as overnight rest stops for migrating bats (Smith and Parmallee 1954, Barbour and Davis 1969).

Because of the limited number of available hibernation caves, bats from wide areas migrate to common hibernation sites. For example, bats from summer colonies, scattered over 27,195 km^2 (10,500 square miles) of Kentucky, southern Illinois, and Tennessee, migrate to a cave in Edmondson County, Kentucky, to hibernate (Hall and Wilson 1966). Tuttle (1976a) found that one-way distances regularly traveled in migration ranged from 17 to 437 km (11 to 272 miles); bats that summer in Florida migrate as far as 500 km (310 miles) to hibernate in cold caves of central Tennessee and northern Alabama.

Gray bats demonstrate strong loyalty (philopatry) 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.

Hibernation

Gray bats return to the same hibernation sites year after year (Tuttle 1976a). They hibernate primarily in deep vertical caves with large rooms (Gore 1992), hanging in compact clusters from the cave ceilings (Burt and Grossenheider 1976). These clusters are composed of several thousand individuals in densities of approximately 1,829 bats per square meter (170 bats per square foot) (Gore 1992). Clusters appear interwoven because the forearms of gray bats protrude at sharp angles instead of lying parallel to the body as in other hibernating bats (Barbour and Davis 1969). Hall (1962) described clusters of 100,000 gray bats that formerly hibernated in Coach Cave, Kentucky, and formed great mats several layers thick on the ceiling. Indiana bats may hibernate in the same caves with gray bats, but they select areas with slightly different temperature ranges.

Hall (1962) reported that gray bats would sometimes hang directly on clusters of Indiana bats in areas of temperature overlap.

Copulation occurs upon arrival of gray bats at winter caves, after which females immediately enter hibernation (Brady et al. 1982). Some mate and begin hibernation by the first of September, and almost all have done so by early October. Males may remain active for several weeks after mating, during which time fat reserves depleted during breeding are replenished. Most juveniles and adult males are hibernating by early November. Supplemental copulation may occur during the period of hibernation (Guthrie 1933, Miller 1939, Mumford 1958, Hall 1962, Saugey 1978).

The gray bat hibernates in the classical pattern of other temperate bats; it 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 6 to 7 months for the duration of hibernation and spring migration (Tuttle 1976a, Tuttle and Stevenson 1977). Adult mortality is especially high in early spring since migration occurs when fat reserves and food supplies are low (Tuttle and Stevenson 1977).

Reproduction and development

Reproduction. Gray bats reach sexual maturity at 2 years of age (Tuttle 1976b), whereas most other North American bats become sexually mature at 1 year (Guthrie 1933, Davis et al. 1962). Reproductive cycling is asynchronous in the sexes (Saugey 1978). Spermatogenesis is initiated in late summer and completed by early fall (Saugey 1978), but viable sperm persists until May (Barbour and Davis 1969). Females store sperm in the uteri throughout the period of hibernation (Guthrie 1933) but do not ovulate until they have emerged from hibernation (Saugey 1978). Fertilization and pregnancy occur soon after females leave the hibernacula (Guthrie and Jeffers 1938).

Adults segregate on the summer range with only the reproductive females and young occupying the maternity cave (Tuttle 1976a). After a gestation period of 60 to 70 days (Saugey 1978), the single young are born in late May and early June (Tuttle 1976b). The naked young cling to adult females for about a week, then remain in the nursery cave while females forage (Burt and Grossenheider 1976).

Development. Growth rates of nonvolant (nonflying) young are positively correlated with colony size (Tuttle 1975), probably because large numbers of clustering bats reduce the thermoregulatory cost per individual (Herreid 1963, 1967) and thus allow energy utilization for growth. Tuttle (1975) found that rates of weight gain varied from 0.20 to 0.39 g (approximately 0.01 oz) per day and correlated best with the number of young bats present on a roost. Growth rates also show positive correlation with higher ambient cave temperatures and the heat-trapping configuration of the roost, namely porous or domed ceilings (Tuttle 1975). Although growth rates vary, most young become volant (begin to fly) by the fourth week of life, which is usually late June to mid-July (Tuttle 1976b, Saugey 1978).

