# Monitoring Trends in Bat Populations of the United States and Territories: Status of the Science and Recommendations for the Future

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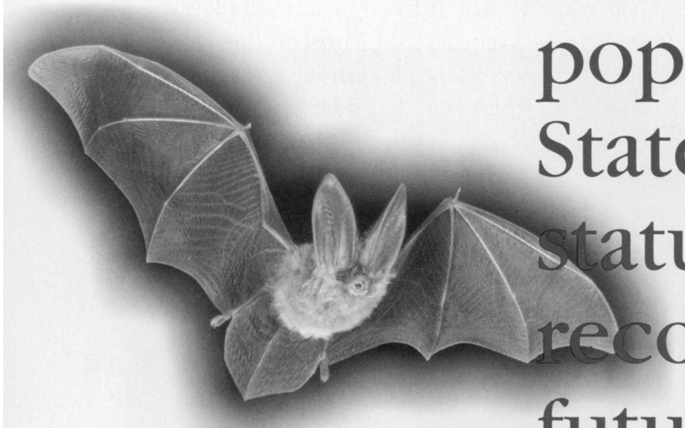

# Monitoring trends in bat populations of the United States and territories: status of the science and recommendations for the future

by Thomas J. O'Shea, Michael A. Bogan, and Laura E. Ellison

**Abstract** Populations of bats (Order Chiroptera) are difficult to monitor. However, current recognition of the importance of bats to biodiversity, their ecological and economic value as ecosystem components, and their vulnerability to declines makes monitoring trends in their populations a much-needed cornerstone for their future management. We report findings and recommendations of a recent expert workshop on monitoring trends in bat populations in the United States and territories. We summarize selected case reports presented by others at the workshop, including reviews of methods and ongoing efforts to monitor a wide range of species of bats in a diverse array of situations. Most efforts at monitoring bat populations involve use of indices that are uncalibrated in relation to population size, do not incorporate measures of variation or detectability, are discontinuous in time and space, and sometimes lack standard protocols. This is in part because the complex and variable natural history of bats poses many challenges to monitoring. We also review principal findings and recommendations made by workshop participants. Recommendations centered on improving methods for monitoring populations of bats, defining objectives and priorities for monitoring, gaining mandates for monitoring, and enhancing information exchange.

**Key Words** bats, Chiroptera, endangered species, population estimation, species of concern, trend monitoring

The bat (Order Chiroptera) fauna of the United States and territories includes about 60 species. There is mounting concern about population status of many species in this diverse group of mammals. There also is growing interest in the science underlying management and conservation of bats. For example, over the decade 1992–2001 we tallied 29 articles in *The Journal of Wildlife Management* and the *Wildlife Society Bulletin* that had

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bats as their major focus of study: 22 of these were published in the past 5 years. In terms of biodiversity, there are about 45 species of bats in the United States including Hawaii (Pierson 1998), 13 species in Puerto Rico and the United States Virgin Islands (including at least 2 species in common with the mainland; Koopman 1989), and 4 species in the Pacific island territories (Flannery 1995). In addition to special status given to some species of bats by many state agencies and conservation organizations, 6 species or subspecies of bats in the continental United States currently are classified as endangered under the United States Endangered Species Act of 1973 (ESA), as is the sole species of bat on Hawaii. In the Pacific islands, 1 species of flying fox (*Pteropus tokudae*) endemic to Guam was last observed in 1967 and is now extinct (Wiles 1987). The single remaining species of flying fox on Guam (*P. mariannus*) is listed as endangered on that island and has been proposed for listing as threatened under the ESA on several islands of the neighboring Commonwealth of the Northern Mariana Islands (CNMI; United States Fish and Wildlife Service [USFWS] 2001). The only insectivorous bat in the Pacific island territories, the Polynesian sheath-tailed bat (*Emballonura semicaudata*), is extinct on Guam and parts of the neighboring CNMI. On American Samoa and parts of the CNMI, the Polynesian sheath-tailed bat is a candidate species for which listing as endangered or threatened under ESA is deemed warranted but precluded due to other priorities (USFWS 2001).

In addition to the species or subspecies noted above that are currently listed or proposed for listing under ESA, a considerable number of additional species of bats in the United States and territories were previously designated as Category 2 candidates for listing under the ESA, including 19 mainland taxa, 4 Pacific island taxa, and 1 species in the Caribbean (Table 1; USFWS 1994). This designation raised interest on the part of many resource agencies about the population status of bats in areas under their management. Category 2 candidates were defined as "taxa for which information...indicates that proposing to list as endangered or threatened is possibly appropriate, but for which persuasive data on biological vulnerability and threat are not currently available to support proposed rules" (USFWS 1994: 58984). Although no candidate taxon received protection pursuant to the ESA, the USFWS published its intent "to monitor the status of all listing candidates to the fullest extent possible" (USFWS 1994: 58983). In 1996, the USFWS discontinued the use of Category 2 (USFWS 1996*a*, 1996*b*), but instead noted that "the Service remains concerned about these species, but further biological research and field study are needed to resolve the conservation status of these taxa. Many species of concern will be found not to warrant listing.... Others may be found to be in greater danger of extinction than some present candidate taxa" (USFWS 1996*a*: 7597). This spurred many resource managers to consider the former Category 2 bats as "species of concern." Use of the former Category 2 list to so designate such species was further clarified in a second notice (USFWS 1996*b*), which pointed out that various sensitive species classifications of other agencies and conservation organizations (which include many bat taxa) are more inclusive of species deserving research and management attention than the earlier Category 2 list.

**New research is needed to develop means to replace currently used indices, particularly if bat population monitoring objectives include detecting declines before they become catastrophic.**

The prior stated intent to monitor candidate taxa, the need to monitor populations of endangered species of bats to define and reach recovery goals, and the widespread interest in managing for bat populations all beg several related questions. How can populations of bats be monitored? Are bat populations currently being monitored using the best procedures? What have we learned about the status of bat populations through monitoring? What directions should be taken to improve the monitoring of populations of bats?