Females continue to nurse their young for a brief period after they learn to fly, but juveniles are apparently left on their own to learn hunting skills (Stevenson and Tuttle 1981). For newly volant young, growth rates and survival are dependent on the commuting distances between roosts and foraging areas (Tuttle 1976b). Tuttle (1976b) established an inverse relationship between body weight of newly volant young gray bats and distance to the nearest overwater feeding areas, concluding that excessive commuting distance exacts an energetic cost that 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 5 years are required for a female to produce two surviving offspring.

During lactation (late May to early July), reproductive females must maintain high body temperatures at their relatively cool roosts (Brady et al. 1982). This requires large amounts of energy; during the period of peak demand when the young are 20 to 30 days old, individual females sometimes feed continuously for more than 7 hr during a single night.

At ambient temperatures as low as 13.9 °C (57 °F), females maintain high body temperatures at maternity roosts throughout the period of lactation (Tuttle 1975). The energetic cost of large differentials between body and ambient temperatures is greatly reduced by the formation of large colonies, clustering behavior, and choice of roost configurations that maximize retention of dissipated body heat.

Food habits

Diet. Gray bats feed almost exclusively on insects and exhibit a great variety in diet. Insects of at least 55 families comprising 15 orders of insects are consumed by gray bats (Clawson 1984, Best et al. 1997). Insects 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 et al. 1995, Best et al. 1997). In Alabama, Best et al. (1997) found that the most common prey, in decreasing order of dietary presence, were moths, flies, and beetles; insects of these taxa represented almost half of the total diets of gray bats at Blowing Wind Cave. Both aquatic and terrestrial species are eaten and range from 2 to 25 mm (0.08 to 1 in.) in body length; however, most are under 10 mm (0.4 in.) (Clawson 1984). Larger prey tend to be soft-bodied insects with poor flying ability, while some of the smallest prey are swarming insects. Arachnids are occasionally found in gray bat diets (Best et al. 1997).

Lacki et al. (1995) found that beetles, stoneflies, flies, and moths occurred in the highest percent volumes in diets of gray bats captured in Jessamine County, Kentucky. However, the percentages that each insect group contributes to gray bat diets are difficult to estimate accurately. Conclusions drawn from fecal analysis, the chief method used in bat food habit studies, is subject to a high degree of bias because of the differential digestibilities of prey items (Rabinowitz and Tuttle 1982). For example, mayflies are highly digestible and usually underestimated in fecal samples, whereas beetle structures are less digestible and tend to be overestimated. Bats also discard some prey body parts, such as mayfly wings, before consumption. Biomass is an important factor in dietary reconstruction; for example, moths composed only 7 percent of meals hand-fed to gray bats but accounted for 27 percent of the biomass in resulting fecal samples.

Barclay and Bingham (1994) found that dietary components of insectivorous bats are strongly correlated with prey abundance in the habitat, and a study by Clawson (1984) indicated this was true of gray bat diets in Missouri. However, Best et al. (1997) showed significant dietary variation over time but no significant correlation between prey selection and availability; the study indicated that gray bats were highly selective of prey, especially for the three major groups (moths, flies, beetles) consumed.

Foraging behavior. In early evening, gray bats emerge from summer roosts and fly to foraging sites, where they feed on insects associated with water or wetland vegetation (Rabinowitz and Tuttle 1982, Clawson 1984, Brack 1985). They usually follow a direct route to feeding areas, often forming a continuous stream from the cave entrance to feeding sites (Tuttle 1976b). Gray bats may also fly overland from relatively land-locked roost sites to reach the main river channel or tributary systems that lead to open-water foraging sites (Thomas 1994, Best and Hudson 1996).

Gray bats feed by continuous pursuit and remain in the air during most of the foraging period (Vaughn 1959). Foraging 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, many gray bats feed in slowly traveling groups; but when insect numbers drop (1.5 to 2 hr after sundown), the bats become territorial (Brady et al. 1982). Depending upon prey abundance, foraging territories may be occupied by 1 to 15 or more bats. Territories are generally located in the same places and used by the same individuals from year to year. A radiotelemetric study by Goebel (1996) supported previous reports that a large percentage of bats return to successful foraging areas.