To attempt to answer some of these questions, a scientific workshop was convened in Estes Park, Colorado in September 1999. The workshop included experts in the biology of major groups of bats in the United States and territories, experts in monitoring populations of other organisms, and experts in statistical aspects of wildlife population estimation. Four objectives of the workshop were enumerated: 1) to review knowledge about the status of populations of selected groups of bats in the United States and territories, including descriptions of how these trends were quantified; 2) to provide an overview of current methods and challenges involved in estimating population size and trends for major ecological groupings of United States bats; 3) to identify critical gaps in knowledge concerning bat population trends in the United States and territories; and 4) to determine, describe, and recommend scientific goals for future monitoring programs, including possible new and innovative

Table 1. Species or subspecies of bats in the United States and territories designated as Category 2 candidates for listing under the Endangered Species Act in 1994 (United States Fish and Wildlife Service 1994). In 1996 the United States Fish and Wildlife Service eliminated Category 2 but considered all species of plants and animals formerly categorized as such to be "species of concern" and noted that the number of such species would be greater than just those previously designated under Category 2 (United States Fish and Wildlife Service 1996*a*, 1996*b*). Recognition of many taxa of bats as species of concern or in other sensitive species categories employed by federal and state agencies and conservation organizations has increased interest in monitoring bat populations. CNMI = Commonwealth of the Northern Mariana Islands.

| Species or subspecies of bat | General distribution in U.S.A. |
|---|---|
| Mexican long-tongued bat (*Choeronycteris mexicana)* | Arizona, New Mexico |
| Polynesian sheath-tailed bat (*Emballonura semicaudata*) | Pacific islands (several island groups) |
| Spotted bat (*Euderma maculatum*) | Western U.S.A. |
| Florida mastiff bat (*Eumops glaucinus floridanus*) | Florida (Category 1) |
| Greater western mastiff bat (*Eumops perotis californicus*) | West coast and southwestern U.S.A. |
| Underwood's mastiff bat (*Eumops underwoodi*) | Arizona |
| Allen's big-eared bat (*Idionycteris phyllotis*) | Southwestern U.S.A. |
| California leaf-nosed bat (*Macrotus californicus*) | Southwestern U.S.A. |
| Southeastern myotis (*Myotis austroriparius*) | Southeastern and south-central U.S.A. |
| Western small-footed myotis (*Myotis ciliolabrum*) | Western U.S.A. |
| Long-eared myotis (*Myotis evotis*) | Western U.S.A. |
| Eastern small-footed myotis (*Myotis leibii*) | Central and eastern U.S.A. |
| Occult little brown bat (*Myotis lucifugus occultus*) | Southwestern U.S.A. |
| Fringed myotis (*Myotis thysanodes*) | Western U.S.A. |
| Cave myotis (*Myotis velifer*) | Southwestern U.S.A. |
| Long-legged myotis (*Myotis volans*) | Western U.S.A. |
| Yuma myotis (*Myotis yumanensis*) | Western U.S.A. |
| Big free-tailed bat (*Nyctinomops macrotis*) | Southwestern U.S.A. |
| Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) | Southeastern and south-central U.S.A. |
| Pale Townsend's big-eared bat (*Corynohinus townsendii pallescens*) | Western U.S.A. (inland populations) |
| Pacific Townsend's big-eared bat (*Corynorhinus townsendii townsendii*) | Western U.S.A. coast |
| Mariana fruit bat (*Pteropus mariannus mariannus*) | CNMI |
| Pagan Mariana fruit bat (*Pteropus mariannus paganensis*) | CNMI (Pagan population) |
| Samoan flying fox (*Pteropus samoensis samoensis*) | American Samoa |
| Red fig-eating bat (*Stenoderma rufum*) | Puerto Rico, U.S. Virgin Islands |

approaches in designs needed to resolve technical challenges in estimating bat population trends. The objectives were not to train individuals in techniques of monitoring or capturing bats, excellent descriptions of which can be found elsewhere (e.g., Kunz 1988, Wilson et al. 1996). The workshop was sponsored by the National Fish and Wildlife Foundation, Bat Conservation International, the United States Forest Service, the United States Bureau of Land Management, and the United States Geological Survey (USGS) (Midcontinent Ecological Science Center, Colorado Cooperative Fish and Wildlife Research Unit, and the USGS Status and Trends program office).

The purpose of this paper is to provide a broad overview and synthesis of the findings of the workshop. We provide summaries of selected case reports on monitoring bats across a range of species and situations. We follow this with a summary of principal findings and conclusions of the workshop participants. A more detailed and comprehensive report of the full workshop proceedings will be forthcoming (O'Shea and Bogan 2003).

## Selected case reports

### *Colonies of Mexican free-tailed bats in summer*

Two subspecies of Brazilian free-tailed bats (*Tadarida brasiliensis*) occur in the United States. LeConte's free-tailed bat (*T. brasiliensis cynocephala*) is a year-long resident found across the southeastern states. The Mexican free-tailed bat (*T. brasiliensis mexicana*) is primarily a seasonal migrant that overwinters in Mexico but is found in the southwestern United States during warm months (some year-round residents occur in the northwestern parts of the distribution). Although they roost in a variety of structures, including rock crevices, buildings, and bridges, Mexican free-tailed bats are perhaps best known to form huge nursery colonies of females and young in caves during the summer in Texas, Oklahoma, Arizona, and New Mexico. Evening exoduses at these United States colonies, which form the largest single aggregations of mammals in the world, are one of the great spectacles of nature. Thus some of these colonies are well

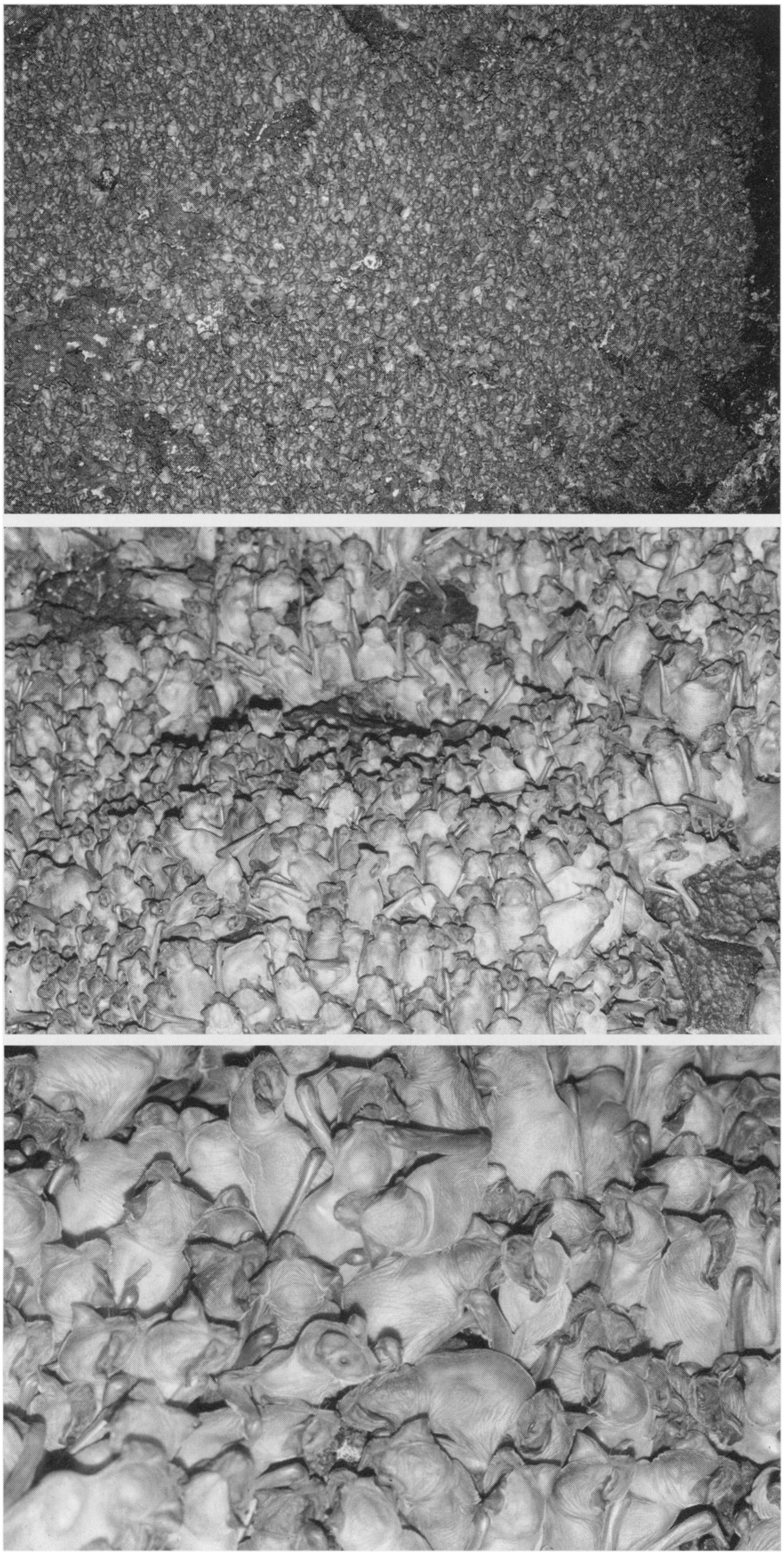

Figure 1. Dense clustering of young Mexican free-tailed bats (*Tadarida brasiliensis mexicana*) viewed at three different scales. Counting of nonvolant young should be explored as a basis for monitoring populations in summer colonies of these bats (photographs by Gary F. McCracken).

known to the public, such as that at Carlsbad Cavern, New Mexico, with past published approximations of colony size at over 8 million in the 1930s (Allison 1937), and Bracken Cave in Texas, with peak numbers given as 20 million in 1957 (Davis et al. 1962).

McCracken (2003) summarized efforts to estimate population size and trend for Mexican free-tailed bats at these large colonies in summer. Despite their notoriety, conspicuousness, and economic importance as consumers of agricultural insect pests, McCracken (2003) found that means to estimate numbers of these bats have been rudimentary, and the techniques employed often have been only vaguely documented in the scientific literature. There also have been only limited attempts to replicate counts over time at any of these sites. McCracken (2003) further pointed out that no past counts have published measures of variation (e.g., SE) associated with them.

A rough overall estimate of about 150 million Mexican free-tailed bats was made for 17 caves in the Southwest in the 1950s and 1960s, and these numbers continue to be quoted as likely present-day abundance because of a general lack of monitoring (McCracken 2003). Techniques employed to arrive at this total were varied and differed by site. They included visual approximations based on sizes of columns of bats exiting roosts and durations of nightly exit flights (Allison 1937); still and motion-picture photography applied to exit flights (Humphrey 1971, Altenbach et al. 1979); extrapolations based on densities of bats on cave ceilings and walls multiplied by estimates of surface area occupied (Constantine 1967); crude indices based on capture and recapture of banded bats (Constantine 1967); and other indices of abundance, such as numbers of bats captured during exits or rates of fecal pellet deposition (Davis et al. 1962, Constantine 1967). McCracken (2003) stated that "None of these attempts to estimate the size of free-tailed bat colonies should be called 'monitoring.' In many cases the descriptions of the techniques used are not adequate to allow replicated counts and monitoring and, in cases where techniques have been described in detail, there have been no published efforts by subsequent researchers to replicate the counts of previous workers. Although there are multiple estimates from a few of the same caves, the different estimates were obtained by different researchers using different techniques."

Although rigorous estimation procedures and replicate counts over years are largely lacking, evidence for major declines in numbers of bats at some of these sites over the past few decades is nonetheless obvious. These include complete losses of colonies as well as orders-of-magnitude drops in abundance at others. Reasons for these changes include exposure to pesticides through the food chain (Geluso et al. 1976, Clark 2001, Clark and Shore 2001), and disturbance due to guano mining, quarrying, vandalism, and cave commercialization (McCracken 2003). Because of a lack of monitoring, however, McCracken (2003) pointed out that it is uncertain how representative such losses at identified locations may be for the overall population of Mexican free-tailed bats in the southwestern United States. In his overview he called for increased research aimed at obtaining improved estimates of population sizes at large colonies of these bats in summer, and establishment of a long-term monitoring program. Efforts to improve estimates should more fully explore photographic techniques as well as new imaging technology, such as advanced high-resolution infrared videography, or satellite imagery of dense columns of emerging bats taken simultaneously at multiple sites (Kunz 2003). Other techniques worthy of further exploration include heat-sensing technology to better calibrate roosting densities on cave surfaces and use of counts of pups in creches (McCracken 2003; Figure 1). Because day-to-day variation in numbers using colony sites can be high and colony sizes also fluctuate seasonally, McCracken (2003) recommended that colony estimation and monitoring take place primarily from late June to mid-July when females care for developing young and are least likely to move among roosts.