Habitat Requirements

Roosting habitat

The gray bat lives in caves year-round (Tuttle 1979) and is probably more restricted to cave habitats than any other mammal native to the United States (Hall and Wilson 1966, Barbour and Davis 1969, Tuttle 1976a). A much wider variety of cave types are used during the spring and fall transient periods than during winter and summer (Brady et al. 1982). At all seasons, males and yearling females seem less restricted than reproductive females to specific cave and roost types (Tuttle 1976a).

Because of highly specific roost and habitat requirements, fewer than 5 percent of available caves are suitable for occupation by gray bats (Tuttle 1979). In accordance with

Dwyer's (1971) general prediction, 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). Caves used by the gray bat 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).

Winter caves. Most winter caves are deep and vertical (Brady et al. 1982). They provide large volume below the lowest entrance and function as cold-air traps with multiple entrances and good air flow (Tuttle and Stevenson 1978). Winter caves average 10 °C (50 °F) below the mean annual surface temperature, and preferred temperatures range from 6 to 9 °C (43 to 48 °F). Hall (1962) found that temperatures were 10 to 11 °C (50 to 52 °F) at winter roosts in Kentucky, and Myers (1964) reported a mean temperature of 8.7 °C (47.7 °F) for winter caves in Missouri. These caves are already cold when gray bats arrive in September (USFWS 1980).

Summer caves. On the summer home range, colony members disperse in groups among several different caves (Tuttle 1976a). Reproductive females form maternity colonies of a few hundred to many thousands of individuals, while males and nonreproductive females congregate in smaller bachelor colonies (Harvey 1992). Only females and their young occupy the maternity cave, while the other groups use more peripheral caves within the area (Tuttle 1976a). After the young are volant, gray bats are more transient within the colony home range and frequently use alternate roost sites (Thomas 1994).

Colonies select summer caves with temperatures that range from 14 to 25 °C (57 to 77 °F) (Brady et al. 1982). The maternity cave is usually the warmest one in the summer home range (Tuttle 1976a). Tuttle (1975) demonstrated that growth and development of the young are influenced by ambient temperature of the maternity cave; nonvolant young reared at 16 °C (61 °F) reached flight age 9 days earlier than those reared at 14 °C (57 °F), and weight gain was even faster in warmer sites.

Nursery populations succeed because gray bat maternity caves contain structural heat traps that capture the metabolic heat from a large number of clustered individuals (Tuttle 1976a). Maternity colonies prefer roost caves that are able to trap body heat from thousands of bats (Tuttle 1975, Tuttle and Stevenson 1978). Typical cave configurations that trap heat include small chambers (Dwyer 1963), high places in domed ceilings (Davis et al. 1962), domes or small pockets within these locations (Dwyer 1963, Dwyer and Hamilton-Smith 1965, Dwyer and Harris 1972), and depth of etching and porosity of the rock surface (Tuttle 1975). Tuttle (1975) found that growth rates of nonvolant young are positively affected by the presence of porous or domed ceilings at roosts.

Artificial roosts. A few gray bat colonies roost at artificial (man-made) sites that simulate summer caves (Hays and Bingham 1964, Gunier and Elder 1971, Elder and Gunier 1978, Timmerman and McDaniel 1992). Storm sewers have been used by gray bats in Kansas (Hays and Bingham 1964), Illinois (Elder and Gunier 1978), and Arkansas (Timmerman and McDaniel 1992). These storm drains have high humidity and running water without sewage, both typical characteristics of natural caves. A small nursery colony of 200 bats roosting in a storm sewer in Pittsburg, KS ((Hays and Bingham 1964), had grown to a population of 8,000 bats by 1971 (Gunier and Elder 1971). This population remained stable during the early 1970s but had decreased by 20 percent in the late 1970s (Phillips and Hays 1978). The colony located in Newark, AR, was estimated at 8,000 bats in 1988 and appeared to be stable in the early 1990s (Timmerman and McDaniel 1992). A large nursery colony was also found in an abandoned barn in Missouri (Gunier and Elder 1971).