## *Hibernating bats in caves and mines*

Many species of bats in the United States form their largest, most consistent aggregations during winter when they hibernate in caves and mine tunnels (Barbour and Davis 1969, Tuttle 1976, 2003). Numbers of bats wintering in such sites can be as high as hundreds of thousands or even millions at key locations. Thus, hibernacula are of great importance for management and for monitoring populations of bats. Tuttle (2003) reviewed aspects of estimating numbers of bats overwintering underground and noted that complete enumeration of hibernating bats is possible in situations where numbers of bats are not extremely large and caves or mines lack great surface irregularities or elaborate passage systems. However, this often is not the case in important hibernacula. In such cases, the only feasible techniques involve estimating densities of bats in roosting clusters and calculating approximate areas covered by clusters of bats (Tuttle 1975, Thomas and LaVal 1988). The accuracy of such techniques has not been evaluated (Tuttle 2003). This is because densities of bats in clusters vary by surface roughness and by temperature at the cluster site; densities within clusters of gray bats (*M. grisescens*), for example, can vary 5-fold (Tuttle 2003). Bats in hibernacula can gather in crevices at unknown densities or roost high above the cave floor on irregular surface contours (Tuttle 2003). Hibernating bats will avoid disturbance by moving to areas within a cave or mine that are inaccessible to biologists attempting to count them, and unknown numbers may hibernate in sections of caves or mines that are unreachable or impossible to discover. Tuttle (2003) pointed out that few mark–recapture studies related to population estimation have been carried out in hibernacula, in part because important assumptions might not be met.

Bats select specific sites for hibernation based on narrow requirements for specific ranges of cool temperatures and humidity (Tuttle and Stevenson 1978). They enter lengthy bouts of torpor at these sites in order to conserve energy for survival through the annual cycle. Over 20 species of United States bats hibernate in caves and mines, and at least 3 of these use caves and mines exclusively (Tuttle 2003). Those species with the narrowest requirements for hibernacula, such as endangered Indiana bats (*Myotis sodalis*) and endangered gray bats, might be the most vulnerable to alteration of conditions in hibernacula; for these 2 species 95% of the known population might hibernate at <12 sites (Tuttle 2003). This brings added challenges to monitoring. Disturbance of hibernating bats due to visitation by people causes energetically costly arousals, which can burn fat at a rate equivalent to 67 days of torpor per arousal (Thomas et al. 1990). This potential effect on survival demands that counts be well planned and well executed and carried out no more frequently than every 2 or 3 years (see Tuttle 2003 for more detailed suggestions, including precautions for personal safety). Furthermore, repeated disturbances might force bats to abandon these optimal sites and hibernate at alternate locations where less suitable temperature regimes lower the prospects for survival or where they are no longer accessible for monitoring (Tuttle 2003). Monitoring of temperatures in hibernacula is important to determine possible causes for changes in abundance, and to signal possible management actions needed to alter structural features of caves or mines to restore optimal conditions.

Tuttle (2003) pointed out that current methods for monitoring bat populations in hibernacula need improvements. Current numbers seldom provide any measure of variance or confidence intervals to the estimates (Thomas and LaVal 1988, Ellison et al. 2003). Disturbance or temperature change can cause roost switching within underground complexes, and researchers need to account for these possibilities when interpreting results of counts (Tuttle and Stevenson 1978, Tuttle 1979). Consistency in sampling efforts should be striven for, as should employment of more refined means of estimating densities (e.g., inclusion of physical sampling frames with counted densities in photographic records, placement of ceiling and wall markers, and development of internal maps prior to winter; Tuttle 2003). Simply determining whether an abandoned mine is used as a hibernaculum can entail considerable effort; in the case of Townsend's big-eared bats in the Great Basin, an average of 7.3 surveys is required to eliminate the possibility that a site is used as a hibernaculum (Sherwin et al. 2003).

## *Bats roosting in foliage or in crevices and cavities in rock and trees*

Many species of bats in the United States do not aggregate in major colonies or roost primarily in caves. These pose special problems for monitoring, and were referred to by workshop participants as "over-dispersed" species. They include 7 species in the genus *Lasiurus* that roost almost exclusively in foliage, often solitarily or in very small groups. Some of these species migrate many hundreds of miles each season. Carter et al. (2003) reviewed anecdotal observations by others that support the contention that historical abundance of some lasiurines (particularly red bats, *L. borealis* and *L. blossevillii,* and hoary bats, *L. cinereus*) was likely much greater than at present. This evidence includes past accounts of seasonal concentrations of these bats, some of which describe large numbers of bats in daylight migrations that are no longer reported (Mearns 1898, Howell 1908, Allen 1939). However, Carter et al. (2003) concluded "No quantitative information concerning long-term population trends of solitary foliage roosting bats can be drawn from existing data. Lack of standardized reporting and the inability to determine the proportion of total populations sampled . . . render all capture data incomparable." Carter et al. (2003) noted that surrogate variables such as trends in habitat or possible indices of abundance, such as submissions to health agencies for rabies testing, offer the only present means to indirectly assess status of these species.

Clark (2003) reviewed the special circumstances of 2 species of bats that roost in part in hollow trees in bottomland hardwood forests of the southeastern United States, Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and the southeastern myotis (*M. austroriparius*). Both of these are former Category 2 species. Prior to the 1990s, almost nothing was known about the occupancy of hollow trees in bottomland hardwood forests by these species (Clark 2003). Since then it has been found that colonies of these bats roost in low densities in these trees (often gum trees, *Nyssa* spp.; Clark 1990, Lance et al. 2001), with most colonies of Rafinesque's big-eared bat numbering less than 50 individuals and southeastern myotis colonies in trees ranging from 100–200 bats (Clark 2003). Use of such roosts was often determined by radiotracking, which also showed that these bats can switch among hollow trees within a stand frequently in a single season, although roost fidelity can be high. Surveys for these bats in bottomland forests have taken place only in limited areas in about one-third of the states in which they occur. Presence–absence information is obtained through sampling with mist nets, and colonies are located by radiotelemetry. Cavity size and configuration make it impossible to see and count bats while they are roosting during the day; numbers of bats in colonies using tree cavities can be determined by counting them as they exit at dark, but bats cannot always be seen (Clark 2003). Monitoring surveys also are challenged by the widely dispersed nature of colonies and the often remote locations of roosts that are difficult to access. Studies of these bats in bottomland forests are too recent to have produced enough data to establish trends in population status, and there are no data on historical abundance (Clark 2003). However, knowledge about bats in bottomland habitats is increasing, and these recent efforts should be built upon to expand the potential for monitoring.

In the western United States, 23 species of bats are known to roost in crevices and cavities in rocks and trees, including 12 former Category 2 species (Bogan et al. 2003). Some of these may use such sites only opportunistically or at certain phases in the annual cycle, whereas for others these roosts are a critical factor in their life history. One additional species, Underwood's mastiff bat (*Eumops underwoodi,* also a former Category 2 species), is likely to roost in crevices in cliffs, but no roosts in the United States have been described in the literature. As noted by Bogan et al. (2003), western crevice- and cavity-dwelling bats show great variability in size and natural history. The smallest (western pipistrelle, *Pipistrellus hesperus*) and largest (greater western mastiff bat, *E. perotis*) bats in the U.S roost in crevices. The group also includes hibernators and migrators, insectivores and nectarivores, and species that also use caves or human-made structures. In many of these species females aggregate in nursery colonies in summer whereas males do not. Colony sizes can vary from a few to hundreds of individuals.

Roosts in crevices in trees and rocks are very important for many species of bats in the West (e.g., Barclay and Brigham 1996, Pierson and Rainey 1998), but their use by bats has mostly gone undetected until the recent advent of small radiotransmitters. Application of telemetry has shown the importance of such sites to small colonies of bats, particularly trees and snags in forested habitats (e.g., Barclay and Brigham 1996, Cryan et al. 2001). Numbers of bats in these colonies often can be completely enumerated by counting as bats exit at dusk. However, bats can frequently change roost locations, sometimes on a nearly daily basis, both as individuals and as colonies (Lewis 1995, Sherwin et al. 2003), and numbers of colonies have not been estimated over meaningful areas of suitable habitat. Long-term monitoring of numbers of bats occupying crevices in cliffs, rocks, and trees generally has not taken place in the western United States, although in a limited number of cases, counts of bats at crevices in cliffs have been repeated after long (≥25 years) intervals (Pierson and Rainey 1998; O'Shea and Vaughan 1999). Some very limited trend information is available for situations in which these bats roost in caves, mines, or bridges (Ellison et al. 2003), but there is no detailed information on trends in colonies of western bats that roost in crevices in cliffs, rocks, and trees. However, increasing research on western bats during the past decade, much of it sponsored by land and resource management agencies, has laid a foundation of new information on colony locations and natural history of poorly known species of bats. It may be possible to expand upon this information in the future for purposes of monitoring populations of western bats. A large amount of habitat used by bats in the western United States is under public domain, and monitoring of bat populations may eventually become a more common component of resource management planning.

## *Flying foxes in the United States Pacific islands*

Three species of flying foxes occur in the United States Pacific island territories. The white-naped flying fox (*Pteropus tonganus*) and the Samoan flying fox (*P. samoensis*) are found on American Samoa. The Mariana flying fox (*P. mariannus*) occurs on Guam and in the CNMI. Populations of Mariana flying foxes in Guam were decimated by hunting, dropping from an undocumented estimate of perhaps 3,000 in the 1950s to <50 bats by the late 1970s. Apparent recolonization from the CNMI occurred, and since the late 1980s the numbers on Guam are thought to be about 10% of those in the 1950s (Utzurrum et al. 2003). Predation on young bats by the exotic brown tree snake (*Boiga irregularis*) has virtually eliminated any recruitment through reproduction on Guam (Wiles et al. 1995). Past surveys of the 14 islands of the CNMI have been incomplete, and results among islands vary in terms of implications for population status. However, illegal hunting and export of the creatures as a delicacy continues to cause concern for the status of Mariana fruit bats in CMNI (Utzurrum et al. 2003). White-naped and Samoan flying foxes were first protected in American Samoa by export bans, prohibition of commercial hunting, and strict regulations on subsistence hunting in 1986. However, abundance of flying foxes in American Samoa dropped substantially (up to 10-fold) following a hurricane and subsequent opportunistic hunting in 1990, resulting in total bans on hunting, harassment, and capture in 1995 (Utzurrum et al. 2003).

These events and conditions underscore the importance of monitoring populations of Pacific island flying foxes. However, such monitoring is faced with numerous methodological challenges, as reviewed by Utzurrum et al. (2003). Populations include both colonial and spatially dispersed or solitary components. These bats roost in treetops or within the forest canopy and can shift locations over large distances (e.g., 100 km) in short periods (days). Variability in group size and detectability can be large and also may be influenced by time of day, reproductive activity, food availability, and other factors (Utzurrum et al. 2003). Island habitats used by these bats often include steep, rugged terrain and forested conditions, which impose severe constraints on visibility and accessibility.

Despite such challenges, assessments of abundance have been attempted over the past 25 years, although Utzurrum et al. (2003) cautioned that efforts at the beginning of this period might have had the largest likelihood for error. Variable circular plots have been attempted on Mariana flying foxes on Sarigan in the CNMI, but several important statistical assumptions of the technique cannot be met (Fancy et al. 1999, Utzurrum et al. 2003). Most surveys have combined different methods of counting, including direct counts of bats roosting in aggregations in trees with the aid of binoculars or spotting scopes from land-based vantage points at distances of 100–300 m. These do not usually represent complete censuses. Even at 50 m, counts at a white-naped flying fox colony varied 10–40% depending on viewing equipment. Such counts have been increased by correction factors that are subjectively determined and that have not been tested for accuracy (Utzurrum et al. 2003). Often, counts at colonies are made by single observers, but Utzurrum et al. (2003) prefer simultaneous independent counts by 2–4 observers. Similar counts are made from boats where colonies cannot be viewed from land, but these suffer the additional problem of observing from a platform in motion. Bats also may be counted in flight from remote vantage points as they leave roosting areas at dusk. Because some bats are missed and others do not fly until well after dark, arbitrary correction factors have sometimes been applied to these results without validation (Utzurrum et al. 2003). In addition to these techniques, abundance of solitary flying foxes has been assessed by standardized counts from fixed stations during early morning or late afternoon. These assessments provide indices of abundance as total number of bats active per unit area per unit time. In addition to providing only an uncalibrated index, these counts from stations also suffer from difficulties in distinguishing species (in American Samoa) and counting some individuals more than once (Utzurrum et al. 2003). However, use of replication has been introduced (Morrell and Craig 1995), and in American Samoa protocols have changed to reduce variance in counts among observers and within counts, to avoid double-counting of individuals and to account for some interhabitat and interannual variation (Utzurrum et al. 2003). These changes make comparisons of recent results with data collected prior to 1987 impossible. Although less than satisfactory, they currently provide the only practical option available for monitoring solitary flying foxes in the Pacific island territories.