Foraging habitat

The gray bat appears to be restricted by its dependence upon major areas of water, as a direct correlation exists between the distribution of summer colonies and bodies of water (Tuttle 1976b). Gray bats forage primarily overwater along rivers or lake shores where flying insects are abundant (Tuttle 1976b, 1979; LaVal et al. 1977). In Tennessee, they use lakes and rivers and rely heavily on reservoirs (Tuttle 1976b); whereas in eastern Missouri, they forage over swift rivers, secluded streams, and the associated riparian vegetation (LaVal et al. 1977). Summer colonies inhabit areas in which open water and the banks of streams, lakes, or reservoirs are within manageable distance of roosting sites and suitable caves in which to rear young (LaVal et al. 1976, 1977; Tuttle 1976b).

Gray bats often follow corridors of trees from roosts to feeding sites (LaVal et al. 1977). LaVal et al. (1977) found that bats flew downstream more often than upstream, suggesting a preference for the wider downstream sections of streams as opposed to narrower, upstream portions. Netting indicated that gray bats used even the smallest of permanently flowing streams, but greater numbers used the larger streams. Gray bats were distributed along 17 km (10.6 miles) of the river upstream and downstream from the roost cave, with a mean distance of 11.1 km (6.9 miles) and a range of 2 to 27.8 km (1.2 to 17.3 miles) from the roosting cave.

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, and adult mortality. For newly volant young, growth rates and survival are inversely proportional to the distance from the roost to the nearest overwater foraging habitat. Quality of foraging area, climatic conditions, and cave temperature are potential factors that influence growth and survival, but these become less significant when the distance from roosts to water becomes excessive.

Forested areas surrounding caves or located between caves and feeding habitat are highly advantageous to gray bat survival (Tuttle 1979). Newly volant young often feed and take shelter in forests surrounding cave entrances, and whenever possible, adult bats travel in the forest canopy between caves and foraging areas (Brady et al. 1982). This behavior provides increased protection from predators such as screech owls (*Otus asio*).

Habitat Assessment Techniques

Installations located within the range of gray bats should be surveyed to determine the presence of potential habitat for this species. The essential element is a cave that fulfills the habitat requirements of either winter hibernating or summer maternity roosts. If a potential summer roost site is located, the area should be surveyed for the presence of available foraging habitat, and the general quality of corridors should be assessed to determine if adequate forest canopy exists for safe travel between the cave and foraging area.

Impacts and Causes of Decline

The total gray bat population has declined drastically since the early 1960s (Brady et al. 1982). Although difficult to estimate, population reductions based on extensive research indicate the severity of the situation (Myers 1964, Tuttle 1979). In the early 1960s, Myers (1964) censused 27 maternity caves in Missouri and found a total population of 238,000 gray bats. By 1978, 16 of these colonies had been abandoned, and the 11 remaining colonies had a population of only 46,500 bats, which is an 80-percent reduction over the 15-year period. Censuses of Kentucky in the late 1970s indicated that 20 caves with a maximum population of 515,400 bats had been reduced to 8 caves with a total population of 61,100 bats, an 88-percent decline (Brady et al. 1982).

Tuttle (1979) censused 22 summer colonies in Alabama and Tennessee from 1968 through 1970 and in 1976. A conservative estimate revealed a 54-percent decline in gray bats during that period and a 76-percent decline from known past maximum population levels. The estimated maximum past population for the 22 colonies was 1,199,000 individuals; by 1970, numbers had dropped to 635,000, a 47-percent reduction. By 1976, the combined population had fallen to 293,000 bats, an additional 54-percent reduction. Some major colonies disappeared entirely within the 6-year period. Seven colonies at their all-time past maximums in 1970 had been reduced to four colonies by 1976, and the largest maternity colony (111,400 bats) in the stable category had declined by at least 95 percent.

The restricted habitat requirements of the gray bat render this species highly vulnerable to impacts resulting from human activities. The few roost caves selected by gray bats in summer must be located near rivers or reservoirs (Tuttle 1976b), and the winter caves must be deep and vertical with unusually low temperatures (Tuttle and Stevenson 1978). The major categories of activities that result in impacts and causes of population decline are human disturbance, environmental disturbance, and impoundment of waterways (Brady et al. 1982).

Human disturbance

The decline of the gray bat is attributed chiefly to human disturbance (Manville 1962; Barbour and Davis 1969; Mohr 1972; Harvey 1975; Tuttle 1977, 1979; USFWS 1980).