## *Southwestern pollinators*

Three species of bats in the family Phyllostomidae are important pollinators of paniculate agaves and columnar cacti in the southwestern United States: the lesser long-nosed bat (*Leptonycteris curasoae),* the greater long-nosed bat (*L. nivalis*), and the Mexican long-tongued bat (*Choeronycteris mexicana*). Fleming et al. (2003) reviewed information on their status and efforts to monitor their populations. All are seasonal migrants from Mexico. The 2 species of *Leptonycteris* were listed as endangered under the ESA in 1988 because of presumed population declines. Lesser long-nosed bats form maternity roosts during the spring in Arizona, where they are found in caves and abandoned mine tunnels in colonies as large as 19,000 adult females. In the late summer lesser long-nosed bats occupy "transient" roosts in south-central and southeastern Arizona and southwestern New Mexico (Fleming et al. 2003). Female and young Mexican long-tongued bats occur in Arizona and New Mexico in very small groups (<50 individuals per roost, usually <15) in various cavity-like shelters, including boulder piles. In the United States, the greater long-nosed bat is known only from 1 roost in Texas and from 2 sites in New Mexico. The records from Texas and New Mexico might represent transient locations. At the Texas site greater long-nosed bats are absent in some years but number in the low thousands in others, suggesting that perhaps these bats occupy roosts in the United States during years of low food abundance in their core range in Mexico (Fleming et al. 2003).

Methods and results of various studies aimed at monitoring populations of southwestern pollinators were reviewed by Fleming et al. (2003). The greatest effort has been directed at lesser long-nosed bats in Arizona and Sonora, Mexico. This species is usually counted at large colonies in caves, where they sometimes roost with large numbers of individuals of other species. Methods to count these bats have varied and include direct counts made during exit flights, counts made from videotapes of exit flights, and counts of bats roosting within caves. Variability due to factors that cause unknown amounts of bias are apparent in counts made at emergence: confusion with other species, variable rates of exiting and return, and lack of departure; discrepancies of up to 40% occur between visual counts and videotaped tallies (Fleming et al. 2003). Counts within roosts usually develop a visual approximation of the density of bats (number in a unit surface area) and multiply that by the total area that observers attempt to note as covered by the bats before they take flight due to disturbance. Counts have been made at 3 sites in Arizona and 2 in Mexico each year since 1988 and less frequently at a small number of other known colony locations. Results indicate that numbers are in the tens of thousands, and these findings, together with other evidence, suggest that populations are much higher and appear to have declined much less than originally thought at the time of listing as endangered (Cockrum and Petryszyn 1991, Fleming et al. 2003).

Little is known about populations of greater long-nosed bats or Mexican long-tongued bats in the United States. The highly variable counts at the transient roost of greater long-nosed bats in Texas ranged from 0–10,650 (in 1967), with counts at ≤5,000 in 1991 and 2,859 in 1993 (reviewed by Fleming et al. 2003). More recent data on this species in New Mexico and Texas have not been published. Mexican long-tongued bats are perhaps the least numerous of the 3 species, but little information is available on their populations. Cryan and Bogan (unpublished data, cited in Fleming et al. 2003) visited 23 of 48 localities in Arizona and New Mexico with historical records of roosts and found them at 17 (74%) of the sites, suggesting no major declines. Colony size averaged 3.8 bats (range 1–15).

## Use of existing data to determine trends in colonial species

With growing interest in monitoring populations of bats, a logical first step is to assess the degree to which existing data may lend itself to interpreting trends in status. Ellison et al. (2003) provided such an initial assessment by developing a bat population database (BPD) of counts of bats in the United States and territories as gleaned from scientific papers, books, agency reports, selected databases, theses, and dissertations. A count was considered 1 colony-size estimate for a particular species of bat on a specific date at a unique location. Ellison et al. (2003) constructed a relational database that organized information about these reported counts according to a number of factors. Although perhaps not fully exhaustive, the efforts were extensive. The BPD includes more than 26,600 observations at 6,082 locations, gleaned from 1,469 publications and several agency and individual researcher databases. This allowed Ellison et al. (2003) to determine the quality of most existing information on bat colony sizes and to assess the feasibility of using such data for analyses of trends in counts through time.

Information was available for 43 species and 3 subspecies in the United States and 7 species in the territories. However, just 6 species accounted for 56% of the counts: Indiana bats, big brown bats (*Eptesicus fuscus*), eastern pipistrelles (*P. subflavus*), little brown bats (*M. lucifugus*), gray bats, and big-eared bats (*Corynorhinus townsendii*) (in descending order). Locations included 2,081 caves, 1,667 buildings, 1,031 mines, 408 bridges, 309 trees, 87 tunnels, 69 in crevices in rock, and minor numbers in a variety of other situations. Most (72%) colony locations were visited only once. Only 14% of colonies had more than 2 distinct annual surveys during the same time of year, with just 81 of the 6,082 colony sites in the United States counted over more than 10 different years. Documentation of methods used to obtain counts often was vague, and methods usually were specified only as "count" (66%). Less than half of all surveys of colonies included upper and lower ranges to the estimated counts, and variance estimates or SE were reported for only 15 out of 23,791 counts (0.06%).

Thus, much of the existing information on counts of bats is of low utility for trend analysis. Because counts were reported from different sources and almost none had sampling variances associated with them, Ellison et al. (2003) used the Mann-Kendall Nonparametric Test for Trend (Kendall and Gibbons 1990, Thompson et al. 1998). This rank correlation technique takes the magnitudes of the counts and ranks their differences as pluses and minuses. An *S*-statistic (time series$\leq$10 years with counts) or a *t*-statistic (for time series >10) is calculated from the pluses and minuses and compared to a probability function (with $P\leq0.05$ used to determine whether a trend was decreasing or increasing for the time series analyzed). Among all existing data, colonies at nearly 500 roost locations had $\geq$4 years (not necessarily consecutive years) in a time series and were analyzed for trend. These data were available for only a few species and types of colonies. Hibernacula accounted for 60% of the roosts and involved 17 species. However, 1 endangered species (the Indiana bat) accounted for 20% of these hibernacula. Fewer summer or maternity locations (175) had colony counts, and 103 of these were of the endangered gray bat, the remainder spread among 20 other species. Significant changes could not be detected in most winter and summer colonies (344), with 72 apparently increasing and 58 decreasing. Details on findings on trends by species were tabulated by Ellison et al. (2003), but the numbers of locations within species for which trend assessments could be made based on existing data were low. Existing data also were subject to many potential biases, making *post hoc* analyses of this information of limited value for long-term monitoring of populations of bats.

## Principal conclusions and recommendations of the workshop

A number of conclusions and recommendations regarding monitoring of United States bat populations emerged at the workshop as a result of case-study presentations, discussions, and working-group reports. Below we highlight major aspects of these findings under 5 general headings as reported by workshop participants, who did not attempt to rank findings by priority.

### *The natural history of bats poses many challenges to population monitoring*

Bats are a heterogeneous group of mammals in terms of natural history and require the application of multiple approaches to monitoring. Some species are essentially solitary and roost cryptically in foliage, whereas others aggregate in the millions at predictable locations. Many others occur in a range of intermediate situations. Bats are highly mobile, predominantly nocturnal, and generally roost in inaccessible or concealed situations. Their annual cycles can include seasonal long-distance migrations, and some species form colonies of different size, sex, and age compositions at different times of the year. They also are susceptible to disturbance (particularly during hibernation), which can reduce survival. Some colonies switch roost locations every few days during warm months, and basic natural history, distribution, roosting preferences, and colony locations are poorly known for many species. The problems these natural history attributes pose for monitoring and managing bats are exemplified by the use of abandoned mines by Townsend's big-eared bats in areas of the western United States; this species requires exhaustive study to determine basic patterns in roost use and abundance (Sherwin et al., 2003).

Despite these problems, workshop participants reported a number of recommendations aimed at improving monitoring of populations of bats in 4 specific categories: colonial species, over-dispersed species (i.e., foliage-, cavity-, and crevice-roosting bats), Pacific island flying foxes, and southwestern pollinators. Monitoring of colonial species can be improved by timing surveys to coincide with periods in the annual cycle when colony size is most stable and at a seasonal peak—for example, conducting exit counts at maternity colonies during the week prior to parturition. Guidelines for making such exit counts are provided in the forthcoming proceedings (O'Shea and Bogan 2003), including using multiple observers to assess observer variation and using standard forms for recording data and ancillary information. Bats that roost in foliage, tree cavities, and rock crevices tend to roost in low densities or solitarily, and present additional challenges for monitoring. Current estimates of relative abundance of these over-dispersed species come primarily from mist-net and echolocation-detector index measures. However, these methods have no means for estimating detectability and thus provide data of limited value for assessing abundance beyond possible presence or absence. Surmounting problems in estimating numbers of these bats will require improvements in methodology. In particular, calibration of mist-net and echolocation-detector data against other, unbiased, and theoretically sound estimators of abundance will be required to make such data more useful for monitoring trends in populations. Development of such estimators has not received sufficient attention. The 3 species of Pacific island flying foxes pose very difficult challenges to population monitoring because of patterns of dispersion, rarity, and inaccessibility. The most pressing need for monitoring populations of these flying foxes is to improve methods of estimating detectability. This might best be developed by improving abilities to capture, mark, and resight these bats. Developing artificial lures through use of sound, scent, or food-based baits and experimenting with means of inducing self-marking merits exploration, as does using controlled hunts of flying foxes to recover marked individuals (other than those protected by the ESA). In the interim, current methods should be continued and standardized, and include measures of logical covariates to abundance. Current monitoring of southwestern pollinators also should be continued because methods now in use are at least likely to reveal major trends or catastrophic declines. However, techniques for monitoring pollinators should be standardized and improved with infrared videotaping and use of additional observers.

### *Major improvements are needed in methods of estimating numbers of bats*

With the possible exception of certain small colonies in which individual bats can be completely counted, attempts to estimate bat population trends in the United States and territories have relied heavily on use of indices at local sites. The use of indices and "convenience sampling" to estimate population size and trends in animals in general is inferior to more statistically defensible methods and can lead to incorrect inferences (Thompson et al. 1998, Anderson 2001). New techniques must be explored and modern statistical designs applied in order to improve the scientific basis for conclusions about future bat population trends. Although the bat research community must strive to improve scientific methods of population estimation for future applications, dramatic changes in bat abundance documented by less direct methods, when accompanied by clear-cut causes, have provided strong evidence of past declines. Bat conservation efforts are well founded, and current monitoring approaches, although they provide scientifically less rigorous information than is desirable, have some merit for conservation if applied cautiously and conservatively.

However, shortcomings of current methods must be fully acknowledged. The use of indices has serious flaws because most indices, including those using echolocation detectors, are affected by a host of variables other than actual trends in populations (Anderson 2001). These include variables associated with the environment, observers, and the bats themselves, all of which can affect counts by altering detection probabilities in complex and largely unknown ways. Furthermore, these variables also may change with time, obscuring the ability to assess and understand the true trends in bat populations. Developing uniform standards for collecting index data can be useful, but aspects of many important variables affecting detection probabilities are unknown and cannot be standardized. This weakens the reliability of index values even when controllable factors are accounted for using standardized approaches (Anderson 2001).