Many people whose actions disturb gray bat colonies erroneously believe that the bats move to other caves when they abandon a roost because of human activity. However, gray bat colonies are extremely loyal to single caves or groups of caves (Tuttle 1976a) and usually have limited ability to move to alternate caves for the rearing of young (Tuttle 1979). Only a small proportion of caves in any area can be used regularly because of the restricted roosting habitat requirements; therefore, any cave not being used by gray bats is probably unsuitable habitat for this species.

Seasonal disturbance. Tuttle (1979) showed a direct correlation between frequency of human disturbance and population reductions in summer colonies in Alabama and Tennessee. Disturbance at maternity caves is most harmful from late May through mid-July when nonvolant young are on the roosts, and thousands may die from a single disturbance (Brady et al. 1982). Bats may also abandon summer caves because of human visitation (Barbour and Davis 1969).

The gray bat congregates in larger numbers at fewer hibernating caves than any other North American bat (Brady et al. 1982); therefore, it is particularly vulnerable to human intrusion. Mohr (1972) considered the concentration of such a large proportion of the population into so few hibernating caves to be the real threat to their survival. At least 95 percent of the entire gray bat population winters in nine caves, and over 60 percent winters in a single cave in northern Alabama (Tuttle 1979).

Human disturbance from mid-August through April is especially detrimental to gray bats. Each human entry into a cave causes all bats within range of sound or light to arouse at least partially, and usually completely, from hibernation (Brady et al. 1982). Although a limited number of natural arousals is necessary for hibernating bats, each arousal demands a high degree of energy; energy reserves (stored in fat) cannot be replenished before spring emergence. Daan (1973) calculated for other myotine species that each arousal causes a bat to expend 20 to 30 days of stored energy reserves. Tuttle's unpublished observations indicated that gray bats may lose as much as 0.48 g (0.02 oz) of weight in the first hour of disturbance and that arousal and movement to a new roost probably costs an individual as much energy as it would normally expend in 10 to 30 days of undisturbed hibernation (Brady et al. 1982). Repeated visits within a single winter can exhaust the limited energy reserve of the colony and result in high mortality. Bats whose energy reserves have been exhausted will likely leave the cave prematurely in search of food and die outside the cave.

Disturbance factors. Human activities that have contributed greatly to colony disturbance include (a) cave exploration, (b) cave commercialization, and (c) vandalism. Cave exploration has become increasingly popular since the 1950s, and many spelunkers seek out caves typical of bat roosts (Harvey 1975). Deep, vertical caves that are accessible only by use of elaborate gear present a challenge to spelunkers (Barbour and Davis 1969). Therefore, many winter colonies that were formerly unknown and thus protected have been exposed to human disturbance that has reduced populations at those caves.

Some of the largest known gray bat colonies have been extirpated because of cave commercialization (Brady et al. 1982). Some caves have been cleared for commercial pursuits by the direct killing of bats (Tuttle 1979), while others expose bats to human contact because of their location in areas now used for recreation (Matthews and Moseley 1990). Although cave flooding is a natural disaster faced by gray bats, it has become increasingly important as they retreat farther into inaccessible places to avoid human disturbance (Brady et al. 1982). Summer colonies often retreat to roosts over deep water, which may become death traps during flooding (Tuttle 1979).

Vandalism has been responsible for the destruction of large numbers of gray bats, sometimes entire colonies. During extensive research throughout the Southeast, Tuttle (1979) found numerous examples of gray bat extirpation resulting from direct, intentional vandalism. Old-timers frequently told him about killing emerging bats for fun when they were children. Some cave owners have attempted to exterminate entire colonies on their properties because of erroneous claims that the colonies were rabid (Fredrickson and Thomas 1965). In more recent times, Harvey (1975) reported an attempted cave bombing with Molotov cocktails (gasoline bombs) in Tennessee, and Tuttle (1979) reported that teenage boys shot large numbers of bats on their roosts and during evening emergence. Marked reduction in a population may be caused by single events such as these.

Environmental disturbance

Because human disturbance has made such an overwhelming contribution to the decline of gray bat populations, the impact of environmental disturbances has not been extensively studied nor clearly defined. However, certain environmental changes produce adverse effects on gray bat populations. The most outstanding impacts probably result from deforestation, chemical contamination, and impoundment of waterways.