New research is needed to develop means to replace currently used indices, particularly if bat population monitoring objectives include detecting declines before they become catastrophic. The workshop participants provided a number of recommendations for improving techniques for estimating population trend and population parameters (e.g., survival, reproduction, dispersal, and movements among locations). These include recommendations to assess the feasibility of applying new theory in mark–recapture statistics to sampling designs, to develop new marking and resighting technology (such as Passive Integrated Transponder tags and microtaggants), to incorporate double-sampling techniques and other means to calibrate indices, and to introduce replication and multiple observers in order to incorporate estimates of variance in exit counts or other counting situations. Developing applications of new technical equipment to assist in estimating numbers also is recommended (Kunz 2003). Such equipment might include video cameras with low-light recording capability, infrared video cameras (reflectance-based imagery), computer methods for counting bats in these images, and infrared cameras and other remote sensing techniques. Attempts to use infrared or other new technology and multiple observers to calibrate indices based on detection of echolocation calls should be explored for estimating abundance of over-dispersed bats.

## *Objectives and priorities of bat population monitoring need careful consideration*

Model species of bats for population monitoring programs should be carefully selected based on specified objectives and relevant spatial scales, and monitoring should be carried out using methodology that can be demonstrated to provide reliable information on population trends. In many cases involving bats, such methodology has yet to be developed. Poorly designed or flawed monitoring programs, however, could lead to unreliable results at the cost of disturbance or other potential harm to bat survival, in addition to wasting limited financial and logistical resources. Priority-setting should consider species distributions, feeding strategies, roosting habits, population status, threats to the species, and feasibility of obtaining reliable data. Species with specialized roosting requirements and very limited numbers of suitable roosts are of high importance for monitoring for conservation of biodiversity. Species with feeding strategies of great economic or ecosystem importance also may be of high priority for monitoring. Although most monitoring has been limited to bats legally classified as endangered (Ellison et al. 2003), monitoring programs might better benefit other species by providing data needed to prevent such taxa from becoming listed in the future. Species with localized distributions might be more amenable to and important for monitoring than species that occur across the continent, particularly considering sampling logistics, potentially smaller population sizes, and greater ability of managers to recognize specific human activities with potential to impact populations. Conversely, a monitoring program for species that roost in moderate-to-large colonies may be quite successful because of the relative ease in detecting such roosts and the fewer sites that need to be monitored.

## *Monitoring bat populations on a broad scale will require strong commitment and well-planned sampling designs*

Changes in bat populations have ramifications for agricultural and forestry segments of the United States economy (because bats are consumers of farm and forest insect pests), ecosystem function, and conservation of national biological diversity. There is a need for status information on a wide range of United States species of bats, and bat population monitoring programs on a national or other broad scale are clearly desirable. However, there is no unifying mandate or legislative foundation for a national bat conservation program. Bats in the United States cross international and state boundaries in their migrations, and models for bat conservation exist in international agreements in Europe (Walsh et al. 2003), the Migratory Bird Treaty Act and the Marine Mammal Protection Act in the United States, as well as other conservation mandates. As in these other examples, population monitoring should be an important component of such mandates, as has been recognized in Britain (Walsh et al. 2003). Firmer foundations for bat conservation and monitoring are needed, including heightening public support through efforts such as a National Bat Awareness Week. Any resulting expansion in population monitoring efforts, however, must recognize the need for development and application of appropriate statistical sampling and hypothesis-testing approaches in order to provide the most scientifically meaningful results. This will require research on basic ecology and life history of some species of bats, breakthroughs in developing detectability functions for population estimation, and development of appropriate spatial sampling frames.

## *Information exchange among bat specialists should be enhanced*

Existing efforts to monitor bat populations are not well linked. Methods and protocols may lack comparability, and information gathered may not be used as effectively as possible in signaling the extent and magnitude of bat population problems needing conservation attention. A web-based clearinghouse should be developed to enhance information exchange about bat population monitoring. A voluntary clearinghouse could provide useful information directly and also provide electronic links to sites maintained by others. As examples, information or links could include a directory of organizations and individuals, descriptions of sampling protocols, a simple metadata description of ongoing studies, a bibliography, databases related to bat populations, and echolocation call libraries. Given the potential value of renewed efforts to mark bats for population studies, a web-based clearinghouse that includes information on bat marking techniques, statistical approaches to marked animal sampling designs and data analysis, pertinent bibliographic references, directories of individuals and organizations marking bats, and metadata on tagging projects would also be of value.

## Conclusions

There is much valid concern about the status of bat populations in the United States and territories and increasing interest in monitoring populations of bats. Considerable activity in this area has been undertaken, primarily in recent years. However, much of this activity is biased toward certain species and situations and primarily involves the uses of index values. Historical count data are of limited value for statistical inference. The state of the science in monitoring bat populations, unfortunately, is not unique. These are common classes of problems facing attempts to monitor many groups of wildlife: even the most well-known programs such as some of those developed to determine trends in populations of migratory birds suffer from shortcomings in sampling designs (Anderson 2001, Sauer 2003). Nonetheless, new research must be directed toward improving methods of estimating population size and trend in bats. This will be very challenging because of the diverse natural histories of bats and their secretive habits and the current lack of a unifying mandate for conservation of bats. These challenges were recognized during the expert workshop held in 1999. As a result, a number of needed directions for future research and sampling have been identified, and specific guidelines for certain groups of bats have been enumerated. Additionally, recommendations and considerations for future bat population monitoring programs, including suggestions for firmer mandates for bat conservation and facilitation of information exchange, have been set forth. Hopefully, this assessment of the state of the science and recommendations for the future will add to other efforts to spur additional actions needed for conservation- and management-oriented monitoring of this unique and important component of the United States mammalian fauna.

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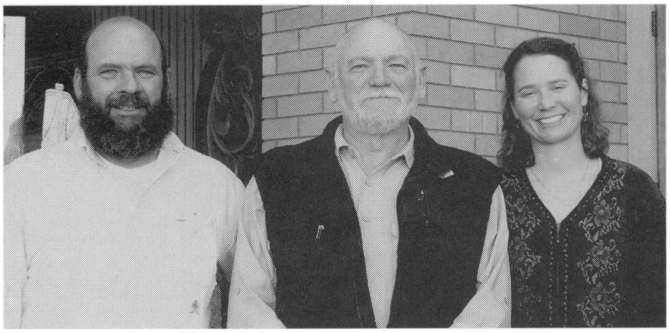

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