Deforestation. Deforestation near cave entrances and between caves and rivers or reservoirs may cause adverse effects to bat populations (Tuttle 1979). Tree canopy is especially important to gray bats in the vicinity of roost caves and along corridors to foraging areas. During evening emergence, gray bats usually fly to their feeding areas in the protection of forest canopy (Tuttle 1976a) and frequently travel out of their way to take advantage of scattered trees along a fence row (Tuttle 1979). Tuttle (1979) has observed that bats will limit foraging to the forested areas near roost caves in extremely cold spring weather. Deforestation and brush clearing near cave entrances increase gray bat susceptibility to predation. Screech owls, a common predator of gray bats, have much greater difficulty capturing bats in forest canopy, and the newly volant young receive greater protection in forest cover. The young are slow, clumsy fliers during the first week of flight and often spend several nights foraging in the forested area around the nursery cave before venturing farther away. Trees also provide protection from wind and convenient resting places for weak fliers.

Chemical contamination. The influence of agricultural pesticides in the decline of North American bats has been reported by several authors (Mohr 1972; Reidinger 1972, 1976; Clark and Prouty 1976; Geluso et al. 1976). Clark et al. (1978) documented mortality in gray bats and probable population decline resulting from routine insecticide use; unusually high levels of residues from heavily used insecticides were found in guano samples from bat caves. Mayflies, a major dietary item of gray bats, are sensitive to aquatic pollution (Tuttle 1976b) and have become rare in many foraging areas where they were once abundant (Fremling 1968). Declines of these and other insects eliminated by insecticides could prove disastrous for insectivore populations (Tuttle 1979).

Impoundment of waterways. The preference of gray bats for caves near rivers has made caves particularly vulnerable to inundation by man-made impoundments (Tuttle 1979). The initial effect of long-established impoundments, such as those in the Tennessee Valley Authority, is difficult to evaluate because of the lack of preimpoundment data; however, available information indicates that many important caves were inundated, and bat populations were probably extirpated. M'Murtrie (1874) described a heavily used bat cave in Alabama that was later 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 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 escapes initial destruction (Tuttle 1979). The presence of reservoirs in gray bat home range can also be detrimental because increased numbers of people visiting reservoirs for recreational purposes can disturb quality foraging habitat.

Military training

Military maneuvers conducted in the vicinity of a roost cave used by gray bats could cause the bats to abandon the cave. As discussed above, colonies show strong loyalty to the home range (Tuttle 1976a), and cave abandonment could lead to the loss of an entire colony (Tuttle 1979). Travel corridors to foraging areas can be degraded by actions such as deforestation or land clearing that increase bat susceptibility to predation (Tuttle 1979). Pesticide use could affect the health of a gray bat colony (Clark et al. 1978).

All Federal agencies must consult with the USFWS about any planned activity on their lands that could adversely affect a colony of gray bats. Such activities on a military installation include training exercises, road construction, pesticide use, and land clearing in areas associated with roost caves and foraging sites.

Inventory and Monitoring

The best time to census gray bat populations is between late July and mid-August, after the young bats are volant (Tuttle 1979). Caves should not be entered during the remainder of the year, especially during hibernation. Mist nets or bat traps can be employed to detect and identify gray bats at summer roosts (Harvey 1992). These methods are especially effective when placed at cave entrances but should be used only by specialists who hold permits for their use. Mist nets are made of fine nylon thread and attached to poles that may be more than 9 m (30 ft) tall. Bat traps consist of two parallel frames, over which are strung thin vertical wires set 2.54 cm (1 in.) apart. Bats flying into a trap detect and avoid the first set of wires, then hit the second set and fall into a collecting bag.

Census methods

Population estimates from cave evidence. Tuttle (1979) described the method used extensively to estimate gray bat populations at summer caves in Alabama and Tennessee. To minimize disturbance, a roost cave was entered at night just after the bats had emerged. The data collected were based on several aspects of cave-bat interactions: (a) the area of stained cave ceiling, (b) the ceiling area covered by the existing colony, and (c) the floor area covered by old versus new guano deposits. The length and width of each part of irregular-shaped roosts or the diameters of round roosts (or guano deposits) were measured with a 15-m (50-ft) steel tape, and these measurements were used to calculate the number of square meters covered by roosting bats. Only well-defined, clearly reddened areas of staining were included in the measurement of roosts, and guano was measured only to the edge of accumulations that were clearly dropped by bats. Roost staining on cave ceilings apparently requires many years and did not occur in a few caves. However, measurement of old guano deposits provided a reliable estimate since the guano falls on the floor directly beneath clustered bats. Visual observations of clustered bats were also used to verify conclusions regarding roosting configuration and density.

In estimating population size, the mean clustering density of 1,828 bats per square meter (170 bats per square foot) (Tuttle 1975) was multiplied by the number of square meters estimated to be covered by roosting bats and rounded to the nearest hundred. Tuttle (1979) found that density of roosting bats varied among colonies, but it appeared to vary only slightly within individual colonies, regardless of changes in colony size. Therefore, variation in clustering density is assumed to have a minimal effect in biasing estimates of population trends within gray bat colonies over time.

Visual estimation technique. A bat population can be estimated by visually counting the numbers of bats emerging from summer roost caves. This procedure was used as one method for estimating gray bat populations at two caves in Alabama (Sabol and Hudson 1995). During evening emergence, a skilled observer counted bats seen crossing his field of view. Counting occurred for intervals of 1 min followed by 1-min rest and recording periods. Since only one-half the bats occupying a cave were counted, a total emergence estimate was obtained by doubling the number counted. When emergence rates were rapid, estimates were made by counting by 10s, 20s, or 100s. An advantage of using this technique is that minimal equipment is needed. However, the observer must be experienced in observation and counting bats on the wing, especially large numbers emerging together from a cave.

Infrared imaging procedures. A census technique developed by Sabol and Hudson (1995) uses thermal infrared-imaging and digital picture processing to estimate gray bat populations. Infrared-imaging systems, which take heat pictures, allow the detection of bats against a cooler background with or without the presence of visible light. This technique was used to estimate numbers of bats during nocturnal emergence at two Alabama caves. A thermal infrared scanning radiometer with a 20° horizontal and 20° vertical field-of-view lens was used in the tests, and imagery was continuously recorded on video tapes, beginning before the first signs of emergence and continuing until the end of emergence, which was about 1 hr.

Several options are available for counting bats with this technique (Sabol and Hudson 1995). An observer may view the video and make a visual count. Automated options include estimation based on sampling frames or on frame-by-frame tracking and counting. The most critical aspect of this technique is setting up the camera to achieve the proper viewing geometry and to view a background that is stationary and thermally bland; a stationary background is an absolute requirement. Prior knowledge of the cave and flight path taken by the bats is helpful. Sabol and Hudson (1995) found close numerical agreement between visual estimation and infrared imaging. This technique should be more consistent than visual estimation and thus enable collection of better trend data. Its most appropriate use would be in estimating large populations for which accurate visual estimation would be most difficult. Calculations for estimating total populations with infrared imaging techniques are given in Sabol and Hudson (1995).

Monitoring

After an initial population estimate has been made, gray bat summer colonies should be monitored each year (Tuttle 1979). However, in the USFWS Recovery Plan, Brady et al. (1982) recommended that hibernacula only be censused every 2 years. Natural resources personnel who have had no experience working with bats should request assistance from agencies that maintain bat specialists on the staff. Federal and State permits must be obtained to use mist nets for collecting and banding bats.

Management and Protection

Species recovery

Recovery plan. The primary objective of the recovery plan is to move the gray bat from endangered to threatened status (Brady et al. 1982). The minimum requirements needed to achieve this goal are (a) documentation of protection of 90 percent of Priority 1[1] hibernacula, and (b) documentation of stable or increasing populations at 75 percent of Priority 1 maternity caves after a period of 5 years. The major recovery actions recommended by the USFWS are the (a) acquisition and protection of caves used by gray bats, (b) control of habitat destruction, and (c) education of the public.

Recovery actions. The most important feature of the recovery plan is the protection of roosting habitat (Brady et al. 1982). This action has required gaining control of important gray bat caves to protect them from human disturbance, and the USFWS has purchased

1 The status assigned to a cave by USFWS based on its importance to gray bat population survival and stabilization.

some important summer roost caves for this purpose. Signposting, gating, fencing, and surveillance by law enforcement agents have been used to protect caves. Major efforts have been made to gain the cooperation of landowners whose property contains historical or potential gray bat caves. Emphasis has been placed on protection during periods of cave residence, and efforts to eliminate disturbance have been concentrated from spring to late summer at maternity caves and from late summer to late spring at hibernacula.

Much of the foraging habitat used by gray bats in their primary population centers (southern Appalachian and Ozark regions) has not been seriously modified by man's activities except for the construction of reservoirs (Brady et al. 1982). Much of the land in these regions is still forested, and water quality is generally adequate for the production of aquatic insects. In some areas, reservoirs provide foraging habitat for gray bats. However, substantial areas of habitat have been altered by clearing, channelization, siltation, and herbicide application. Foraging habitat associated with summer roost caves still needs protection, maintenance, and in some cases, restoration.

Emphasis has been placed on educating government officials, landowners, and the general public regarding the ecological role of bats (Brady et al. 1982). Brochures and other literature have been made available to all of these groups throughout the range of the gray bat. Cave users (e.g., spelunkers) have been informed, and slide programs, interpretive signs at caves, and ranger-naturalist talks have helped to educate the public.

Management techniques

The appropriate USFWS offices and State wildlife agencies should be notified of existing or potential gray bat caves on a military installation. The natural resources management plan should include measures for the protection, maintenance, and rehabilitation of these roost sites or hibernacula.

Caves. Protection from human disturbance is essential, and gray bat caves must have means of preventing unauthorized entry (Brady et al. 1982). Warning signs should be designed with proper wording to engage cooperation from potential cave users or illegal entrants. Gates or fences may be erected at cave openings. However, 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 and Stevenson 1977). Protection efforts should be concentrated during the periods of cave residence. All disturbance must be avoided at maternity caves between early April and the end of July, and disturbance should be avoided at hibernacula between mid-August and mid-May. If necessary, caves should be monitored by law enforcement agencies during these periods.

The physical structure of roost sites must be maintained or restored (Brady et al. 1982). Entrances and subsurface areas that have been adversely modified should be rehabilitated. Carcasses of unusual numbers of dead bats found in caves should be analyzed for lethal concentrations of pesticides, followed by identification and control of the contamination source.

Foraging habitat. It is essential to maintain and restore the habitat associated with foraging activities (Brady et al. 1982). Water quality of foraging areas and surrounding forest cover should be preserved. Any activities that might adversely affect foraging habitat within 25 km (15.5 miles) of major 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.

Monitoring. To determine the effectiveness of gray bat management and protection, populations and habitat must be monitored periodically. Population trends can be obtained by the annual census of roost caves and biennial census of hibernacula (Brady et al. 1982). Habitat can be evaluated by visual estimates of forest cover in travel corridors and at cave sites. The adequacy of foraging areas can be determined by sampling for appropriate food items (insects), water quality, and chemical residues. Insects, guano, and bats should be checked for toxic chemicals if unexplained numbers of carcasses are found or the population appears to decrease after stabilization.

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13. ABSTRACT ***(Maximum 200 words)***

The gray bat (*Myotis grisescens*) is a medium-sized bat with gray or chestnut-brown fur. The species was listed as Federally endangered in 1976 throughout its range by the U.S. Fish and Wildlife Service, primarily due to human disturbance, environmental disturbance, and impoundment of waterways. Gray bats are year-round cave residents but migrate between caves in wintering and summering areas of the midwestern and southeastern United States. Populations are mainly concentrated in Alabama, Arkansas, Missouri, Tennessee, and Kentucky. The species has been documented on one military installation in the southeastern United States; installations with suitable habitat in other sections of the United States should also benefit from this profile. This report is one of a series of Species Profiles being developed for threatened, endangered, and sensitive species inhabiting southeastern United States plant communities. The work is being conducted as part of the Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP). The report is designed to supplement information provided in plant community management reports for major United States plant communities found on military installations. Information provided on the gray bat includes status, life history and ecology, habitat requirements, impacts and causes of decline, habitat assessment techniques, inventory and monitoring, and management and protection.

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